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Weiterentwicklung der postendodontischen Versorgung mittels Stiftaufbauten durch digitale Technologien in der Zahnheilkunde.

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Verzeichnis der Publikationen zur kumulativen Habilitation

1. **J.A.H. Vogler**, M. Lehmann, P. Rehmann, B. Wostmann, Survival time of post and cores: A 16 year retrospective follow-up study, J Dent 117 (2022) 103923, 1-9. (IF 2022: 4,4)

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* In der vorliegenden Arbeit wird das generische Maskulin verwendet. Die Personenbezeichnungen beziehen sich – sofern nicht anders kenntlich gemacht – auf alle Geschlechter.

1 Einleitung

1.1 Klinische Bedeutung der postendodontischen Versorgung

In der Zahnmedizin ist die Versorgung von Zahnhartsubstanzdefekten eine der Hauptaufgaben, welche sich im Laufe der letzten Jahrzehnte durch die Einführung neuer Behandlungstechniken und Materialien radikal verändert hat. Solche koronalen Zahnhartsubstanzdefekte können einerseits durch ein dentales Trauma oder anderseits durch kariöse Zerstörung entstehen und eine endodontische Behandlung des betroffenen Zahnes notwendig machen.[1-4] Hierbei wird das pulpale Weichgewebe in dem Zahn entfernt, der Wurzelkanal mit Feilen erweitert und nach einer chemischen und mechanischen Reinigung, das Lumen mit Wurzelfüllungsmaterial gefüllt. Häufig verbleibt nach der koronalen Zerstörung und der endodontischen Behandlung nicht genügend Resthartsubstanz, um die Restauration an dem Zahn zu befestigen, sodass ein Stiftaufbau zur Verankerung notwendig sein kann.[5, 6] Hierfür wird ein Teil der Wurzelfüllung von koronal entfernt, um zusätzliche Retentionsfläche an den Wänden des Wurzelkanals zu generieren. Die Abbildung 1 zeigt exemplarisch einen frakturierten Frontzahn mit unzureichender Retentionsfläche für eine Einzelzahnkronenversorgung (links), bei dem ein Stiftaufbau zur Vergrößerung der Stumpfretentionsfläche inseriert wurde (Mitte und rechts).

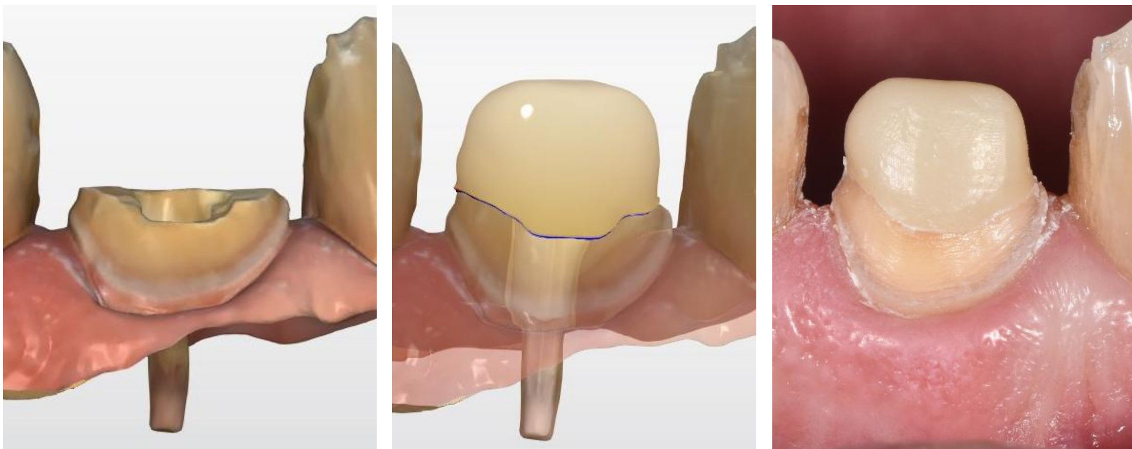


Abbildung 1: Frakturierter Frontzahn mit unzureichender Retentionsfläche für eine Einzelkronenversorgung (links), bei dem ein Stiftaufbau zur Vergrößerung der Retentionsfläche gesetzt wurde (Mitte und rechts).

Auch wenn durch die Entwicklung der adhäsiven Füllungstechnik nicht mehr jeder endodontisch behandelte Zahn einen Stiftaufbau benötigt, so kann auf diesen auch heute noch

bei großen, koronalen Defekten nicht verzichtet werden.[5, 7] Im Gegenteil hat die Einführung adhäsiver Befestigungsverfahren in der Zahnmedizin sogar zur Entwicklung neuer Stiftaufbausysteme geführt,[8] bei denen speziell im Frontzahnbereich konfektionierte Glasfaserstifte zu einer Widerherstellung des natürlichen Erscheinungsbildes traumatisierter Zähne beitragen können.[9]
Verschiedene Übersichtsarbeiten beschreiben in diesem Zusammenhang die Prävalenz des dentalen Traumas im bleibenden Gebiss mit 25-30%,[2-4] wobei zumeist die oberen Schneidezähne in der ästhetisch relevanten Zone betroffen sind.[2] Vor diesem Hintergrund sind nicht nur die Stabilität und Langlebigkeit der postendodontischen Versorgung von hoher klinischer Bedeutung,[6] sondern auch die langfristige ästhetische Beeinträchtigung des Patienten durch die zahnärztliche Behandlung.[9]
Auch wenn kariöse Läsionen bei jungen Patienten, durch die Verbesserung der Prophylaxemaßnahmen in der Zahnmedizin und die Verbreitung fluoridhaltiger Mundhygieneartikel, in den letzten Jahren immer seltener vorkommen, ist im gleichen Zeitraum jedoch die Kariesprävalenz in der Gruppe der Senioren sogar angestiegen.[1] Da es sich bei dieser Gruppe um das hauptsächliche Patientenklientel in der zahnärztlichen Prothetik handelt, nimmt folglich die postendodontische Versorgung als Vorbehandlung eine Schlüsselrolle in vielen prothetischen Behandlungskonzepten ein.[6, 10] Des Weiteren ist im deutschen Gesundheitswesen ein Trend von herausnehmbarem hin zu festsitzendem Zahnersatz zu verzeichnen, weshalb auch bei den älteren Patienten der Zahnerhalt und damit die postendodontische Versorgung einen immer größeren Stellenwert bekommt.[10] Es wurden alleine im Jahr 2022 über die gesetzlichen Krankenkassen in Deutschland knapp sechs Millionen endodontische Behandlungen und mehr als 800.000 Stiftaufbauten koronal stark zerstörter Zähne abgerechnet,[11] wobei die privatzahnärztlichen Behandlungen zu dieser Anzahl noch hinzukommen, hierüber jedoch keine Daten öffentlich verfügbar sind.
Vor diesem Hintergrund wird die klinische Relevanz der vorliegenden kumulativen Habilitationsschrift deutlich, die zum Ziel hat, durch eine strukturierte Evaluation der postendodontischen Versorgung mittels Stiftaufbauten an unserer Klinik, eine Weiterentwicklung dieser Behandlungsoption durch Verwendung moderner, digitaler Technologien voranzutreiben.

1.2 Entwicklung der postendodontischen Versorgungen

Bereits 1728 beschrieb *Fauchard*, dass Zahnersatz mithilfe von Stiftaufbauten an abgebrochenen Zähnen befestigt werden kann.[12] Hierzu wurden edelmetallhaltige Stifte, mit Naturstoffen im Wurzelkanal verkeilt, um die Retention für den Zahnersatz zu gewährleisten.[13] Ab dem 18. Jahrhundert wurden in vergleichbarer Weise Holzstifte verwendet,[14] welche zusätzlichen Halt durch aufquellen im Wurzelkanal generierten. Diese ersten Techniken führten jedoch bereits bei physiologischer Kaubelastung zu Wurzelfrakturen, weshalb Stiftaufbauten in den Folgejahren wieder aus den Beschreibungen in der zahnmedizinischen Literatur verschwanden.[12] Erst 1880 wurde die Idee von *Richmond* wieder aufgefasst, der ursprünglich im Wurzelkanal ein Gewinderöhrchen befestigte und darin eine mit Porzellan verblendete Einzelzahnkrone verschraubte (Abbildung 2).[15]

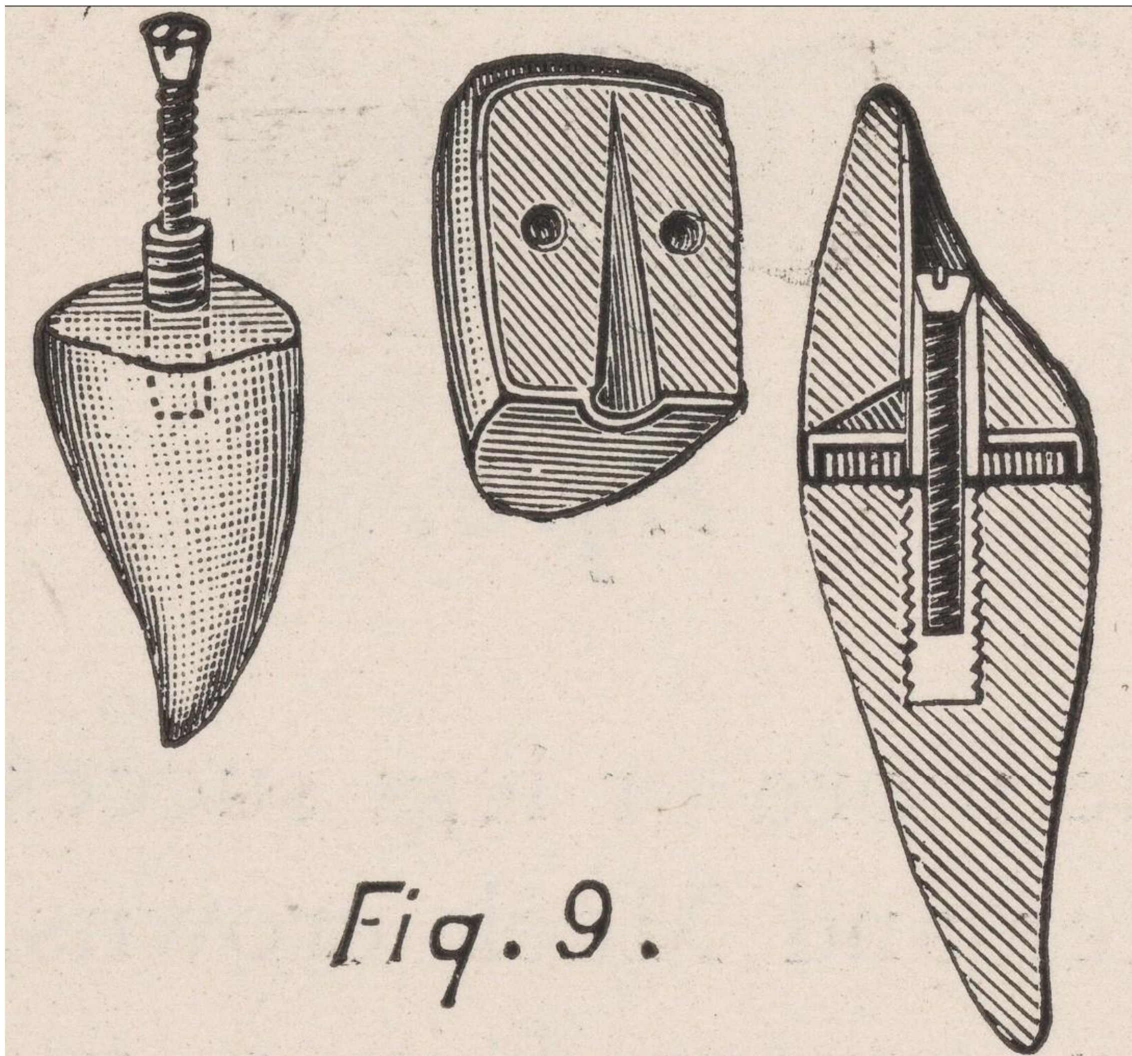


Abbildung 2: Design der ursprünglichen „Richmond Krone“ nach C. M. Richmond, 1880. Quelle: *Principles and practice of crowning teeth: a practical, systematic and modern treatise upon the requirements and technique of artificial crown work, including some incidental reference to bridgework. - Hart John Goslee, 1903*

Um aus Praktikabilitätsgründen auf das Gewinderöhrchen zu verzichten, wurde die Einzelkrone in der Folge um einem einzementierbaren Stiftanteil erweitert und das ursprüngliche, zeiteilige Design damit zu einem Einteiligen modifiziert.[15] Bis heute ist diese Versorgungsart als „Richmond-Krone“ bekannt, welche in der modernen zahnmedizinischen Praxis jedoch nur noch selten Verwendung findet.[16] Der Grund hierfür ist das immer noch vergleichsweise hohe Wurzelfrakturrisiko durch das fehlenden Ferrule-Design, bei dem der Kronenanteil die Zahnwurzel zirkulär um 1-2 mm umfasst.[5] *Naumann et al.* konnten in einer Übersichtsarbeit zeigen, dass das Ferrule-Design, neben der Menge der vorhandenen Restzahnhartsubstanz, das wichtigste Kriterium für den Langzeiterfolg einer postendodontischen Versorgung ist.[5] Aus diesem Grund wurden in den 1930er Jahren als Weiterentwicklung der „Richmond-Krone“ die individuell gegossenen Stiftaufbauten entwickelt, die noch heute als Goldstandard bei der Versorgung stark zerstörter

Zähne gelten.[12] Hierbei wird zunächst der koronale Defekt durch einen Stiftaufbau, bestehend aus einem zusammenhängenden Stift- und einem Stumpfanteil, rekonstruiert und das Ferrule-Design durch eine später darauf zementierte Krone gewährleistet.[5] Da der individuell gegossene Stiftaufbau in der Regel in einem analogen Workflow durch den Zahntechniker hergestellt wird, ist für die Insertion bisher immer ein zweiter Behandlungstermin notwendig.[12] Um eine einzeitige postendodontische Versorgung mittels Stiftaufbau zu ermöglichen, wurden daher in den folgenden Jahrzenten konfektionierte Stiftsysteme entwickelt, die unmittelbar nach der Aufbereitung in den Wurzelkanal eingesetzt werden können und der Stumpfanteil durch plastische Füllungsmaterialien ergänzt wird.[17] Die ersten konfektionierten Stiftsysteme waren hierbei Schrauben, die in das Dentin eingedreht wurden,[18, 19] wobei jedoch Stress auf die Hartsubstanz der Zahnwurzel ausgeübt wurde, was zu Spannungsspitzen im Bereich der Gewindegänge und damit zu Mikrorissen im Dentin führte.[20] Hierdurch können, vor allem im Frontzahnbereich durch die nichtaxiale Kaubelastung, Wurzelfrakturen entstehen, die eine Extraktion des Zahnes unumgänglich machen.[21] Trotz des, durch den kraftschlüssigen Verbund zwischen Gewinde und Wurzeldentin bedingten, geringen Retentionsverlustrisikos des Stiftaufbaus,[20, 22] werden schraubenförmige Stifte aufgrund der erhöhten Gefahr von Wurzelfrakturen[23] generell nicht mehr empfohlen.[24] Stattdessen wurden konfektionierte Stiftaufbausysteme entwickelt, deren Stiftanteil - wie schon bei der „Richmond-Krone“- durch Zementierung im aufbereiteten Wurzelkanal befestigt werden.[24, 25] Im Vergleich zu geschraubten Stiften besteht hierbei zwar ein höheres Dezementierungsrisiko,[21] selbst wenn ein haftstärkerer, adhäsiver Einsetzkomposit verwendet wird,[26] jedoch sind diese zementierbaren, konfektionierten Stiftaufbauten aufgrund des geringeren Wurzelfrakturrisikos und der möglichen Sofortversorgung des Zahnes in den zahnärztlichen Praxen weit verbreitet.[27]

Signifikante Weiterentwicklungen bei den Stiftaufbauten sind danach erst wieder nach der Jahrtausendwende durch technische Neuerungen im Bereich der digitalen Zahnmedizin erzielt worden.[12] Durch die Nutzung der Computer-Aided-Design/Computer-Aided-Manufacturing (CAD/CAM) Technologie können heute individuelle Stiftaufbauten auch aus anderen Materialien, als Metallen hergestellt werden, was das Indikationsspektrum für den Zahnarzt erweitert hat.[28-31]

1.3 Einteilung moderner Stiftaufbausysteme

Die modernen und aktuell in der Zahnmedizin häufig Verwendung findenden Stiftaufbausysteme zur Rekonstruktion von Zähnen mit einem ausgedehntem koronalen Hartsubstanzverlust lassen sich generell in konfektioniert und individuell unterteilen.[12] Diese Systeme unterscheiden sich nicht nur in ihrer Herstellungsart, sondern auch in ihrem Indikationsspektrum. Während konfektionierte Stiftaufbausysteme mit plastischen Füllungsaufbauten bei kleineren Defekten eingesetzt werden können,[32, 33] kommen bei größeren Zahnhartsubstanzdefekten individuelle Stiftaufbauten zum Einsatz,[12, 33] welche aufgrund ihres einteiligen Aufbaus aus Stift- und Stumpfanteil eine höhere Stabilität aufweisen.[34] Die Abbildung 3 zeigt links einen konfektionierten Stift, bei dem der Stumpfaufbau mit Komposit ergänzt wird und rechts einen individuellen Stiftaufbau, bestehend aus einem zusammenhängenden Stift- und Stumpfanteil.

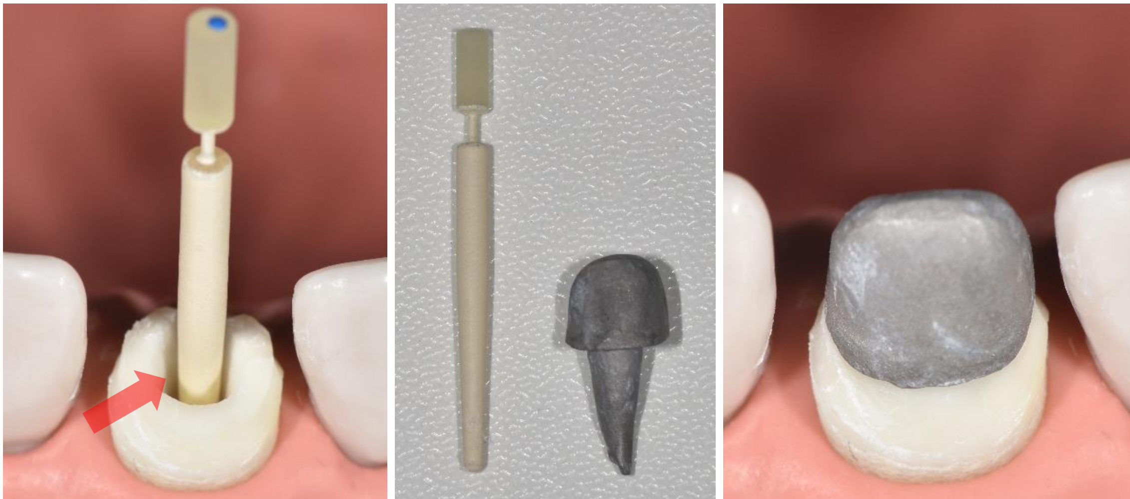


Abbildung 3: Konfektionierter Stift, bei dem der Stumpf mit Komposit ergänzt wird (links) und individueller Stiftaufbau, bestehend aus einem zusammenhängenden Stift- und Stumpfanteil (rechts). Bei dem konfektionierten Stift besteht im Bereich des Wurzelkanaleingangs ein Spalt zwischen Zahn und Stift, der die schlechtere Passgenauigkeit verglichen mit einem individuellen Stiftaufbau verdeutlicht (roter Pfeil).

1.3.1 Konfektionierte Stiftaufbauten

Die Vorteile der konfektionierten gegenüber der individuellen Stiftaufbausysteme liegen darin, dass diese in nur einer Behandlungssitzung, also im Sinne einer Sofortversorgung, inseriert werden können.[12] Die hieraus resultierende Verringerung der Behandlungszeit ist der hauptsächliche Grund, weshalb diese Stiftaufbausysteme in der zahnärztlichen Praxis weit verbreitet sind.[27] Mit den glasfaserverstärkten Materialien ist es darüber hinaus möglich Stiftaufbauten mit mechanischen Eigenschaften vergleichbar denen des Wurzeldentins einzusetzen.[32] Viele Autoren beschreiben, dass hierdurch die Spannung auf die Zahnwurzel, speziell bei nichtaxialer Belastung, reduziert wird, was wiederum die Gefahr einer Wurzelfraktur reduziert.[12, 35-39] Darüber hinaus tragen Glasfaserstiftaufbauten aufgrund ihrer dentinähnlichen Farbe und Transluzenz zu einem ästhetischen und natürlichen Erscheinungsbild, speziell bei der Versorgung mit vollkeramischem Zahnersatz, bei.[38-41] *Kurbad* und *Müller* beschreiben, dass durch den Einsatz von konfektionierten Glasfaserstiftaufbauten unter vollkeramischen Kronen, Licht in den krestalen Wurzelbereich eingeleitet werden kann, was die Gingiva im Bereich von wurzelkanalbehandelten Zähnen natürlicher erscheinen lässt.[40]

Ein Nachteil der konfektionierten im Vergleich zu den individuellen Stiftaufbauten ist die mangelhafte Passgenauigkeit in konisch aufbereiteten oder im Querschnitt nicht runden Wurzelkanälen (siehe roter Pfeil in Abbildung 3).[12] Hieraus resultiert eine vergrößerte Klebefuge und eine damit einhergehende Spannung auf die Zahnwurzel durch die Polymerisationsschrumpfung des adhäsiven Einsetzkomposites.[42] Verschiedene Autoren beschreiben im Zusammenhang hiermit den Retentionsverlust als die häufigste Misserfolgsursache bei diesen Stiftaufbausystemen.[42-45] Ein weiterer Nachteil der konfektionierten gegenüber den individuellen Stiftaufbausystemen ist der zweiteilige Aufbau aus Stift- und Stumpfanteil. Hieraus resultiert eine Phasengrenze zwischen den Materialien beider Anteile, was zu einer mechanischen Schwachstelle bei der Belastung und einer Verminderung der Transluzenz mit einhergehender Verdunklung der Restauration führen kann.[12, 34] Bei einigen Systemen kann zwar der Stiftanteil, der in den Wurzelkanal eingebracht wird, durch direktes Anpassen im Mund des Patienten individualisiert werden, jedoch wird auch bei diesen Systemen der Stumpfanteil mit Komposit aufgebaut und damit eine Phasengrenze zwischen den Anteilen geschaffen.[32, 46] Studien, die den Langzeiterfolg dieser Stiftaufbausysteme untersucht haben, sind zudem in der Literatur bisher nicht publiziert worden und auch deren Verbreitung in den zahnärztlichen Praxen ist gering.[46]

1.3.2 Individuelle Stiftaufbauten

Die ursprünglichen und über lange Jahre etablierten individuellen Stiftaufbauten werden seit Jahrzenten auf Grundlage einer konventionellen Abformung der Stiftbettpräparation zunächst mit Wachs auf einem Gipsmodell modelliert und anschließend im lost-wax Verfahren in Dentallegierungen gegossen.[6] Die Abbildung 4 zeigt eine konventionelle Abformung eines aufbereiteten Wurzelkanals durch den Zahnarzt (oben) sowie die anschließende Herstellung eines individuell gegossenen Stiftaufbaus im zahntechnischen Labor (unten).

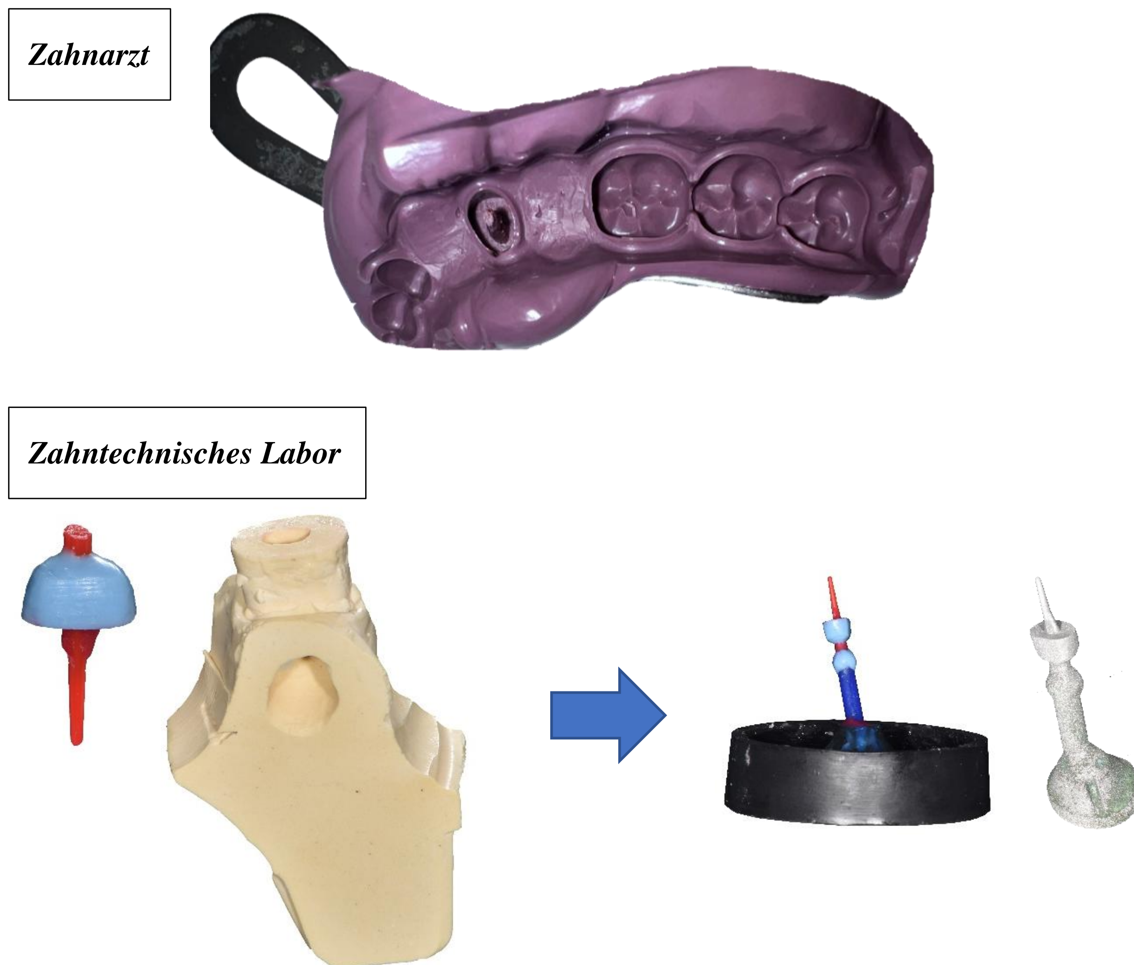


Abbildung 4: Konventionelle Abformung der Stiftbettpräparation durch den Zahnarzt (oben) und anschließende Gipsmodellherstellung, Wachsmodellation und Guss des individuellen Stiftaufbaus im zahntechnischen Labor (unten).

Seit Einführung der CAD/CAM Technologie in die Zahnmedizin und Zahntechnik, können individuelle Stiftaufbauten darüber hinaus seit einigen Jahren auch auf Grundlage eines digitalen Modells entweder aus einem CAD/CAM-Material gefräst[47] oder additiv im 3D-Druckverfahren[48] hergestellt werden. Da der individuelle Stiftaufbau jedoch bisher in der Regel durch ein zahntechnisches Labor hergestellt wird, kann dieser

aufgrund des Zeitbedarfes des Herstellungsprozesses nicht in derselben Behandlungssitzung inseriert werden.[12] Ein damit verbundener Nachteil der individuellen Stiftaufbauten ist der notwendige provisorische Verschluss zwischen den Behandungssitzungen, welcher durch Undichtigkeiten und mangelhafte Stabilität zu einer Reinfektion der Wurzelfüllung oder einer Fraktur des stiftaufbereiteten Zahnes führen kann.[49] Zwischen den Behandlungssitzungen wird die Stiftaufbereitung zudem häufig nur mit einer provisorischen Füllung verschlossen, was zu ästhetischen und funktionellen Beeinträchtigungen für den Patienten führt. Der Grund dafür ist, dass temporäre Stiftaufbauten in Kombination mit provisorischem Zahnersatz mit einer erhöhten Frakturgefahr des Zahnes einhergehen, weshalb die Deutsche Gesellschaft für Zahn- Mund- und Kieferheilkunde in einer Stellungnahme grundsätzlich von temporären Stiftaufbauten abrät.[50].
In der zahnärztlichen Praxis werden konventionelle, individuelle Stiftaufbauten in der Regel aus metallischen Dentallegierungen gegossen[12] oder aus hochfestem Zirkoniumdioxid gefräst.[51] Diese Materialien sind aufgrund ihrer Werkstoffeigenschaften nicht oder nur wenig transluzent, weshalb es zu einer Verdunklung der zahnumgebenden Gingiva und einer Beeinträchtigung des ästhetischen Erscheinungsbildes der Restauration kommen kann.[40, 52] Des Weiteren haben metallische Dentallegierungen und hochfestes Zirkoniumdioxid ein weitaus höheres Elastizitätsmodul, als das Wurzeldentin.[51] In der Literatur werden Stiftaufbauten aus diesen Materialien daher mit einem höheren Risiko für Wurzelfrakturen[35, 53] und Dezementierungen[54], speziell bei nichtaxialer Belastung wie bei Oberkieferfrontzähnen, in Verbindung gebracht. Zwar konnten *Figueiredo et al.* in einer Metaanalyse zu dieser Fragestellung keine signifikante Erhöhung des Wurzelfrakturrisikos feststellen, wiesen jedoch auf die eingeschränkte Aussagekraft der Ergebnisse aufgrund der Heterogenität der eingeschlossenen Studien hin.[55] In einer aktuelleren Übersichtsarbeit beschrieben *Maciel et al.* zwar ebenfalls keinen signifikanten Unterschied zwischen rigiden Stiftaufbaumaterialien und solchen, die mit den mechanischen Eigenschaften des Dentin vergleichbar sind, wenn die kummulierten Ergebnisse aller Zahntypen betrachtet werden, jedoch zeigten sich signifikant schlechtere Überlebensraten, bei rigiden Stiftaufbauten in Frontzähnen. Hieraus folgerten die Autoren, dass bei Zähnen, die einer nichtaxialen Belastung unterliegen, konfektionierte Glasfaserstiftaufbauten zu präferieren sind, da diese zu einer homogen Kaukraftweiterleitung beitragen und damit die mechanische Überlastung des Zahnes verhindern.[56]

Der Hauptvorteil der individuellen Stiftaufbauten liegt in der sehr guten Passgenauigkeit aufgrund der Herstellung anhand einer Abformung des aufbereiteten Wurzelkanals.[57] Hieraus resultiert ein schmaler Zementspalt, wodurch die Belastungsspannungen gleichmäßig auf die Wurzel verteilt werden können.[12] Des Weiteren führt der einteilige Aufbau aus Stift- und Stumpfanteil zur Vermeidung einer mechanischen Schwachstelle, wie sie bei konfektionierten Stiftaufbauten mit einem plastischen Stumpfaufbau durch die Phasengrenze notwendiger Weise vorliegt.[12, 28]

Bei individuellen Stiftaufbauten ist zudem zu beachten, dass lediglich metallische Werkstoffe in einem rein konventionellen Workflow hergestellt werden können. Zirkoniumdioxid und andere ausschließlich fräsbare Materialien, lassen sich nur in einem zumindest teilweise digitalen Workflow verarbeiten, was erklärt, warum diese Materialien erst seit kurzer Zeit zur Herstellung von Stiftaufbauten verwendet werden.[58] *Al-Qarni* untersuchte in einer Übersichtsarbeit die wissenschaftliche Literatur zu individuellen Stiftaufbauten, welche in CAD/CAM-Systemen gefertigt wurden:[12] Die meisten der eingeschlossenen Studien waren Laboruntersuchungen oder klinische Fallberichte, bei denen ein Gipsmodell einer konventionellen Stiftabformung im Labor digitalisiert wurde.[28, 29, 59] Bei einigen anderen Studien wurde ein im aufbereiteten Wurzelkanal modellierter Stiftaufbau aus Kunststoff oder Wachs anschließend im Labor digitalisiert und in einem CAD/CAM-Prozess hergestellt.[41, 42, 47] Lediglich bei drei Untersuchungen wurde der aufbereitet Wurzelkanal in einem volldigitalen Workflow direkt gescannt, der Stiftaufbau virtuell konstruiert und anschließend in einem CAD/CAM-Prozess hergestellt. Bei zwei Untersuchungen handelte es sich jedoch um reine Laboruntersuchungen unter idealen Bedingungen.[48, 60] Eine Untersuchung beschrieb lediglich einen klinischen Fallbericht, bei dem der Wurzelkanal sehr konisch und kurz aufbereitet wurde, was die Scanbarkeit für den Intraoralscanner begünstigte und damit nicht der üblichen klinischen Situation entspricht.[61] *Al-Qarni* schlussfolgerte, dass die klinische Datenlage noch sehr limitiert ist und daher mehr in vivo Untersuchungen benötigt werden, um die vielversprechenden Ergebnisse des klinischen Fallberichtes zu bestätigen.[12]

1.4 Langzeiterfolg von Stiftaufbauten

1.4.1 Klinische Datenlage

Stiftaufbauten werden in der zahnärztlichen Praxis häufig zur postendodontischen Versorgung stark zerstörter Zähne verwendet, weshalb deren Überlebenszeit von klinischem Interesse ist und daher in der Vergangenheit vielfach untersucht wurde. Darüber hinaus sind die publizierten Daten von verschiedenen Autoren bereits in unterschiedlichen Metaanalysen zusammengefasst worden, um klinisch praktizierenden Zahnärzten einen evidenzbasierten Leitfaden für die Beratung der Patienten und die Behandlung zu liefern. In der Tabelle 1 werden die Ergebnisse dieser Metaanalysen zusammengefasst:

Tabelle 1: Ergebniszusammenfassung der publizierten Metaanalysen zur Überlebenszeit von Stiftaufbauten

Autor / Jahr	**Anzahl der eingeschlossenen Studien**	**Anzahl der eingeschlossenen Stiftaufbauten**	**Mittlerer Beobachtungszeitraum (Jahre)**	**Mittlere Überlebensraten**
Figueiredo et al. / 2015 [55]	14	3202	8,2	90,0 %
Maciel et al. / 2024 [56]	14	k.A.	6,5	62,8 %
Martins et al. / 2021 [62]	10	844	4,2	82,7 %
Tsintsadze et al. / 2024 [26]	8	1106	4,3	85,5 %
Garcia et al. / 2018 [63]	6	721	5,0	83,5 %
Marchionatti et al. / 2017 [64]	11	1394	5,3	73,7 %

Die in Tabelle 1 beschriebenen Metaanalysen zeigen, dass die Ergebnisse der mittleren Überlebensraten zwischen 62,8 [56] und 90,0 % [55] variieren. Darüber hinaus wurden unterschiedlich viele Studien und Stiftaufbauanzahlen, mit ungleich langen

Beobachtungszeiträumen eingeschlossen. Diese Heterogenität in den Studienaufbauten und Einschlusskriterien der Metaanalysen wird von vielen Autoren beschrieben und mit einer erschwerten Vergleichbarkeit der Ergebnisse in Verbindung gesetzt.[63, 65-68] Des Weiteren beziehen sich alle in Tabelle 1 beschriebenen Übersichtsarbeiten auf Stiftaufbauten unter Einzelkronen oder Brücken und exkludieren damit beispielsweise die tendenziell schlechteren Ergebnisse von Stiftaufbauten in Verbindung mit herausnehmbarem Zahnersatz.[44] *Figueiredo et al.* beschrieben, dass bei vielen Studien Unterschiede bei der Randomisierung und Verblindung vorliegen, sodass die Ergebnisse und Schlussfolgerungen hierdurch zudem verfälscht werden können.[55] Zusammenfassend lässt sich daher aus den bisher in der wissenschaftlichen Literatur publizierten Daten und Metaanalysen zur Überlebenszeit von Stiftaufbauten keine Aussage treffen, die eine strukturierte und zielgenaue Weiterentwicklung der postendodontischen Versorgung mittels Stiftaufbauten an unserer Klinik zulässt. Hierfür waren eigenständige Überlebenszeitanalysen notwendig, die in Kapitel 2.1 beschrieben werden und Teil dieser kumulativen Habilitationsarbeit sind.

1.4.2 Risikofaktoren

Auch die Misserfolgsursachen von Stiftaufbauten wurden in der Literatur bereits von vielen Arbeitsgruppen über die letzten Jahrzehnte hinweg untersucht.[44, 65, 68-70] Am Häufigsten wird hierbei der Retentionsverlust beschrieben, [6, 67, 71-73] welcher jedoch nicht immer zu einem Verlust des Pfeilerzahnes oder einer Neuanfertigung des Stiftaufbaus führen muss, da in manchen Fällen eine Rezementierung möglich ist.[32, 53, 74, 75] Aus diesem Grund wird ein Retentionsverlust von einigen Autoren nicht als Misserfolg des Stiftaufbaus erfasst, was die Ergebnisse zwischen den verschiedenen Untersuchungen nur bedingt vergleichbar macht.[6, 13] Andere Arbeitsgruppen unterscheiden die Misserfolgsursachen nach „relativ“ und „absolut“, wobei eine absolute Misserfolgsursache zwingend mit der Extraktion des Zahnes oder einer Zerstörung des Stiftaufbaus einhergeht.[6, 76] Wieder andere Autoren definieren im Hinblick auf die Überlebenszeit von Stiftaufbauten „success“ und „survival“, wobei nur die Zeit bis zu einem möglichen Retentionsverlust als „success“ bezeichnet wird.[75] Allerdings beschreiben längst nicht alle Autoren in der wissenschaftlichen Literatur die Misserfolgsursachen in ihren Untersuchungen so differenziert, was einen gegenüberstellenden Vergleich der Ergebnisse studienübergreifend erschwert.[55, 65, 66, 70]

Neben den eigentlichen Misserfolgsursachen einer Therapie mittels Stiftaufbau, wird auch die Abhängigkeit von patienten- oder restaurationsimmanenten Faktoren in der Literatur unterschiedlich bewertet.[6, 77-79] Beispielsweise beschreiben *Balkenhol et al.* sowie *Bergman et al.* einen alleinigen, signifikanten Einfluss der Art der prothetischen Versorgung auf die Überlebenszeit von Stiftaufbauten.[6, 80] Andere Autoren konnten hierbei wiederum keinen signifikanten Unterschied verzeichnen, jedoch beeinflusste in deren Studie die Zahngruppe (Frontzahn, Prämolar, Molar) die Überlebenszeit der Stiftaufbauten.[67, 81] Zusammenfassend zeigen alleine schon diese Beispiele den kontrovers diskutierten Einfluss verschiedener Parameter, sodass eine klare Behandlungsempfehlung hinsichtlich der Therapie mit Stiftaufbauten in der Literatur bisher nicht definiert werden konnte. Diesbezüglich hat sich die Arbeitsgruppe um *Machry* in einer aktuellen Literaturübersichtsarbeit mit der Frage beschäftigt, ob Stiftaufbauten aufgrund der Weiterentwicklungen auf dem Gebiet der dentalen Adhäsivtechnik überhaupt noch nötig sind und hierbei verschiedene Risikofaktoren und aktuell immer noch bestehende Indikationen für Stiftaufbauten herausgearbeitet.[82] Ebenso wie *Naumann et al.*[30] konstatierten sie, dass das Ferrule-Design und die vorhandene Restzahnhartsubstanzmenge der wichtigste

Faktor für den Langzeiterfolg von Stiftaufbauten ist.[82] Nichtsdestotrotz schlossen die Autoren aus den in ihre Übersichtsarbeit eingeschlossenen Studien, dass selbst bei Vorliegen eines Ferrule-Effektes und einer akzeptablen Menge an Restzahnhartsubstanz, klinisch ein nicht zu vernachlässigender Einfluss von nicht-axialen Kaukräften in Verbindung mit Materialen, die in ihrem Elastizitätsmodul vom Dentin abweichen, besteht. Hierbei beschrieben sie speziell die Indikation von konfektionierten Glasfaserstiftaufbauten im durch den physiologischen Überbiss nicht-axial belasteten Frontzahnbereich, da hierdurch sogar eine Steigerung der Frakturresistenz des Zahnes im Vergleich zu einem Verzicht auf einen Stiftaufbau erzielt werden kann.[83] Andererseits weisen sie jedoch auch auf das gesteigerte Dezementierungsrisiko bei diesen Stiftaufbauten hin, da hierbei aufgrund ihrer konfektionierten Bauart ein tendenziell größerer Zementspalt zwischen Stift und Wurzelkanalwand entsteht, als bei individuellen Stiftaufbauten.[26] Speziell im europäischen Raum besteht hinsichtlich der nicht-axialen Belastung noch ein weiterer Risikofaktor für Stiftaufbauten und für die mit diesen versorgten Zähne, da in diesen Ländern Teleskopprothesen eine weit verbreitete Behandlungsoption sind.[6, 84] Durch die körperliche Fassung des Zahnes mit der Prothese besteht ein besserer Halt, als bei Klammerprothesen,[85] jedoch wirken in diesem Zusammenhang nichtaxialen Kräfte auf den Zahn, wenn die Teleskopprothese durch den Patienten falsch ein- und ausgegliedert wird,[6] oder der Prothesensattel eine Inkongruenz zum Tegument aufweist.[86] Aus diesem Grund beschreiben die meisten Autoren, die bei der Überlebenszeitanalyse von Stiftaufbauten auch diese Art der prothetischen Versorgung berücksichtigen, die schlechtesten Ergebnisse überhaupt in Verbindung mit Teleskopprothesen.[6, 84]

Zusammenfassend können auf Grundlage der heterogenen Daten in der Literatur keine Risikofaktoren der postendodontischen Versorgung mittels Stiftaufbauten an unserer Klinik identifiziert werden. Aus diesem Grund waren, wie auch schon bezogen auf die allgemeinen Überlebenszeitanalysen, eigenständige Untersuchungen notwendig, um eine zielorientierte Weiterentwicklung dieser Therapieoption mittels digitaler Technologien zu ermöglichen. Diese Studien werden in Kapitel 2.1 beschrieben und sind Teil der vorliegenden Habilitationsarbeit.

1.5 Weiterentwicklung der postendodontischen Versorgung mittels Stiftaufbauten durch Verwendung digitaler Technologien

Das Ziel einer Weiterentwicklung der postendodontischen Versorgung besteht darin, die beschriebenen Vorteile der konfektionierten mit denen der individuellen Stiftaufbauten zu verbinden und gleichzeitig die Nachteile und Schwachstellen zu eliminieren. Hierzu muss die Stiftbettpräparation unweigerlich mittels Intraoralscanner digitalisiert werden, um die zeitaufwendigen, analogen Arbeitsschritte bei der Herstellung individueller Stiftaufbauten durch einen volldigitalen, schnelleren Workflow zu ersetzen. Erst hierdurch wird eine Sofortversorgung, wie bei konfektionierten Stiftaufbauten, auch mit passgenaueren, individuellen Stiftaufbauten möglich. Durch die Verfügbarkeit von CAD/CAM-Materialien, die ähnliche mechanische Eigenschaften wie Dentin aufweisen, können daraufhin individuelle Stiftaufbauten hergestellt werden, die das Wurzelfrakturrisiko minimieren und die Kaukraft homogen auf den Zahn übertragen können.

1.5.1 *Digitale Stiftabformung mittels Intraoralscanner*

Direkte digitale Stiftabformungen mit Intraoralscannern sind durch die jüngsten technischen Weiterentwicklungen erst seit Kurzem möglich geworden.[12, 87] Die Abbildung 5 zeigt exemplarisch eine solche direkte, digitale Stiftabformung mittels eines Intraoralscanners anhand eines frakturierten Teleskoppfeilerzahnes.

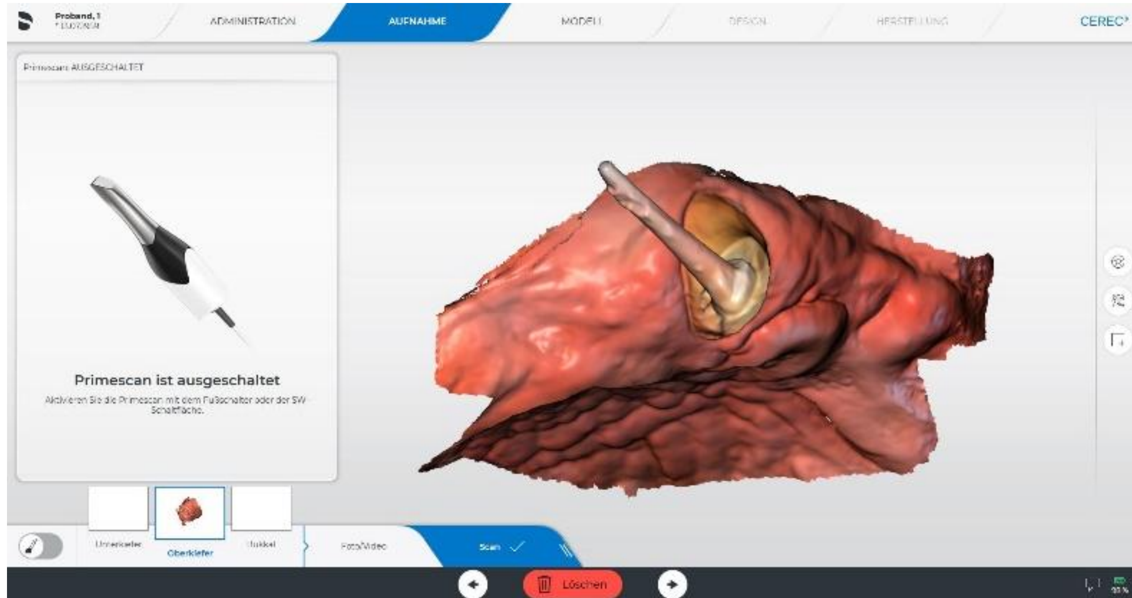


Abbildung 5: Direkte, digitale Stiftabformung mittels Intraoralscanner.

Der Vorteil der digitalen im Vergleich zu der konventionellen Stiftabformung ist, dass die digitale Stiftabformung weitgehend unabhängig von der Erfahrung und dem manuellen Geschick des Behandlers ist, da diese sofort auf dem Bildschirm auf Vollständigkeit überprüft und gegebenenfalls ergänzt werden kann.[88] Hierbei handelts sich darüber hinaus um einen Behandlungsschritt, der in der zahnärztlichen Praxis regelmäßig an die Assistenz delegiert werden kann, was dem Zahnarzt einen zeitlichen und damit wirtschaftlichen Mehrwert bringt.[89] Eine konventionelle Stiftabformung ist dagegen schwer zu ergänzen und insbesondere im apikalen Bereich ist es unmöglich zu überprüfen, ob das Abformmaterial jeden Teil des aufbereiteten Wurzelkanals erreicht hat, was zu einer schlechten Passgenauigkeit des herzustellenden Stiftaufbaus führen kann.[88] Konventionelle Präzisionsabformungen werden daher in der Regel durch den Zahnarzt selbst durchgeführt und nicht an die Assistenz delegiert, da es sich hierbei um einen Behandlungsschritt handelt, bei dem selbst minimale Abweichungen vom standardisierten Vorgehen zu einem schlussendlich nicht passenden Zahnersatz führen.[13, 90]

Nichtsdestotrotz ist auch die digitale Abformung nicht ganz trivial, da alle bisher eingeführten Geräte, optische Systeme sind, bei denen das Licht für eine vollständige

Abformung jeden Bereich der Präparation erreichen muss, was speziell bei tiefen Stiftaufbereitungen schwierig sein kann.[91] Aus diesem Grund ist die Qualität der digitalen Stiftabformung und damit die Passgenauigkeit des daraus resultierenden CAD/CAM Stiftaufbaus signifikant von der Hard- und Software des verwendeten Intraoralscanners und im Speziellen von der Tiefenschärfe abhängig.[92] *Pinto et al.* verglichen die Abformungenauigkeit zwischen konventionellen und digitalen Stiftabformungen bei unterschiedlichen Aufbereitungslängen und zeigten, dass mit dem verwendeten Intraoralscanner signifikant weniger von der apikalen Stiftaufbereitung erfasst wurde.[93] Zu beachten ist bei der Interpretation der Ergebnisse jedoch, dass weder die von den Autoren im Jahr 2017 verwendete Hard- noch die Software mit aktuellen, heute am Markt verfügbaren Intraoralscannern vergleichbar ist. Ein Einfluss dieser Faktoren auf das Scanergebnis ist in der Literatur beschrieben worden.[94] *Emam et al.* zeigten mit moderneren Intraoralscannern und aktualisierter Software eine mehr als zehnmal kleinere Abweichung zwischen digitalen und konventionellen Stiftabformungen.[95] *Elter et al.* verwendeten einen modernen Intraoralscanner, da dieser laut Herstellerangaben eine sehr hohe Tiefenschärfe hat. Sie berichteten jedoch trotzdem, dass die digitale Abformung im apikalen Aufbereitungsbereich limitiert ist und signifikant von der Tiefe und dem Durchmesser der Präparation abhängt.[92] Dies zeigt, dass auch andere Umgebungsfaktoren, wie der Speichelfluss oder die Lichtintensität einen Einfluss auf die Qualität von digitalen Abformungen haben können.[85] *Ochoa-Lopez et al.* zeigten, dass die Genauigkeit einer digitalen Abformung mit Intraoralscannern signifikant von der Umgebungsbeleuchtung abhängt,[85] was offensichtlicher Weise speziell bei tiefen Stiftbettpräparationen zum Tragen kommt. Hierbei ist zu beachten, dass jedes von den Autoren untersuchte Scansystem unter anderen Umgebungslichtverhältnissen die höchste Genauigkeit zeigte. Der Intraoralscanner, den *Elter et al.* in ihrer Laborstudie verwendeten zeigte die besten Ergebnisse bei 10.000 Lux, was wenn überhaupt nur durch Verwendung einer zusätzlichen Lichtquelle im apikalen Bereich der tiefen Stiftbettpräparation zu erreichen ist.

1.5.2 CAD/CAM Materialien mit dentinähnlichen mechanischen Eigenschaften

Ursprünglich wurden glasfaserverstärkte Komposite für die Luftfahrtindustrie entwickelt und werden dort seit Jahrzehnten mit großem Erfolg verwendet.[96] Verschiedene Autoren in der Literatur haben darüber hinaus die Verwendung von glasfaserverstärkten Kunststoffen zur Herstellung von Stiftaufbauten aufgrund der günstigen mechanischen und ästhetischen Werkstoffeigenschaften beschrieben.[28-31] *Liu et al.* beschrieben in einem klinischen Fallbericht die Herstellung eines Stiftaufbaus zur Versorgung eines tief frakturierten Oberkieferfrontzahnes und wiesen auf die Vorteile des einteiligen Aufbaus und das mit 30-40 GPa ähnliche Elastizitätsmodul des von ihnen verwendeten Werkstoffes im Vergleich zum Wurzeldentin (circa 18,6 GPa) hin.[28] *Chen et al.* untersuchten in einer Laborstudie mit Stiftaufbauten aus demselben Material anhand von koronal stark zerstörten Oberkieferfrontzähnen, die Spannungsverteilung in der Wurzel mit der Finite-Elemente Analyse. Sie postulierten, dass aufgrund der günstigen mechanischen Eigenschaften die Verwendung dieses Materials für Stiftaufbauten bis zu einem knöchernen Attachmentverlust von 2/3 der Wurzel empfohlen werden kann. Allerdings wurde das mechanische Verhalten des Knochens in deren Modell nicht mit simuliert.[30] Die Annahme des homogenen und proportionalen Verhaltens von Umgebungsstrukturen ist eine grundsätzliche Limitation aller bisher publizierten, rein digitalen Belastungssimulationen in der Zahnmedizin.[97] *Pang et al.* verglichen in einer Laborstudie die Frakturresistenz von CAD/CAM gefertigten, glasfaserverstärkten Kunststoffstiftaufbauten mit der Frakturresistenz von individuell gegossenen und konfektionierten Stiftaufbauten. Sie zeigten eine signifikante Steigerung der Frakturresistenz durch die Verwendung von CAD/CAM gefertigten, glasfaserverstärkten Kompositstiftaufbauten.[60] *Moustapha et al.* untersuchten in einer Laborstudie die Zementspaltdicke von individuellen Stiftaufbauten aus glasfaserverstärktem Komposit. Sie zeigten, dass die direkte Digitalisierung des Kanallumens mit einem Intraoralscanner zu der besten Passgenauigkeit des Stiftaufbaus führte.[98]

Bei einigen glasfaserverstärkten Kompositen sind die Glasfasern nicht zufällig in die Kunststoffmatrix eingebettet, sondern unidirektional oder multidirektional im Fräsblock oder der Ronde angeordnet.[51] Außerdem besteht der Glasfaseranteil nicht aus kurzen, sondern längeren Fasern, die in Matten oder Fäden angeordnet sind. Dies führt zu einer besseren Spannungsverteilung bei der Belastung.[99] Darüber hinaus wirken die langen Fasern wie ein Lichtleiter, was die Transluzenz und damit das ästhetische

Erscheinungsbild der Restauration verbessern kann.[40] *Libonati et al.* verwendeten in einem klinischen Fallbericht einen glasfaserverstärkten Komposit (*Trilor, Bioloren, Saronno, Italien*) bei dem die Fasern multidirektional angeordnet sind.[61] *Ruschel et al.* verglichen die mechanischen Eigenschaften von gefrästen Stiftaufbauten aus demselben CAD-CAM-Material mit konfektionierten Glasfaserstiften, bei denen die Fasern unidirektional in Achsenrichtung angeordnet sind. Sie zeigten, dass die mechanischen Eigenschaften der gefrästen Stiftaufbauten signifikant von der Orientierung des Faserverlaufes zur Kraftachse abhängen. Sie beschrieben darüber hinaus, dass der Faseranteil im Verhältnis zur Kunststoffmatrix nicht zu hoch sein darf, da die Bruchlinien hauptsächlich entlang der Faser-Matrixgrenzen verlaufen.[51] In einer materialwissenschaftlichen Vergleichsstudie wurde *Trilor* mit einem anderen multidirektional orientierten glasfaserverstärkten CAD/CAM-Komposit (*Trinia, Bicon., Boston, USA*) verglichen. Die Autoren beschrieben, dass *Trinia* einen um 20% geringeren Glasfaseranteil besitzt, durch seine Struktur die Funktion der Sharpeyschen Fasern imitieren und damit ein natürliches Kaugefühl erzeugen kann. Darüber hinaus hat das Material eine sehr geringe Wasserabsorptionsrate von 0,03%, was bei Stiftaufbauten das Wurzelfrakturrisiko durch Quellung des Stiftaufbaus verringert.[96] Der signifikante Einfluss des Faserverlaufes zur Kraftachse wurde auch für dieses Material in der Literatur beschrieben: Wird *Trinia* senkrecht zum Faserverlauf belastet, steigt die Biegefestigkeit im Vergleich zur parallelen Belastung um den Faktor 2,5 an.[99]

Die Ergebnisse von *Ruschel et al.[51]*, *Bechir et al.[96]* sowie *Suzaki et al.[99]* weisen darauf hin, dass es sich bei den aktuell bereits am Markt verfügbaren, glasfaserverstärkten CAD/CAM Kompositen - und im Speziellen bei *Trinia* - um ideale Materialien für die Herstellung von Stiftaufbauten handelt. In Verbindung mit der digitalen Stiftabformung mittels Intraoralscannern können somit Stiftaufbauten hergestellt werden, die die Vorteile der etablierten, individuell gegossenen mit denen der konfektionierten Glasfaserstiftaufbauten verbinden und damit die postendodontische Versorgung von Patienten verbessert. Hierdurch entstehen wirtschaftliche Vorteile für den Zahnarzt und eine komfortablere Behandlung für den Patienten, die erst durch den Einsatz moderner, digitaler Technologien möglich geworden sind.

Vor diesem Hintergrund ist zusammenfassend festzuhalten, dass in verschiedenen Studien technische und werkstoffkundliche Weiterentwicklungen beschrieben wurden, die zwar zu einer Verbesserung der postendodontischen Versorgung mittels Stiftaufbauten beitragen können, jedoch bisher keine konkreten Workflows publiziert sind, die diese

Weiterentwicklungen für den praktizierenden Zahnarzt in den unterschiedlichen Indikationen klinisch nutzbar machen. Dies ist daher eines der Ziele der vorliegenden Habilitationsschrift und wird im folgenden Abschnitt durch Zusammenfassung der durchgeführten Studien beschrieben.

2 Wissenschaftliche Einordnung und Diskussion

In dem folgenden Teil der Habilitationsschrift, werden die durchgeführten Studien mit deren Ergebnissen zusammengefasst und vor dem Hintergrund der wissenschaftlichen Literatur diskutiert. Vor dem Hintergrund der in Kapitel 1 beschriebenen uneinheitlichen Studienergebnisse in der Literatur und einer mangelhaften Vergleichbarkeit aufgrund geringer Fallzahlen, kurzer Beobachtungszeiträume und uneinheitlicher Datenstrukturen, wurden zunächst in mehreren retrospektiven Überlebenszeitstudien mit verschiedenem Fokus die Risikofaktoren der Stiftaufbauten beziehungsweise der mit Stiftaufbauten versorgten Zähne herausgearbeitet und näher analysiert (Kapitel 2.1). Aufgrund der in der Literatur kontrovers diskutierten Einflussfaktoren verschiedener prothetischer und patientenassoziierter Parameter war eine strukturierte Analyse notwendig, um die Risikofaktoren der an unserer Klinik etablierten Behandlungsweise zu evaluieren und eine strukturierte Weiterentwicklung der postendodontischen Versorgung mittels Stiftaufbauten unter Verwendung moderner, digitaler Technologien voranzutreiben. Diese Weiterentwicklung wird anschließend in Kapitel 2.2 beschrieben.

2.1 Retrospektive Überlebenszeitanalysen von Stiftaufbauten

Das Fehlen von Langzeitüberlebensdaten ist ein seit Jahrzehnten bekanntes Problem, welches nicht nur für Stiftaufbauten, sondern nahezu jede prothetische Restaurationsart vorliegt. Aufgrund dessen wurde 2004 das „Multizentrische Dokumentation" Programm (MZD) entwickelt und im Rahmen einer durch die Deutsche Forschungsgemeinschaft geförderter multizentrischen Studie an allen teilnehmenden Universitätszahnkliniken eingeführt.[100] An der Poliklinik für Zahnärztlichen Prothetik der Justus-Liebig Universität Gießen wurde dieses Programm nach Abschluss der Studie zur Behandlungsdokumentation beibehalten und kontinuierlich weiterentwickelt. Auf diese Weise wurde die Datenerfassung für retrospektive Überlebensstudien standardisiert und damit besser auswertbar gemacht. Seit 2004 ist somit ein strukturierter Datenpool gewachsen, der digital auswertbar ist und damit menschliche Fehler bei der Datenakquise vermeidet und die Auswertung eines großen Patientenkollektives über einen langen Zeitraum ermöglicht. Hierdurch wird die statistische Aussagekraft der Daten gestärkt, sodass eine strukturierte Evaluation und Optimierung des Langzeiterfolgs unter Anderem der postendodontischen Versorgung mittels Stiftaufbauten ermöglicht wurde. Für die statistische Auswertung der nachfolgend beschriebenen retrospektiven Überlebenszeitanalysen wurde die Kaplan-Meier Methode verwendet, da diese Patientendatenpools mit unterschiedlich langen Beobachtungszeiträumen, sowie solchen Fällen ohne einen während des Beobachtungszeitraumes eingetretenen Misserfolg des Stiftaufbaus (zensierte Fälle) berücksichtigen und untereinander vergleichen kann.[101-104] Somit können univariante Einflüsse verschiedener patienten- oder restaurationsimmanenter Parameter direkt auf den Langzeiterfolg hin untersucht und signifikante Unterschiede identifiziert werden.[101, 105] Um multivariante Einflüsse zu untersuchen, wurde in den nachfolgend beschriebenen Studien darüber hinaus eine Cox-Regressionsanalyse durchgeführt.[106, 107] Hierdurch ist es möglich, die in der Kaplan-Meier Analyse identifizierten, signifikanten Unterschiede hinsichtlich ihres kombinierten Einflusses auf den Langzeiterfolg hin zu überprüfen und dadurch näher zu spezifizieren. Die Kombination aus Kaplan-Meier und Cox-Regressionsanalyse wird in der Literatur von den meisten Arbeitsgruppen mit ähnlichen, wissenschaftlichen Fragestellungen verwendet,[66, 102-104] was die Vergleichbarkeit der nachfolgend beschriebenen Ergebnisse mit der Literatur verbessert.[55, 65]

2.1.1 Primärüberlebenszeitanalyse aller Stiftaufbauten und deren beeinflussende Parameter

Zunächst wurde für diese kumulative Habilitation eine Primäranalyse aller Stiftaufbauten, die in dem Beobachtungszeitraum 2004-2020 an der Poliklinik für Zahnärztlichen Prothetik der Justus-Liebig Universität Gießen eingesetzt wurden, durchgeführt und deren potenziell überlebenszeitbeeinflussende Parameter untersucht.[79] Hierdurch sollten mögliche Risikofaktoren identifiziert werden, die anschließend in fokussierenden Analysen näher untersucht wurden, um eine möglichst evidenzbasierte Grundlage für die Optimierung der postendodontischen Versorgung mittels Stiftaufbauten zu schaffen. In einer Vorgängerstudie aus unserer Arbeitsgruppe wurden noch analoge Patientenakten, in denen in dem Beobachtungszeitraum 1995-2004 ein individuell gegossenen Stiftaufbau eingesetzt wurde, retrospektiv nachuntersucht und aufgrund der Ergebnisse, das Behandlungskonzept optimiert.[6] Diese Anpassungen sollten in der hier beschriebenen Studie zudem hinsichtlich einer Verbesserung der Überlebenszeit überprüft werden. Aufgrund der Daten dieser Primärüberlebenszeitanalyse ist folgende Originalarbeit entstanden und international publiziert worden.

J.A.H. Vogler, M. Lehmann, P. Rehmann, B. Wostmann, Survival time of post and cores: A 16 year retrospective follow-up study, J Dent 117 (2022) 103923, 1-9. (IF 2022: 4,4)

Zum Zeitpunkt der Untersuchung bestand in der Literatur eine inhomogene Datenlage hinsichtlich der überlebenszeitbeeinflussenden Paramater von Stiftaufbauten. Als Grund hierfür werden von vielen Autoren die zwischen den Studien unterschiedlichen Stiftarten, Materialien und prothetischen Versorgungsarten und die damit einhergehende, eingeschränkte Vergleichbarkeit der Ergebnisse beschrieben.[6, 55, 65] In der Studie von *Balkenhol et al.* wurden nur individuell gegossene Stiftaufbauten berücksichtigt, während in der Primäruntersuchung für diese kumulative Habilitation auch konfektionierte Glasfaserstifte mit einbezogen wurden,[6] um damit das gesamte Spektrum der verwendeten Stiftaufbauten an unserer Poliklinik mit in die Analyse einzubeziehen. Entsprechend der in der Literatur beschriebenen Indikationstellung,[71, 103] wurden konfektionierte Glasfaserstifte mit Kompositstumpfaufbauten verwendet, wenn der koronale Defekt des Zahnes moderat war. Bei Zähnen mit größeren Defekten wurden individuell gegossene Stiftaufbauten angefertigt und eingesetzt. Hinsichtlich der prothetischen Restauration wurden

sowohl festsitzender, als auch herausnehmbarer Zahnersatz berücksichtigt und dies als potenziell überlebenszeitbeeinflussender Faktor mit modelliert. Darüber hinaus wurden die Art des Zahnes, welcher mit einem Stiftaufbau versorgt wurde (Frontzahn / Prämolar / Molar), der Kiefer (Ober- bzw. Unterkiefer), das knöcherne Attachment (physiologisch / pathologisch), das Befestigungsmaterial (konventioneller Zement / adhäsiver Einsetzkomposit), sowie die Erfahrung des Behandlers (Zahnarzt / Zahnmedizinstudent) berücksichtig. Es wurden lediglich die Stiftaufbauten ausgeschlossen, bei denen kein Ferrule-Design vorlag, da in der Literatur diesbezüglich Konsens besteht, dass ohne eine solche zirkuläre Umfassung der Zahnwurzel durch die Restauration, kein Langzeiterfolg des Stiftaufbaus zu erzielen ist.[5, 82] Als Endpunkt der Überlebenszeitanalyse wurden Ereignisse gewertet, die entweder zu einer Extraktion des Zahnes, einer Neuanfertigung des Stiftaufbaus oder einer Dezementierung des Stiftaufbaus geführt haben.

Aufgrund der wenig limitierten Einschlusskriterien konnten somit in dieser Studie ein, verglichen mit der wissenschaftlichen Literatur, sehr großes Patientenkollektiv von 653 Patienten mit insgesamt 923 Stiftaufbauten über einen langen Beobachtungszeitraum von bis zu 16,33 Jahren nachuntersucht werden. Am Häufigsten wurde hierbei ein Retentionsverlust als Misserfolgsursache bei den untersuchten Stiftaufbauten dokumentiert. Die kumulative Überlebenszeit aller Stiftaufbauten lag im Durchschnitt bei 10,9 Jahren und war am besten, bei festsitzendem Zahnersatz, Molaren, konfektionierten Glasfaserstiftaufbauten und physiologischem Knochenattchment.
Die potentiellen Risikofaktoren für einen Stiftaufbau sind dementsprechend, die Versorgung von Teleskoppfeilerzähnen und Frontzähnen, speziell mit gegossenen Stiftaufbauten sowie bei Patienten mit einem parodontal bedingten Knochenabbau. Die Abbildung 6 zeigt die kumulative Kaplan-Meier Überlebenskurve aller Stiftaufbauten mit einem prognostizierten Misserfolg bei der Hälfte aller Versorgungen nach circa 10 Jahren (schwarze und grüne Markierung). Dies verdeutlicht das große Verbesserungspotenzial der postendodontischen Versorgung mittels Stiftaufbauten, was das Ziel dieser kumulativen Habilitation ist.

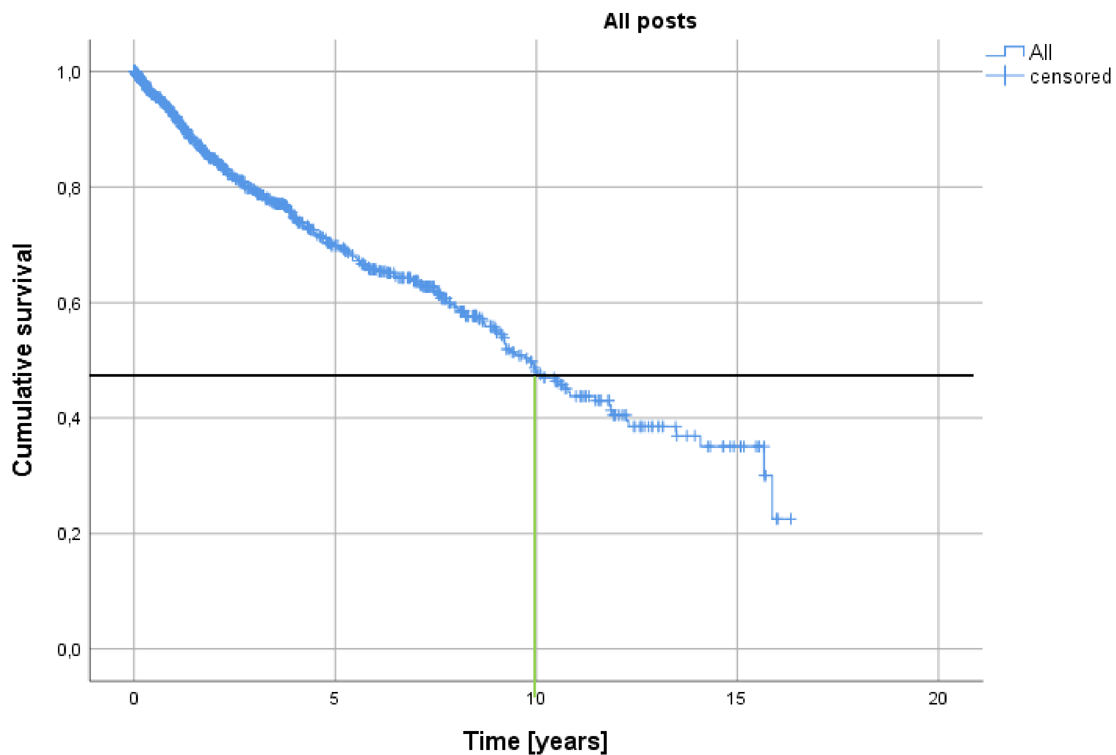


Abbildung 6: Kumulative Kaplan-Meier Kurve aller Stiftaufbauten mit einem prognostizierten Misserfolg bei der Hälfte aller Versorgungen nach circa 10 Jahren (schwarze und grüne Markierung).

Wenn auch in vergleichbaren Untersuchungen in der Literatur entweder kürzere Beobachtungszeiträume oder kleinere Patientenkollektive betrachtet wurden und die Daten damit weniger statistisch aussagekräftig sind, so sind die Ergebnisse der vorliegenden Studie mit denen anderer Autoren, die ebenfalls konfektionierte und individuelle Stiftaufbauten bei herausnehmbarem und festsitzendem Zahnersatz untersucht haben, doch vergleichbar.[70, 72] Die signifikant schlechteren Überlebensraten für Stiftaufbauten unter Teleskopprothesen und unter Frontzähnen lassen sich durch die hierbei nicht in Zahnachsenrichtung wirkenden Kräfte erklären. Sowohl bei Frontzähne während des Kauvorgang,[45, 108] als auch bei Teleskopprothesen im Falle eines falschen Ein- und Ausgliedern[6] beziehungsweise einer Inkongruenz des Prothesensattels mit dem Kieferkamm,[86] kommt es zu unphysiologischen Hebelkräften auf den Zahn und damit auch auf den Stiftaufbau. Signifikant schlechtere Überlebensraten von Stiftaufbauten in Frontzähnen beziehungsweise in Teleskopprothesenpfeilern werden so auch von anderen Autoren in der Literatur begründet.[6, 84, 109] Verglichen mit den Ergebnissen der Untersuchung von *Balkenhol et al.* sind die Überlebensraten nahezu unverändert, weshalb daraus zu schließen ist, dass die vorgenommenen Veränderungen des Behandlungskonzeptes mit Stiftaufbauten nicht den gewünschten Erfolg erbracht haben und damit weiterer Optimierungsbedarf besteht.

Aufgrund der Ergebnisse dieser Primäruntersuchung, wurden folgende klinische relevante und fokussierende Untersuchungen durchgeführt:

- Fokussierende Untersuchung des Retentionsverlustes als häufigste Misserfolgsursache der untersuchten Stiftaufbauten.[109]
- Fokussierende Untersuchung der Überlebenszeit in Verbindung mit Teleskopprothesen als häufigste prothetische Versorgungsart der untersuchten Stiftaufbauten mit der gleichzeitig schlechtesten Prognose.[110]
- Fokussierende Untersuchung der Überlebenswahrscheinlichkeit des mit einem Stiftaufbau versorgten Zahnes.[111]
- Fokussierende Untersuchung der optimalen Stiftaufbereitungstiefe bezogen auf den Langzeiterfolg des Stiftaufbaus.[112]

2.1.2 Fokussierende Untersuchung des Retentionsverlustes als häufigste Misserfolgsursache der untersuchten Stiftaufbauten.

Wie auch die Primärüberlebenszeitanalyse aller Stiftaufbauten, die Teil dieser kumulativen Habilitation ist,[79] so haben auch die meisten anderen Autoren als häufigste Misserfolgsursache bei Stiftaufbauten einen Retentionsverlust beschrieben.[67, 71-73, 102] Da dieser jedoch nicht in allen Fällen zu einem Verlust des Pfeilerzahnes oder einer Neuanfertigung des Stiftaufbaus führt, weil der Stiftaufbau häufig wiederbefestigt werden kann,[32, 53, 74, 75] werten einige Studien die Dezementierung nicht als Misserfolg, was die Vergleichbarkeit der Studienergebnisse untereinander einschränkt.[55, 65, 66, 70, 102] Allerdings ist in diesem Zusammenhang in der Literatur ebenfalls beschrieben worden, dass es durch ein partielles und daher unbemerktes Versagen des Befestigungsmaterials zu Sekundärkaries und einem höheren Wurzelfrakturrisiko kommen kann,[113, 114] was schlussendlich die Überlebenszeit des Zahnes negativ beeinflusst.

Vor der Durchführung der Studie lagen darüber hinaus in der Literatur keine Daten hinsichtlich des Langzeiterfolges von rezementierten Stiftaufbauten vor. Der Grund hierfür ist, dass in den bis zu diesem Zeitpunkt publizierten Überlebenszeitanalysen entweder der erste Retentionsverlust als Endpunkt registriert,[32, 72, 74, 102, 115-118] oder ein Retentionsverlust gar nicht mit einbezogen wurde[55, 65, 66, 70]. Die als Teil der vorliegenden kumulativen Habilitation im Folgenden beschriebene Studie, war somit die erste Analyse, die die Überlebenszeit von rezementierten Stiftaufbauten hinsichtlich ihrer beeinflussenden Parameter strukturell untersucht hat. Darüber hinaus sollte die Frage beantwortet werden, ob die Dezementierung tatsächlich eine relative Misserfolgsursache darstellt, das heißt, ob im Detail durch die Wiederbefestigung ein erneuter Retentionsverlust des Stiftaufbaus vermieden werden kann und, ob die Überlebenswahrscheinlichkeit von rezementierten Stiftaufbauten damit gleich hoch ist, wie diese nach dem primären Einsetzen bis zur ersten Dezementierung.

Die Daten der nachfolgend beschriebenen Analyse wurden in folgender Originalarbeit international publiziert:

J.A.H. Vogler, M. Lehmann, M.A. Schlenz, K. Zierden, P. Rehmann, B. Wöstmann, Survival time of post and cores after recementation: A 16-year retrospective study with special focus on loss of retention, J Dent 127 (2022) 104314. (IF 2022: 4,4)

In dem Beobachtungszeitraum von 2004-2020 wurden insgesamt bei 112 Stiftaufbauten mindestens ein Retentionsverlust dokumentiert. Die Überlebenszeitanalyse wurde in diesen Fällen nach der Rezementierung - und auch im Falle eines mehrfachen Retentionsverlustes - jeweils erneut durchgeführt sowie die beeinflussenden Parameter ausgewertet. 42% der Stiftaufbauten wurden mehr als einmal wiedereingesetzt und die Überlebenszeit nahm nach jedem Retentionsverlust statistisch signifikant ab. Aus diesem Grund ist die häufig in der Literatur beschriebene Betrachtung des Retentionsverlustes als relativer Misserfolg problematisch,[55, 65, 66, 70, 102] da keine andere Studie bisher die Überlebenszeit nach der Rezementierung untersucht hat. Aufgrund der Ergebnisse dieser Studie stellt der Retentionsverlust also eher einen verzögerten absoluten Misserfolg dar, was zwangsweise Auswirkung auf die klinische Bewertung der Rezementierung von Stiftaufbauten hat und so auch mit dem Patienten kommuniziert werden sollte.
Hinsichtlich der den Retentionsverlust beeinflussenden Parameter, zeigte sich ein signifikant negativer Einfluss, wenn der Stiftaufbau in Pfeilern für eine Teleskopprothese oder in Frontzähnen eingesetzt wurde. Signifikant weniger Retentionsverluste wurden bei konfektionierten Glasfaserstiftaufbauten, einer Befestigung mit adhäsiven Einsetzkompositen und einem physiologischen Knochenattachment registriert. Die mit Abstand meisten der 112 registrierten Retentionsverluste wurden im Zusammenhang mit Teleskopprothesen registriert (n=101). In diesen Fällen führte auch eine adhäsive Wiederbefestigung nicht zu besseren Retentionswahrscheinlichkeiten, sodass geschlussfolgert werden konnte, dass Stiftaufbauten grundsätzlich unter Teleskopprothesen vermieden werden sollten oder einer grundlegenden Optimierung des Behandlungskonzeptes bedürfen. In jedem Fall war eine fokussierende Analyse von Stiftaufbauten in Verbindung mit Teleskopprothesen notwendig, da sowohl die Primärüberlebenszeitanalyse aller Stiftaufbauten, als auch die Untersuchung des Retentionsverlustes die schlechtesten Ergebnisse bei dieser prothetischen Versorgungsoption zeigten und zudem diesbezüglich keine Daten in der Literatur vorlagen.

2.1.3 *Fokussierende Untersuchung der Überlebenszeit in Verbindung mit Teleskopprothesen als häufigste prothetische Versorgungsart der untersuchten Stiftaufbauten mit der gleichzeitig schlechtesten Prognose.*

In der Primärüberlebenszeitanalyse aller Stiftaufbauten, die Teil dieser kumulativen Habilitation ist,[79] sowie auch in den meisten anderen Studien, die Stiftaufbauten in Verbindung mit Teleskopprothesen mit einbezogen haben, wurden zahlenmäßig die meisten Stiftaufbauten in Verbindung mit dieser prothetischen Behandlungsoption beschrieben.[6, 65, 73, 84] Gleichzeitig publizierten viele Autoren die schlechteste Überlebenswahrscheinlichkeit für Stiftaufbauten, die in Teleskopprothesenpfeilern inseriert wurden, verglichen mit allen anderen prothetischen Versorgungsoptionen.[6, 84] Hierbei muss jedoch bei genauerer Betrachtung unterschieden werden, ob der Stiftaufbau zum Zeitpunkt der Eingliederung der Teleskopprothese bereits in situ war oder, ob der Stiftaufbau aufgrund einer Pfeilerzahnfraktur nachträglich zur Wiederbefestigung einer Teleskopkrone inseriert werden musste, da bei letzteren die Überlebenszeit signifikant schlechter ist und damit die Ergebnisse zwischen den Studien nur bedingt vergleichbar sind.[119]
Zum Zeitpunkt der Durchführung der Studie waren in der wissenschaftlichen Literatur noch keine Daten publiziert worden, die diese beiden Zeitpunkte der Stiftaufbauinsertion in Verbindung mit Teleskopprothesen strukturiert untersucht und einander gegenüber gestellt haben.

Bereits bei der Planung einer prothetischen Versorgung mit einer Teleskopprothese, werden häufig Pfeilerzähne mit einbezogen, die einen großen koronalen Defekt nach einer Wurzelkanalbehandlung aufweisen und damit einen Stiftaufbau benötigen. Ein Grund hierfür ist, dass für Teleskopprothesen eine statisch günstige Verteilung der Pfeilerzähne von großer Bedeutung ist und daher in vielen Fällen auch noch Zähne mit einbezogen werden, die bei anderen prothetischen Versorgungsoptionen extrahiert worden wären.[86, 120, 121] Darüber hinaus zeigen endodontisch behandelte Pfeilerzähne, die mit Stiftaufbauten versorgt wurden bessere Überlebensraten, als wenn auf den Stiftaufbau verzichtet wurde und lediglich eine Wurzelfüllung vorlag.[120, 122]

Nachdem die Teleskopprothese eingesetzt und schon für eine gewisse Zeit in Funktion war, werden Stiftaufbauten vor allem aufgrund von Pfeilerzahnfrakturen notwendig. *Wöstmann et al.* dokumentierten in einer Studie 134 solcher Fakturen während eines neun jährigen Beobachtungszeitraums von insgesamt 1758 Pfeilerzähnen und beschrieben diese Komplikation als eine der Häufigsten in Verbindung mit Teleskopprothesen.[86]
Da für Teleskopprothesen vergleichsweise viel Zahnhartsubstanz entfernt werden muss,

kommt es bereits bei der Präparation zu einer Schwächung des Zahnes, was eine spätere Fraktur im Bereich des Stumpfes begünstigen kann.[86, 123] Häufig ist in diesen Fällen die Teleskopkrone wiederverwendbar, jedoch ist aufgrund der fehlenden Retentionsfläche eine einfache Wiederbefestigung ohne Stiftaufbau nicht möglich.[5, 124] Voraussetzung hierfür ist allerdings, dass die Frakturlinie mindestens 1-2 mm oberhalb der Präparationsgrenze für die Teleskopkrone verläuft und damit ein ausreichendes Ferrule-Design besteht.[5] Weiterhin wird die Frakturgefahr bei Teleskoppfeilern durch nichtaxiale Kräfte auf den Zahn begünstigt, die durch ein falsches Ein- und Ausgegliedert [6] oder eine Inkongruenz zwischen dem Kieferkamm und der Prothesenbasis entstehen können.[86]
Zu dieser Fragestellung wurde die unten beschriebene, retrospektive Überlebenszeitanalyse durchgeführt und die Daten in folgender Veröffentlichung präsentiert:

J.A.H. Vogler, W. Abrahamian, S.M. Reich, B. Wöstmann, P. Rehmann, Post and Core Treatment to Refit Telescopic Crown-Retained Dentures after Abutment Tooth Fracture: An Evaluation of Therapy by Retrospective Survival Analysis, Dent J (Basel) 12(7) (2024). (IF 2024: 2,5)

Die hier beschriebene Studie umfasste einen Beobachtungszeitraum von 2004 bis 2023, in dem insgesamt 246 Patienten mit 399 Stiftaufbauten in Teleskopprothesenpfeilerzähnen eingeschlossen werden konnten. Hiervon waren 132 Stiftaufbauten zum Zeitpunkt der Eingliederung der Teleskopprothese bereits in situ und 267 Stiftaufbauten wurden eingegliedert, um eine Teleskopkrone nach einer Pfeilerzahnfraktur wieder zu befestigen.

Die statistische Auswertung ergab sowohl in der univarianten Kaplan-Meier also auch in der multivarianten Cox-Regressionsanalyse einen höchst signifikanten Unterschied zwischen den beiden Eingliederungszeitpunkten der Stiftaufbauten. Die Abbildung 7 verdeutlicht die unterschiedlichen Verläufe in den Kaplan-Meier Überlebenskurven: Die Stiftaufbauten zur Wiederbefestigung einer Teleskopkrone nach einer Pfeilerzahnfraktur (blaue Kurve) unterschreiten nach circa 4 Jahren die prognostizierte 50% Überlebenswahrscheinlichkeit (schwarze und grüne Markierungen), während Stiftaufbauten, die vor der Eingliederung der Teleskopprothese bereits in situ waren, diese Grenze erst nach circa 10 Jahren unterschreiten (schwarze und orangene Markierungen).

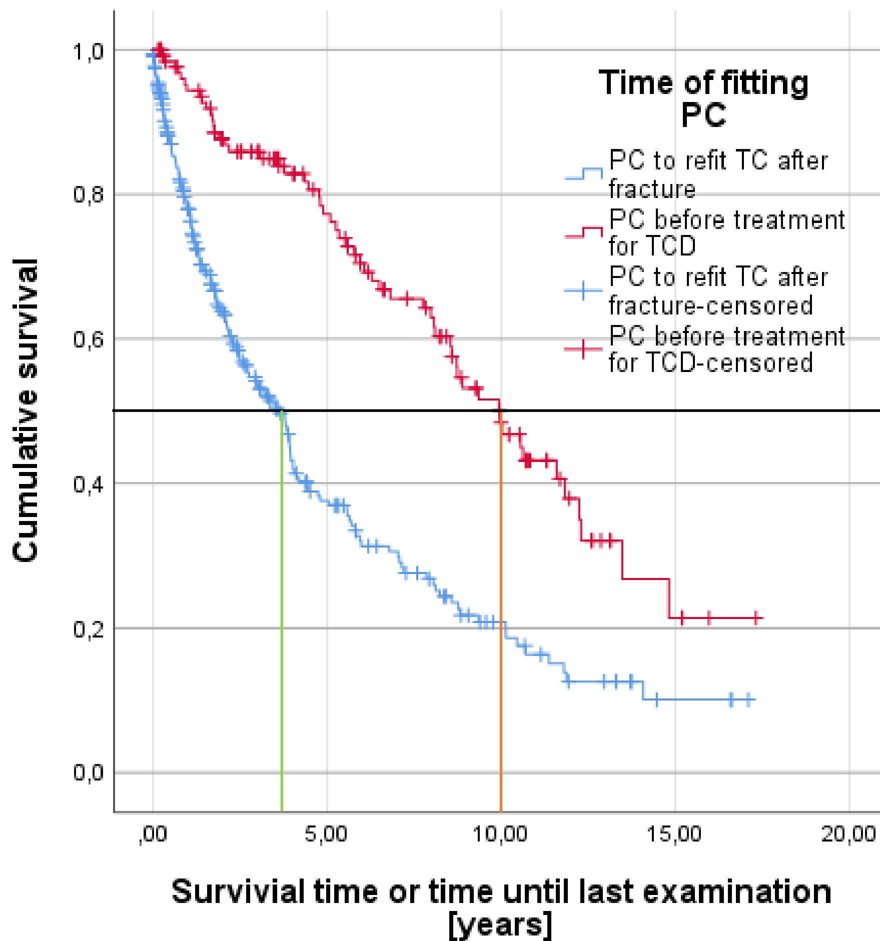


Abbildung 7: Kaplan-Meier Kurven der Stiftaufbauten zur Wiederbefestigung einer Teleskopkrone nach Pfeilerzahnfraktur (blaue Kurve) und der Stiftaufbauten, die zum Zeitpunkt der Eingliederung der Teleskopprothese bereits in situ waren (rote Kurve) mit einem prognostizierten Misserfolg bei der Hälfte aller Versorgungen nach circa 4 bzw. 10 Jahren (schwarze und grüne / orangene Markierungen).

Aufgrund der Ergebnisse der vorliegenden Studie konnte geschlussfolgert werden, dass Stiftaufbauten zur Wiederbefestigung einer Teleskopkrone nach einer Pfeilerzahnfraktur aufgrund der schlechten Überlebenswahrscheinlichkeiten vermieden, und anstatt dessen wurzelkanalbehandelte Zähne zum Zeitpunkt der Eingliederung der Prothese bereits mit einem Stiftaufbau versorgt werden sollten. Diese Ergebnisse sind mit den Daten in der Literatur vereinbar [119, 120, 122] und unterstreichen einerseits die Notwendigkeit einer strikten Nachsorge bei Patienten mit Teleskopprothesen, um eine Inkongruenz der Prothesensättel und damit einhergehend ein erhöhtes Risiko für Pfeilerzahnfrakturen zu vermeiden.[86, 125] Andererseits zeigen die Ergebnisse, dass eine Optimierung der postendodontischen Versorgung zur Wiederbefestigung einer Teleskopkrone nach einer Pfeilerzahnfraktur nötig ist und die Therapie unserer Patienten signifikant verbessern würde. Aus diesem Grund wurde hierfür ein digitaler Workflow entwickelt, der im

Rahmen dieser kumulativen Habilitation ebenfalls beschrieben wird und aktuell zur internationalen Publikation angenommen wurde (siehe Kapitel 2.2.3).

2.1.4 Fokussierende Untersuchung der Überlebenswahrscheinlichkeit des mit einem Stiftaufbau versorgten Zahnes.

Auch wenn die Überlebenszeit von Stiftaufbauten in der Literatur von vielen Arbeitsgruppen untersucht wurde,[44, 55, 69] so hat doch bis zum Zeitpunkt der Durchführung dieser Studie kein Autor Daten hinsichtlich des Extraktionsrisikos des Zahnes nach der Eingliederung des Stiftaufbaus publiziert.[111] Die Überlebenszeit des Stiftaufbaus kann man in diesem Zusammenhang nicht unmittelbar auf die Überlebenszeit des Zahnes selbst übertragen, da die häufigste Misserfolgsursache der Retentionsverlust darstellt,[71, 72, 79, 102] hierbei der Stiftaufbau in vielen Fällen rezementiert werden kann und damit der Zahn nicht zwangsläufig extrahiert werden muss.[32, 53, 75] Zwar wurde von manchen Autoren die Extraktion des Zahnes als Misserfolgsursache in deren Publikation diversifiziert beschrieben, jedoch nicht der eigentliche Extraktionsgrund dokumentiert.[6, 124] Offensichtlicher Weise kann in diesem Zusammenhang, die Extraktion als Folge einer Sekundärkaries aufgrund mangelhafter Mundhygiene, einer Veränderung des prothetischen Behandlungsplanes oder einer Zahnlockerung aufgrund einer Parodontitis nicht unmittelbar auf die Eingliederung des Stiftaufbaus zurückgeführt werden, was jedoch - wie in den Studien der genannten Autoren bei einer alleinigen Betrachtung der Zahnextraktion - die publizierten Daten zum Einfluss des Stiftaufbaus auf das Extraktionsrisiko des Zahnes beeinflusst.
Zum Einfluss von Stiftaufbauten auf die Überlebenszeit des damit versorgten Zahnes ist folgende Publikation entstanden:

J.A.H. Vogler, A.L. Stummer, K.A. Walther, B. Wöstmann, P. Rehmann, Survival of teeth treated with post and core - A retrospective study of more than 1000 cases with observation periods up to 18 years, J Dent 138 (2023) 104723. (IF 2023: 4,4)

Darüber hinaus ist diese Publikation von dem *Elesevier Verlag* und *der American Dental Association* zur „2023 Top Story in Clinical Dentistry: *Managing Patients With Endodontically treated Teeth*“ auf der Plattform *Practice Update* für praktizierende Zahnärzte prämiert worden (https://www.practiceupdate.com/content/2023-top-story-in-clinical-dentistry-managing-patients-with-endodontically-treated-teeth/158200/53/23/3).

Die hier vorgestellte retrospektive Überlebenszeitanalyse untersuchte 1053 mit einem Stiftaufbau versorgte Zähne bei 735 Patienten hinsichtlich der Extraktionsgründe und unter Berücksichtigung potenziell überlebenszeitbeeinflussender Parameter über einen Beobachtungszeitraum von bis zu 18 Jahren.

Als häufigster Extraktionsgrund wurde hierbei eine Wurzelfraktur bei Teleskopprothesenpfeilern in den ersten 5 Jahren nach Eingliederung des Stiftaufbaus dokumentiert. Wie bereits unter 2.1.3 beschrieben könnte dies auf die nichtaxialen Kräfte in Verbindung mit Teleskopprothesen zurückzuführen sein, da in der hier vorgestellten Studie in diesem Zusammenhang zudem auch die rigiden Materialien einen signifikant negativen Einfluss auf die Überlebenszeit der Zähne zeigten. Am Zweithäufigsten in den ersten fünf Jahren wurden die untersuchten Zähne aufgrund einer apikalen Entzündung extrahiert, was ebenfalls mit der Insertion des Stiftaufbaus zusammenhängen kann, da bei tiefen Stiftaufbereitungen die apikale Versiegelung durch die Wurzelfüllung beeinträchtigt werden kann.[126, 127] Gründe für eine Zahnentfernung, die primär nicht auf die Insertion des Stiftaufbaus zurückzuführen waren, traten vermehrt erst zu einem späteren Zeitpunkt auf. Die Abbildung 8 verdeutlicht die beschriebenen Ergebnisse in einem Balkendiagramm, in dem die Extraktionsgründe in Abhängigkeit von der Überlebenszeit des Zahnes dargestellt sind.

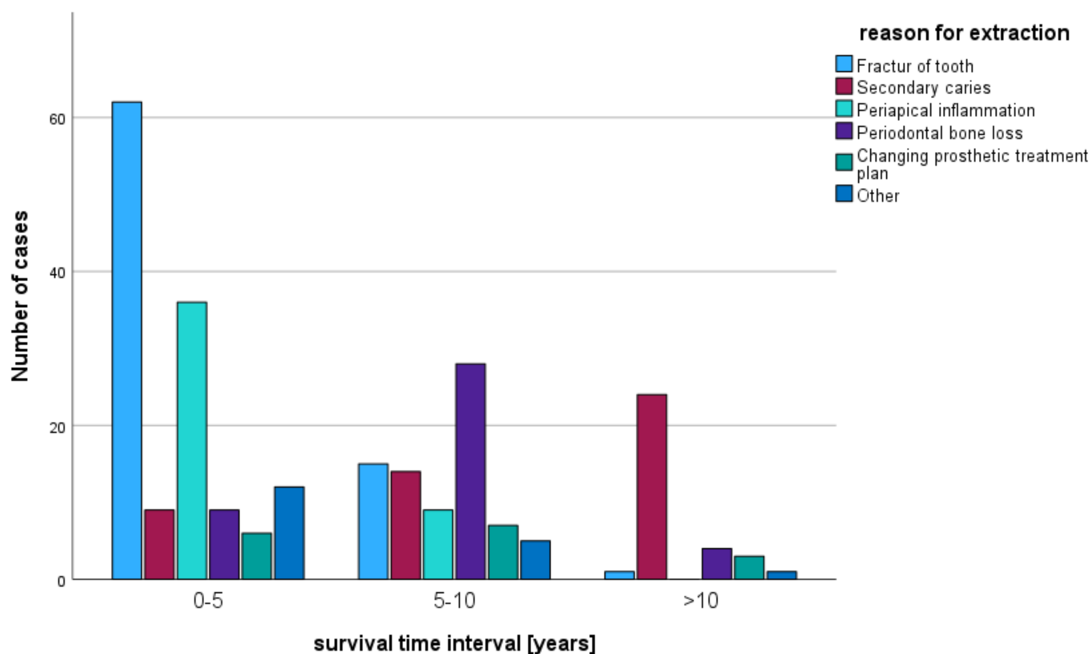


Abbildung 8: Balkendiagramm der Extraktionsgründe in Abhängigkeit von der Überlebenszeit des Zahnes.

Des Weiteren zeigte sich in den Ergebnissen ein höchst signifikanter Einfluss der prothetischen Versorgungsart auf die Extraktionswahrscheinlichkeit der mit Stiftaufbauten versorgten Zähne. Anhand des Balkendiagramms in Abbildung 9 wird deutlich, dass

unabhängig vom dokumentierten Extraktionsgrund die mit Abstand meisten untersuchten Zähne in Verbindung mit Teleskopprothesen und aufgrund einer Fraktur extrahiert wurden.

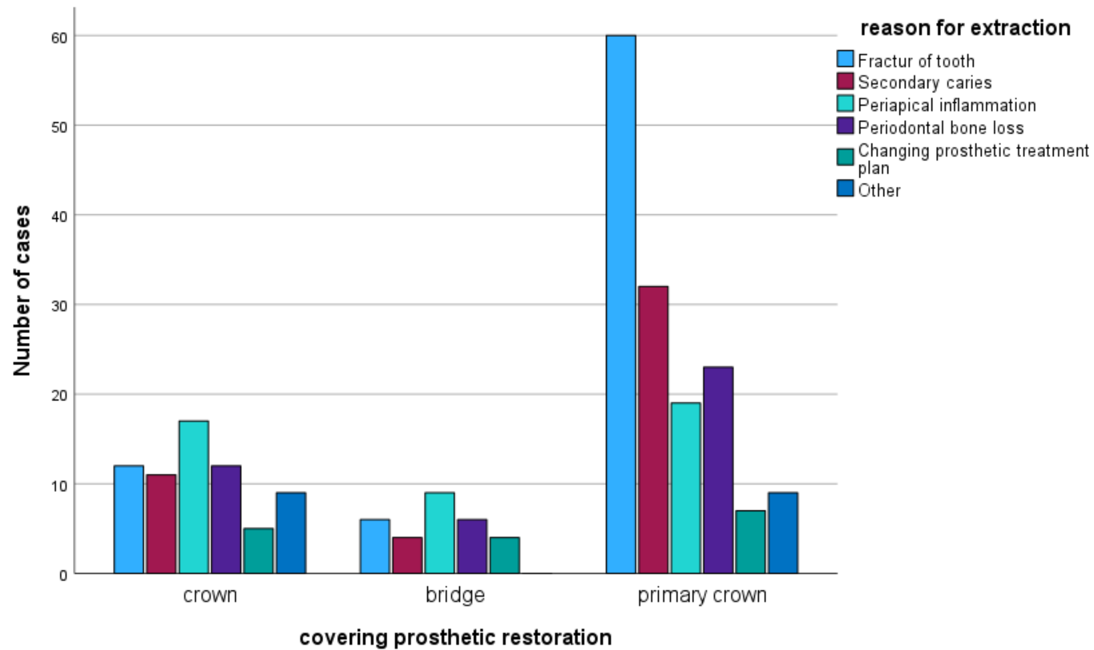


Abbildung 9: Anzahl der Extraktionen von mit Stiftaufbauten versorgten Zähnen in Abhängigkeit von der Restaurationsart.

2.1.5 Fokussierende Untersuchung der optimalen Stiftaufbereitungstiefe bezogen auf den Langzeiterfolg des Stiftaufbaus.

Stiftaufbauten sind eine der am Häufigsten verwendeten postendodontischen Versorgungsoptionen überhaupt.[11] Nichtsdestotrotz, sind die Behandlungsempfehlungen hinsichtlich der optimalen Stiftaufbereitungslänge in der Literatur uneinheitlich beschrieben worden und beruhen im Allgemeinen auf überholten Studiendaten, da hierbei Stiftaufbausysteme und Befestigungsverfahren verwendet wurden, die mit modernen Behandlungsverfahren nicht mehr vergleichbar sind.[128, 129] Die meisten Autoren in der Literatur beschreiben in diesem Zusammenhang eine anzustrebende, maximale Aufbereitungstiefe unter Einhaltung einer apikalen Versiegelung durch das Belassen einer Restwurzelfüllung von mindestens 4 mm.[130-133] Durch die Einführung neuer Techniken in die Zahnmedizin können Stiftaufbauten seit einigen Jahren adhäsiv mit dem Wurzeldentin verbunden werden, was die notwendige Retentionsfläche für den Stiftaufbau im Wurzelkanal reduzieren kann.[8] Aus diesem Grund wird von manchen Autoren eine Verkürzung der Aufbereitungstiefe gefordert, um zum einen die apikale Versiegelung durch die Wurzelfüllung nicht zu beeinträchtigen und zum anderen das Perforationsrisiko bei der Aufbereitung zu verringern.[134-136] Vor diesem Hintergrund sollten auch die Ergebnisse der unter 2.1.4 beschrieben Studie zur Überlebenszeit der mit Stiftaufbauten versorgten Zähne betrachtet werden, da eine der häufigsten Extraktionsgründe eine apikale Entzündung war, deren Ursache eine Beeinträchtigung der apikalen Versiegelung durch die Stiftaufbereitungstiefe sein kann.[111] Hinsichtlich einer Weiterentwicklung der postendodontischen Versorgung mittel Stiftaufbauten unter Einsatz digitaler Technologien, ist die Aufbereitungstiefe ebenfalls von Interesse, da alle aktuell am Markt etablierten Intraoralscanner optische Systeme sind, bei denen das Licht jeden Bereich der Präparation erreichen muss.[91] Somit ist die digitale Abformung umso leichter durchführbar, je weniger tief die Stiftaufbereitung vorgenommen wurde.[92]

Um die optimale Aufbereitungstiefe unter Berücksichtigung moderner Werkstoffe und Behandlungstechniken zu überprüfen wurde folgende Studie durchgeführt und die Daten in der unten beschriebenen Originalarbeit publiziert:

S.M. Reich, K.A. Walther, B. Wöstmann, P. Rehmann, **J.A.H. Vogler**, How long must a post be? A retrospective survival analysis on a large cohort with long follow-ups, J Dent (2024) 104879. (IF 2024: 4,4)

In der hier vorgestellten Studie wurde die Überlebenszeit von 1026 Stiftaufbauten hinsichtlich der Aufbereitungstiefe und des Längenverhältnisses von Stift- zu Stumpfanteil retrospektiv bis zur Dezementierung bzw. bis zur Extraktion des Zahnes nachuntersucht, um eine Aussage über die optimale Aufbereitungstiefe treffen zu können. Da nach jeder Insertion eines Stiftaufbaus ein Kontrollzahnfilmröntgenbild angefertigt wird, konnte aufgrund dessen und unter Verwendung von Softwarewerkzeugen die individuelle Aufbereitungslänge, sowie das Verhältnis von Stift- zu Stumpfanteil bestimmt werden. Für die statistische Auswertung wurde hierbei eine Kategorisierung in Aufbereitungslängen bis ins koronale, mittlere bzw. apikale Wurzeldrittel vorgenommen und die Stift- zu Stumpfverhältnisse in „Stift > Stumpf“, „Stift = Stumpf“ und „Stift < Stumpf“ unterteilt. Die Abbildung 10 zeigt exemplarisch die Auswertung der Kontrollzahnfilmröntgenbilder anhand eines gegossenen Stiftaufbaus nach der Insertion.

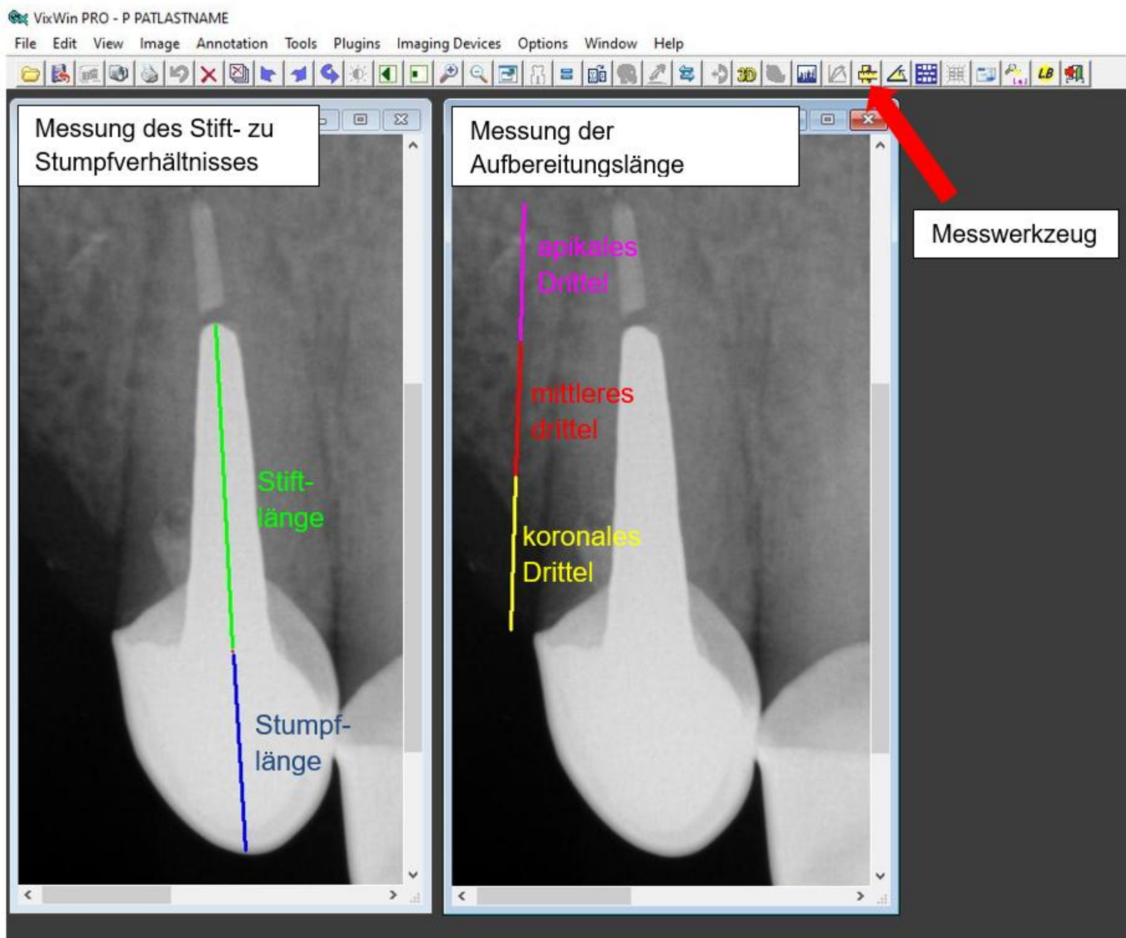


Abbildung 10: Auswertung eines Kontrollröntgenbildes nach der Stiftaufbauinsertion und Kategorisierung der Aufbereitungslänge (rechts) und des Stift- zu Stumpfverhältnisses (links).

Bezogen auf die Aufbereitungstiefe zeigten Stiftaufbauten, bei denen die Aufbereitung bis ins mittlere Wurzeldrittel reichte höchst signifikant bessere Überlebenszeiten, als wenn der Stiftaufbau bis ins koronale oder apikale Wurzeldrittel reichte (Abbildung 11). Hinsichtlich des Stift- zu Stumpfverhältnisses zeigte sich kein signifikanter Unterscheid zwischen „Stift = Stumpf“ und „Stift > Stumpf“, wohl aber höchst signifikant schlechtere Überlebenszeiten, wenn der Stiftanteil kürzer war, als der Stumpfanteil (Abbildung 12). Die beschriebenen Ergebnisse waren für die untersuchten Zielereignisse „Dezementierung“ und „Extraktion“ kongruent. Die Abbildungen 11 und 12 verdeutlichen diese Ergebnisse anhand der Kaplan-Meier Kurven für die Überlebenszeit bis zur Dezementierung (links) bzw. bis zur Extraktion des mit dem Stiftaufbau versorgten Zahnes (rechts).

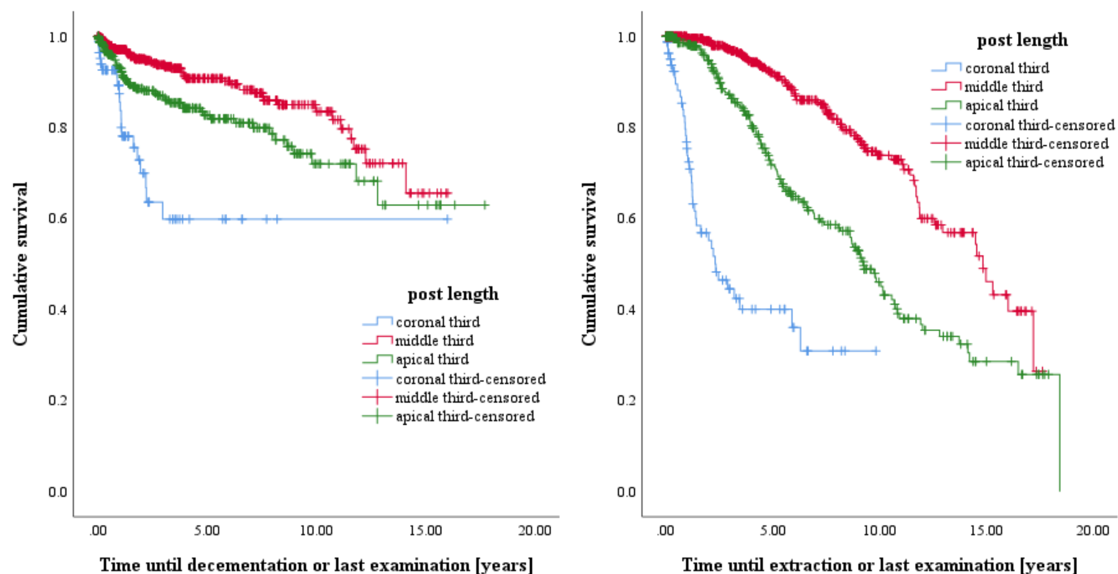


Abbildung 11: Kaplan Meier Überlebenskurven bis zur Dezementierung des Stiftaufbaus (links) bzw. bis zur Extraktion des Zahnes (Rechts) in Abhängigkeit von der Aufbereitungslänge: Koronales Drittel (blaue Kurve), mittleres Drittel (rote Kurve) und apikales Drittel (grüne Kurve).

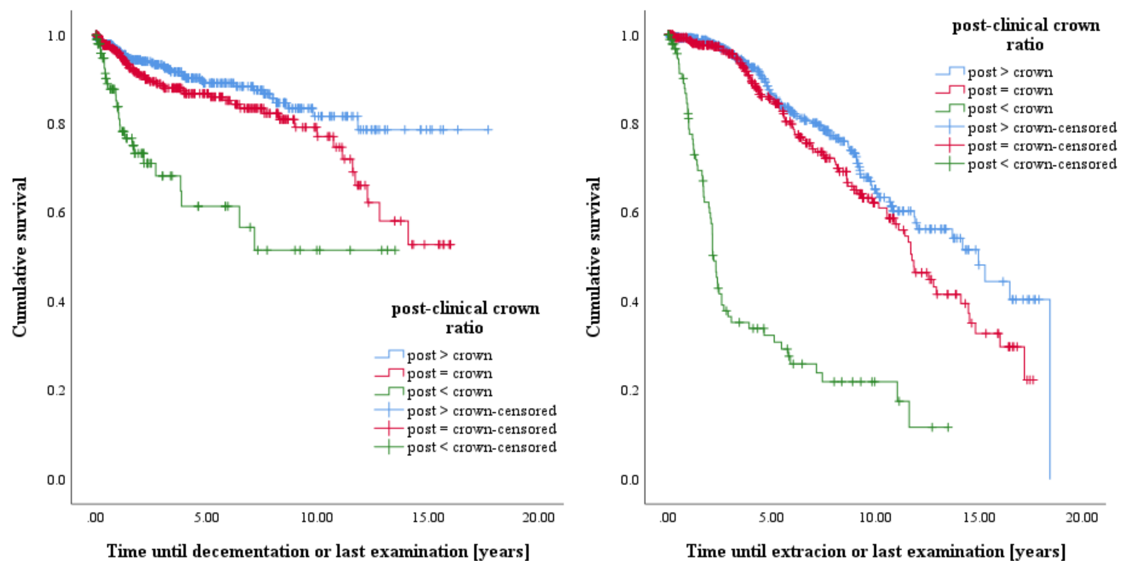


Abbildung 12: Kaplan Meier Überlebenskurven bis zur Dezementierung des Stiftaufbaus (links) bzw. bis zur Extraktion des Zahnes (Rechts) in Abhängigkeit von dem Stift- zu Stumpfverhältnis: Stift > Stumpf (blaue Kurve), Stift = Stumpf (rote Kurve) und Stift < Stumpf (grüne Kurve).

Aus den Ergebnissen der hier vorgestellten Studie konnte geschlussfolgert werden, dass die Stiftaufbereitungslänge nicht über das mittlere Wurzeldrittel hinaus reichen sollte, jedoch gewährleistet werden muss, dass der Stiftanteil mindestens der Länge des Stumpfanteils entspricht. Werden diese Präparationsrichtlinien berücksichtigt, bestehen die besten Überlebenswahrscheinlichkeiten sowohl bezogen auf die Dezementierung des Stiftaufbaus, als auch bezogen auf die Extraktion des Zahnes selbst.

Macedo et al. und *Rosen et al.* beschrieben in Laboruntersuchungen ebenfalls, dass die mechanische Belastung optimiert wird, wenn der Stiftanteil mindestens der Länge des Stumpfanteils entspricht.[137, 138] Auch *Zicari et al.* beobachteten in einer mechanischen Belastungsstudie unter Laborbedingungen günstigere Frakturmuster bei Zähnen mit konfektionierten Glasfaserstiften, wenn die Aufbereitungstiefe reduziert wird und stimmen daher mit den Ergebnisses der hier vorgestellten Studie überein.[134] Bis zum Zeitpunkt der Durchführung der Studie hatte jedoch keine Autorengruppe in der Literatur die Aufbereitungstiefe unter klinischen Bedingungen anhand eines großen Patientenkollektives über einen langen Beobachtungszeitraum untersucht. Vor diesem Hintergrund betrachtet, wird die Aussagekraft der Ergebnisse der hier vorgestellten Studie deutlich, da hierbei zum ersten Mal auch klinische Misserfolgsursachen, wie beispielsweise die apikale Entzündung mit der Aufbereitungslänge in Bezug gesetzt werden konnten. Diese biologischen Komplikationen, die durch die Stiftaufbereitung beeinflusst werden, können in Laboruntersuchungen nicht berücksichtigt werden. Die positiven Ergebnisse einer

reduzierten Aufbereitungstiefe begünstigten die digitale Weiterentwicklung der postendodontischen Versorgung mittels Stiftaufbauten, die in dem folgenden Kapitel beschrieben wird, da die digitale Stiftabformung in diesen Fällen zu passgenaueren Stiftaufbauten führen kann.[92]

2.2 Weiterentwicklung der postendodontischen Versorgung mittels Stiftaufbauten unter Verwendung moderner, digitaler Technologien

Nachdem durch die in Kapitel 2.1 beschriebenen, strukturierten Analysen der postendodontischen Versorgung mittels Stiftaufbauten, die Risikofaktoren identifiziert wurden, war eine zielgerichtete Weiterentwicklung dieser Behandlungsoption durch die Verwendung moderner, digitaler Technologien möglich.
Die beschriebenen Ergebnisse konnten zeigen, dass eine Optimierung hinsichtlich der Passgenauigkeit notwendig ist, da der Retentionsverlust des Stiftaufbaus die mit Abstand häufigste Misserfolgsursache darstellt[79] und eine Rezementierung weiterhin zu einer signifikanten Reduktion der Überlebenszeit führt[109]. Eine Dezementierung konnte hierbei auch nicht durch die Verwendung moderner, adhäsiver Einsetzkomposite verhindert werden.[109] Zwar sind die Haftwerte bei Einsetzkompositen höher als bei konventionellen Zementen, jedoch geht eine schlechte Passgenauigkeit mit einer großen Einsetzkompositschichtstärke zwischen dem Stiftaufbau und dem Wurzelkanallumen einher, was durch die Polymerisationsschrumpfung ebenfalls zu einem höheren Dezementierungsrisiko führen kann.[42] In diesem Zusammenhang erhöht auch ein Missverhältnis zwischen dem Elastizitätsmodel des Wurzeldentins und dem des Stiftaufbaumaterials das Risiko eines Retentionsverlustes unter zyklischer Belastung während des Kauvorganges, da ein rigider Stiftaufbau die entstehenden Scherkräfte vornehmlich auf das Befestigungsmaterial weiterleitet, welches damit wahrscheinlicher versagt.[114] In der Literatur wird kontrovers diskutiert, ob der Einfluss der Passgenauigkeit oder des Elastizitätsmoduls auf das Dezementierungsrisiko des Stiftaufbaus überwiegt.[139-142]
Unbenommen davon kann jedoch folglich alleine durch die Herstellung passgenauerer Stiftaufbauten in Kombination mit einem Material mit mechanischen Eigenschaften, die denen des umgebenden Wurzeldentins entsprechen, die Dezementierungsrate von Stiftaufbauten gesenkt werden.[32, 39, 42, 54]

Darüber hinaus ist eine Optimierung hinsichtlich der Materialien zudem notwendig, da rigide Stiftaufbauten, vor allem in Verbindung mit nichtaxial wirkenden Kräften bei Frontzähnen und Teleskoppfeilern,[79] in den vorgestellten Studien häufig zu Wurzelfrakturen führten.[111] Wie auch schon bei der Dezementierung, kann auch hierbei die Verwendung von Materialien mit dem Dentin entsprechenden mechanischen

Eigenschaften vorteilhaft sein, da durch die Vermeidung von Spannungsspitzen auf die Wurzel bei der Kaubelastung, Wurzelfrakturen vermieden werden können.[12, 35-37]

Des Weiteren zeigten die vorgestellten Ergebnisse, dass ein Optimierungsbedarf bei der Versorgung von frakturierten Teleskoppfeilern mittels Stiftaufbauten bestand, da diese in der zahnärztlichen Praxis häufig notwendige Therapie mit sehr schlechten Überlebensraten einhergeht (siehe Kapitel 2.1.3).[110] Stiftaufbauten zur Wiederbefestigung einer Teleskopkrone nach einer Fraktur des Pfeilerzahnes hatten, in den im Rahmen dieser kumulativen Habilitation durchgeführten retrospektiven Analysen, sogar die schlechtestes Überlebensraten überhaupt, was mit dem oben Beschriebenen erklärbar wird: Bei dieser Versorgungsoption nimmt die Passgenauigkeit des Stiftaufbaus eine noch entscheidendere Rolle ein, da dieser nicht nur im Wurzelkanal, sondern auch unter die Teleskopkrone exakt passen muss. Darüber hinaus wirken bei Teleskopprothesen durch den langen Prothesensattel noch höhere nicht axiale Kräfte auf den Zahn, als beispielsweise bei Frontzähnen mit anderen prothetischen Versorgungen. Die Wiederbefestigung einer Teleskopkrone nach der Fraktur des Pfeilerzahnes stellt somit eine Art „Worst-Case-Szenario“ für Stiftaufbauten dar.
Unter Berücksichtigung der beschriebenen Ergebnisse zur optimalen Stiftaufbereitungslänge[112] wurde daraufhin ein Workflow entwickelt, der die Vorteile der individuell gegossenen Stiftaufbauten mit denen der konfektionierten Glasfaserstifte unter Anwendung digitaler Technologien verbindet. Hierbei wird der Wurzelkanal mittels Intraoralscanner digital abgeformt und ein individueller Stiftaufbau aus einem glasfaserverstärkten CAD/CAM Komposit chairside gefräst. Nachfolgend wurde in drei Studien der Einfluss dieser Stiftaufbauten auf die Dezementierung und das Wurzelfrakturrisiko unter Kausimluation (Kapitel 2.2.1), die klinische, intraorale Passgenauigkeit (Kapitel 2.2.2) und die Anwendbarkeit zur Versorgung frakturierter Teleskoppfeilerzähne (Kapitel 2.2.3) hin untersucht. Diese Studien werden im Folgenden Abschnitt vorgestellt und vor dem Hintergrund der wissenschaftlichen Literatur diskutiert.

2.2.1 *Einfluss glasfaserverstärkter CAD/CAM Komposit Stiftaufbauten auf die Dezementierungs- und Wurzelfrakturgefahr unter Kausimulation.*

Speziell unter dem Einfluss nichtaxialer Kräfte auf den Stiftaufbau führt die Verwendung von rigiden Materialien zu einer inhomogenen Weiterleitung der Kräfte auf die Zahnwurzel.[12, 35-37] Um dem entgegenzuwirken, können in Fällen, bei denen der koronale Defekt vergleichsweise klein ist, flexiblere, konfektionierte Glasfaserstifte in Kombination mit Kompositstumpfaufbauten verwendet werden, um ausreichend Retention für die anschließende Restauration des Zahnes zu schaffen.[35-37] Bei größeren koronalen Defekten werden jedoch in der Literatur individuelle Stiftaufbauten empfohlen,[12, 143] die in der Regel aus Metalllegierungen mit einem deutlich höheren Elastizitätsmodul, als das des Wurzeldentins gegossen werden.[12] Diese Stiftaufbauten haben zwar eine bessere Passgenauigkeit im Wurzelkanal und sind durch ihren einteiligen Aufbau aus einem zusammenhängenden Stift und Stumpfanteil mechanisch stabiler,[12] jedoch kann, wie oben beschrieben, das Dezementierungs- sowie das Wurzelfrakturrisiko durch das Missverhältnis des Elastizitätsmoduls zwischen Dentin und Metalllegierung negativ beeinfluss werden.[12, 35-37, 114]

Um den Einfluss von CAD/CAM gefrästen Stiftaufbauten aus glasfaserverstärktem Komposit hinsichtlich des Dezementierungs- sowie des Wurzelfrakturrisikos zu untersuchen, wurden diese Stiftaufbauten einer Kausimulation unter nicht axialer Belastung unterzogen und als Kontrollgruppe mit gegossenen Stiftaufbauten, welche bisher als der Goldstandard für die Rekonstruktion von großen, koronalen Defekten gelten,[12, 143] verglichen. Darüber hinaus wurde die Abweichung zwischen der konventionellen Stiftabformung für die Herstellung der gegossenen Stiftaufbauten und der digitalen Stiftabformung für die Herstellung der CAD/CAM Stiftaufbauten evaluiert.

Aufgrund der Daten dieser Studie ist folgende Publikation entstanden:

J.A.H. Vogler, L. Billen, K.-A. Walther, B. Wöstmann, Fibre-reinforced CAD/CAM post and cores: The new "gold standard" for anterior teeth with extensive coronal destruction? - A fully digital chairside workflow, Heliyon (2023) e19048. (IF 2023: 4,0)

Für diese Laboruntersuchung wurden 30 in ihrer Dimension vergleichbare,[144, 145] einwurzelige Zähne endodontisch behandelt und die Krone entfernt, um einen koronalen Defekt ohne Restdentinwände zu simulieren. Anschließend wurde eine Stiftaufbereitung

bis zu einer Länge von 10 mm, und damit bis ins mittlere Wurzeldrittel durchgeführt.[112] Bei allen Zähnen wurde eine digitale, sowie eine konventionelle Stiftabformung durchgeführt. Für die digitale Stiftabformung wurde der aufbereitete Wurzelkanal mit einem Intraoralscanner gescannt und daraus ein STL-Datensatz erzeugt. Aus der konventionellen Stiftabformung wurde ein Gipsmodell hergestellt und dieses ebenfalls mit dem Intraoralscanner gescannt, um wiederum einen STL-Datensatz zu erzeugen. Die beiden Datensätze wurden anschließend in einer externen Analysesoftware mittels „Best-Fit" Algorithmus überlagert und somit die Abweichung zwischen den beiden Abformvarianten ermittelt.

Für den Vergleich des Dezementierungs- bzw. Wurzelfrakturrisikos zwischen den beiden Stiftaufbauvarianten, wurde aufgrund der digitalen Stiftabformung in der scannerimmanenten Software ein Stiftaufbau konstruiert und anschließend an einer kompatiblen Fräseinheit in wenigen Minuten aus einem glasfaserverstärkten CAD/CAM-Komposit (*Trinia*) ausgefräst. Die Abbildung 13 zeigt die digitale Stiftabformung, die virtuelle Konstruktion, sowie die chairside Herstellung eines glasfaserverstärkten CAD/CAM-Komposit Stiftaufbaus.

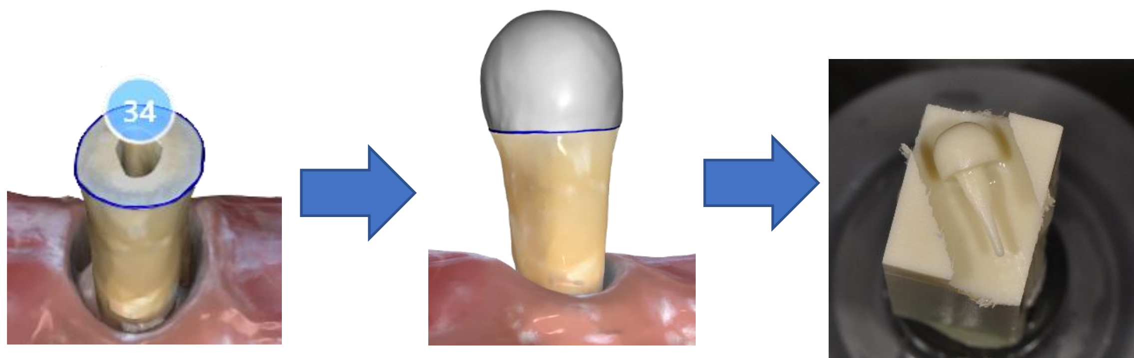


Abbildung 13: Digitale Stiftabformung (links), virtuelle Konstruktion (Mitte) und Herstellung (rechts) des CAD/CAM Stiftaufbaus aus glasfaserverstärktem Komposit (*Trinia*).

Für die Herstellung des gegossenen Stiftaufbaus wurde das Gipsmodell der konventionellen Stiftabformung verwendet und hierauf der Stiftaufbau zunächst aus Wachs modelliert und anschließend im „Lost-Wax Verfahren" gegossen.[6] Die Abbildung 14 zeigt die konventionelle Stiftabformung, das Gipsmodell mit der Wachsmodellation und den gegossenen Stiftaufbau.

Abbildung 14: Konventionelle Stiftabformung (links), Gipsmodell mit der Wachsmodellation (Mitte) und gegossener Stiftaufbau (rechts)

Sowohl die CAD/CAM als auch die gegossenen Stiftaufbauten wurden in den Wurzelkanal eingesetzt und eine Zahnfilmröntgenaufnahme durchgeführt. Anschließend wurden die Zähne in den Kausimulator eingespannt, sodass die simulierte Kaubelastung im 45° Winkel auf den Stumpfanteil einwirkte. Um eine möglichst exakte Simulation des intraoralen Milieus zu gewährleisten, wurde eine zyklische Thermowechsellast durch eine Umspülung des Zahnes im Wasserbad eingestellt. Die Abbildung 15 zeigt die nicht axiale Belastung der beiden Stiftaufbauvarianten in dem Kausimulator.

Abbildung 15: Nicht axiale Belastung der Stumpfanteile bei einem gegossenen (links) und einem glasfaserverstärkten CAD/CAM-Komposit Stiftaufbau (rechts) im Kausimulator unter Thermowechsellast im Wasserbad.

Hinsichtlich der Abweichung zwischen der konventionellen und digitalen Stiftabformung zeigten sich höchst signifikante Unterschiede, die von koronal nach apikal im Verlauf der Stiftaufbereitung zunahmen. Die angefertigten Zahnfilmröntgenaufnahmen nach der Stiftaufbauinsertion konnten zeigten, dass die gegossenen Stiftaufbauten im apikalen Bereich vielfach die tiefste Stelle der Aufbereitung nicht erreichten, während die CAD/CAM Stiftaufbauten auch apikal eine gute Passgenauigkeit aufwiesen. Hieraus konnte geschlussfolgert werden, dass bei der konventionellen Stiftabformung in einigen Fällen das plastische Abformmaterial nicht jeden Bereich der Stiftaufbereitung erreichte, während

die Vollständigkeit der digitalen Abformung auf dem Bildschirm kontrolliert werden konnte.[88] Aus diesem Grund führte die digitale Abformung zu reproduzierbar passgenaueren Stiftaufbauten, als die konventionelle Abformung, was von anderen Autoren in der Literatur bestätigt wurde.[12, 92, 98]
Bezogen auf die Dezementierungs- und Wurzelfrakturrate zeigten sich während der Kausimulation fünf Dezementierungen und zwei Wurzelfrakturen bei den gegossenen Stiftaufbauten, wobei bei den glasfaserverstärkten CAD/CAM-Komposit Stiftaufbauten weder Dezementierungen noch Wurzelfrakturen dokumentiert wurden. Diese Ergebnisse stimmen mit den von anderen Autoren publizierten Daten in der Literatur überein, wonach das höhere Elastizitätsmodul von gegossenen Stiftaufbauten, Wurzelfrakturen begünstigen kann.[12, 35-37] Auch das geringere Dezementierungsrisiko bei Stiftaufbauten mit mechanischen Eigenschaften, die mit denen des Dentins vergleichbar sind, ist von *Santos et al.* in einer Laboruntersuchung mit einer Finite-Elemente Analyse beschrieben worden und stimmt damit mit den hier vorgestellten Ergebnissen überein.[114] Durch Kausimulationen unter mit der intraoralen Situation vergleichbaren Bedingungen, wie in der hier vorgestellten Studie, werden Werkstoffe in der wissenschaftlichen Literatur regelmäßig getestet, um diese für neue Indikationen zu untersuchen.[146, 147] Hierdurch können wichtige, präklinische Daten erhoben werden, ohne dass die Gefahr einer Patientenwohlgefährdung durch das Materialversagen im Munde des Patienten besteht.[148]
Bezogen auf die retrospektiven Überlebensdaten, die im Rahmen dieser kumulativen Habilitation erhoben wurden, sind die Ergebnisse der hier vorgestellten Laborstudie ebenfalls auf die klinische Situation an unserer Poliklinik übertragbar: Innerhalb der ersten fünf Jahre nach Eingliederung der Stiftaufbauten, war der häufigste Extraktionsgrund eine Wurzelfraktur in Verbindung mit einem gegossenen Stiftaufbau und nicht axial einwirkenden Kräften[111] und die häufigste Misserfolgsursache, eine Dezementierung, ebenfalls bei gegossenen Stiftaufbauten[79, 109]. Vor diesem Hintergrund stellen die glasfaserverstärkten CAD/CAM-Komposit Stiftaufbauten, die aufgrund des in dieser Studie vorgestellten rein digitalen Workflows hergestellt werden, eine Verbesserung der postendodontischen Versorgung dar und zeigen günstigere Eigenschaften hinsichtlich der Passgenauigkeit und mechanischen Belastbarkeit, als der bisherige Goldstandard in Form von konventionellen, gegossenen Stiftaufbauten. In diesem Zusammenhang besteht ein weiterer Vorteil speziell bei der Versorgung von Frontzähnen mit glasfaserverstärkten CAD/CAM-Komposit Stiftaufbauten, da hierbei neben mechanischen Eigenschaften auch das ästhetische Erscheinungsbild nach der Restauration eine entscheidende Rolle

spielt.[38-40] Die dentinähnliche Farbe und Transluzenz dieses Werkstoffes kann hierbei zu einer Verbesserung der Ästhetik und damit einhergehend zu einer Steigerung der Patientenzufriedenheit beitragen, da im Vergleich zu metallischen Stiftaufbauten eine Verdunklung der Restauration und der umgebenden Gingiva, speziell bei der Eingliederung von vollkeramischem Zahnersatz, vermieden wird.[9, 39, 149]

Zusammenfassend führen die mechanischen Vorteile der Stiftaufbauten aus glasfaserverstärktem Komposit durch das dentinähnliche Elastizitätsmodul, gemeinsam mit den ästhetischen Vorteilen durch die dentinähnliche Farbe und Transluzenz dieses Materials zu einer Verbesserung der Versorgung von koronal stark zerstörten Zähnen, da Dentin am geeignetsten durch ein Material ersetzt werden kann, das in seinen Eigenschaften dem Verloren gegangenen entspricht. Eine solche „Restitutio ad integrum“ oder zumindest eine „Restitutio ad similem“ ist seit jeher das Ziel einer jeden prothetischen Versorgung, wird jedoch durch die bisher vorhanden Restaurationsmaterialen und -techniken in der Vergangenheit nur selten erreicht.[150, 151] Hierbei können moderne, digitale Technologien neue Wege eröffnen und die klinische Behandlung nicht nur bei der postendodontischen Versorgung, sondern auch in vielen anderen Bereichen weiterentwickeln.[12, 152]

2.2.2 Vergleich der klinischen Passgenauigkeit zwischen glasfaserverstärkten CAD/CAM-Komposit und konventionellen, gegossenen Stiftaufbauten.

Um die positiven Laborergebnisse der individuellen, glasfaserverstärkten CAD/CAM-Komposit Stiftaufbauten auf der Grundlage einer digitalen Stiftabformung auch unter klinischen Bedingungen zu bestätigen, wurde im Rahmen dieser kumulativen Habilitation eine in vivo Studie zum Vergleich der Passgenauigkeit dieser Stiftaufbauten mit dem bisherigen Goldstandard in Form von gegossenen Stiftaufbauten auf der Grundlage einer konventionellen Stiftabformung durchgeführt.

Auch wenn konfektionierte Glasfaserstifte mit Kompositstumpfaufbauten, vor allem wegen der Möglichkeit einer Restauration des Zahnes in einer einzigen Sitzung,[12] in der zahnärztlichen Praxis weit verbreitet sind,[62, 104] zeigen diese eine schlechtere Passgenauigkeit als individuelle Stiftaufbauten, speziell in konischen Wurzelkanälen oder solchen mit einem nicht runden Querschnitt.[12, 38, 42, 153] Durch den großen und inhomogenen Zementspalt bei konfektionierten Stiftaufbauten kommt es zu einer ungleichmäßigen Kraftweiterleitung auf die Wurzel, was das Dezementierungs- und Wurzelfrakturrisiko erhöhen kann.[42-45] Aus diesem Grund beschränken manche Autoren die Indikation dieser Stiftaufbauten auf moderate, koronale Defekte mit einer ausreichend hohen Restzahnhartsubstanzmenge, um den Kompositstumpfaufbau dauerhaft adhäsiv befestigen zu können.[5, 84, 154] Ein weiterer Grund für diese Limitation ist, dass konfektionierte Stifte nur dann rotationsstabil sind, wenn der plastische Stumpfaufbauten, durch das Vorhandensein von Restdentinwänden, Torsionskräften entgegenwirkt.[155] In Fällen mit größeren koronalen Defekten, sind nur individuelle Stiftaufbauten durch die gute Passgenauigkeit im Wurzelkanal rotationsstabil, sodass bei konfektionierten Stiftaufbauten das Befestigungsmaterial alleine die Torsionskräfte aufnehmen muss.[156, 157] Dies führt in der Regel durch die zyklische Kaubelastung früher oder später zu einem Versagen der Retention und damit zu einem Misserfolg der Restauration.[158]

Um die Vorteile der konfektionierten Glasfaserstifte mit denen der individuellen, gegossenen Stiftaufbauten zu verbinden, ist eine direkte Digitalisierung des aufbereiteten Wurzelkanals unumgänglich. Zum einen muss in dem Workflow zur Herstellung der Stiftaufbauten auf zeitaufwendige, analoge Arbeitsschritte verzichtet werden, da ansonsten keine Behandlung in nur einer einzigen Sitzung möglich ist. Zum anderen lassen sich Materialien mit dentinähnlichen, mechanischen Eigenschaften zur Herstellung von individuellen Stiftaufbauten nur in einem digitalen CAD/CAM Workflow verarbeiten.[12, 159, 160] Auch wenn der CAD/CAM Workflow sowie die glasfaserverstärkten Komposite generell

schon seit mehreren Jahrzenten in der Industrie eingesetzt werden,[96] sind digitale Stiftabformungen und damit die Herstellung von CAD/CAM Stiftaufbauten in der Zahnmedizin erst durch neueste Weiterentwicklungen im Bereich der Intraoralscanner möglich geworden.[12] *Pinto et al.* publizierten 2017 eine Laborstudie zum Vergleich der konventionellen und digitalen Stiftabformung. Sie zeigten, dass der Wurzelkanal signifikant weniger tief abgeformt werden konnte, als mit der konventionellen Stiftabformung und folgerten daher, dass eine digitale Stiftabformung nicht zuverlässig möglich ist.[93] Allerdings entspricht der von den Autoren verwendete Intraoralscanner hinsichtlich seiner Soft- und Hardwareleistung nicht mehr dem aktuellen Stand der Technik, sodass *Elter et al.* mit einem moderneren Intraoralscanner in einer Laborstudie aus dem Jahr 2022 signifikant bessere Abformergebnisse zeigen konnten.[92] Der Einfluss der Hard- und Softwareleistung von Intraoralscannern auf die Genauigkeit und Präzision ist in der wissenschaftlichen Literatur von vielen Autoren beschrieben worden.[94, 161-163] In vivo Studien, die die konventionelle und digitale Stiftabformung verglichen haben, sind jedoch bisher in der wissenschaftlichen Literatur nicht publiziert worden. Aus diesem Grund zeigen die nachfolgend vorgestellten Daten die ersten Ergebnisse, bei denen unter klinischen Bedingungen die digitale und konventionelle Stiftabformung vergleichend gegenübergestellt wurden.

Die Ergebnisse sind in der folgenden Originalarbeit international publiziert worden:

J.A.H. Vogler, L. Billen, K.A. Walther, B. Wöstmann, Conventional cast vs. CAD/CAM post and core in a fully digital chairside workflow - An in vivo comparative study of accuracy of fit and feasibility of impression taking, J Dent 136 (2023) 104638. (IF 2023: 4,4)

In diese in vivo Studie wurden 25 Patienten, bei denen im Rahmen des prothetischen Therapiekonzeptes ein oder mehrere individuell gegossene Stiftaufbauten nötig waren, eingeschlossen. Bei insgesamt 30 Zähnen wurde nach der Aufbereitung des Wurzelkanals für den Stiftaufbau jeweils eine konventionelle und eine digitale Stiftabformung durchgeführt und entsprechend der in Abschnitt 2.2.1 beschriebenen Workflows ein konventionell gegossener und ein gefräster, glasfaserverstärkter CAD/CAM-Komposit Stiftaufbau hergestellt. Die beiden Stiftaufbauten wurden anschließend intraoral anprobiert und die Passgenauigkeit anhand eines standardisierten Fragebogens mit visuellen

Analogskalen bewertet. Hierbei wurden die klinisch etablierten Bewertungskriterien für Stiftaufbauten (Rotierbarkeit, Friktion gegen Herausziehen, Anpassungszeit bis der Stiftaufbau in Sollposition geht) sowie die Schwierigkeit der konventionellen und analogen Stiftabformung evaluiert. Die Abbildung 16 zeigt exemplarisch die Anprobe eines gegossenen (unten) und eines gefrästen Stiftaufbaus (oben) im Mund des Patienten.

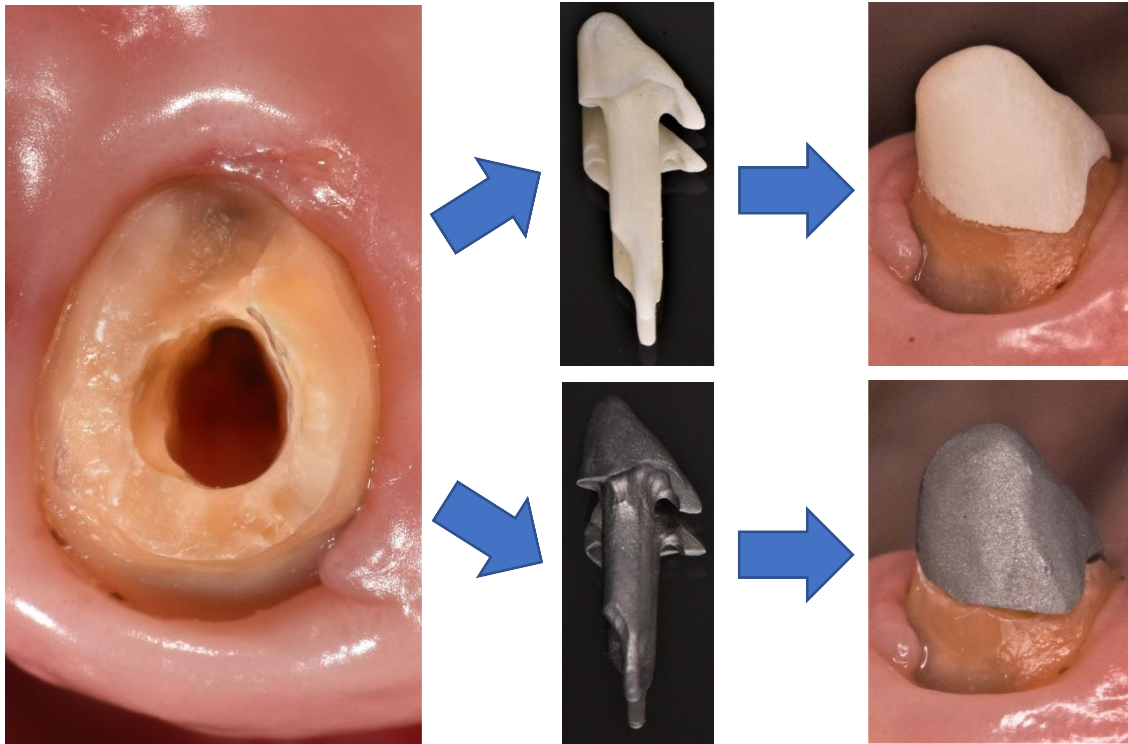
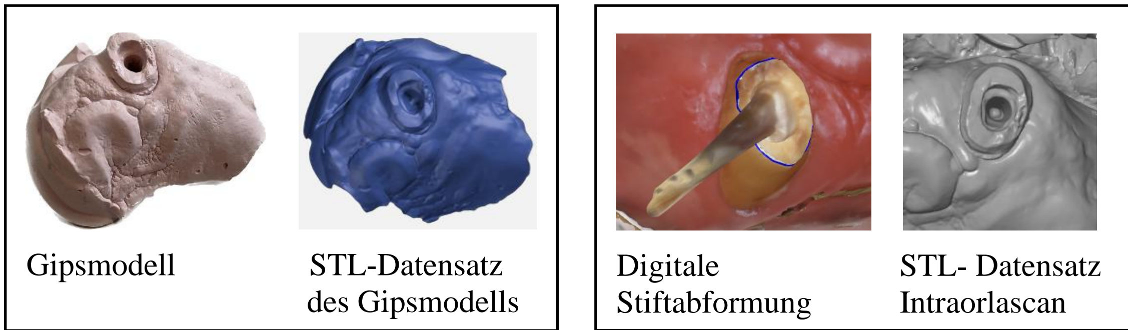


Abbildung 16: Intraorale Anprobe eines gegossenen (unten) und eines gefrästen CAD/CAM-Komposit (oben) Stiftaufbaus im aufbereiteten Wurzelkanal (links).

Darüber hinaus wurde entsprechend der Beschreibung in Abschnitt 2.2.1 das Gipsmodell vor der Herstellung des gegossenen Stiftaufbaus gescannt und mit dem Datensatz der digitalen Stiftabformung durch Überlagerung in einer externen Analysesoftware verglichen. Anhand dieser Überlagerung wurde zudem die individuelle Aufbereitungstiefe bestimmt und damit die Abformbarkeit des apikalen Bereichs der Stiftbettpräparation mit der konventionellen und digitalen Stiftabformung evaluiert (Abbildung 17).



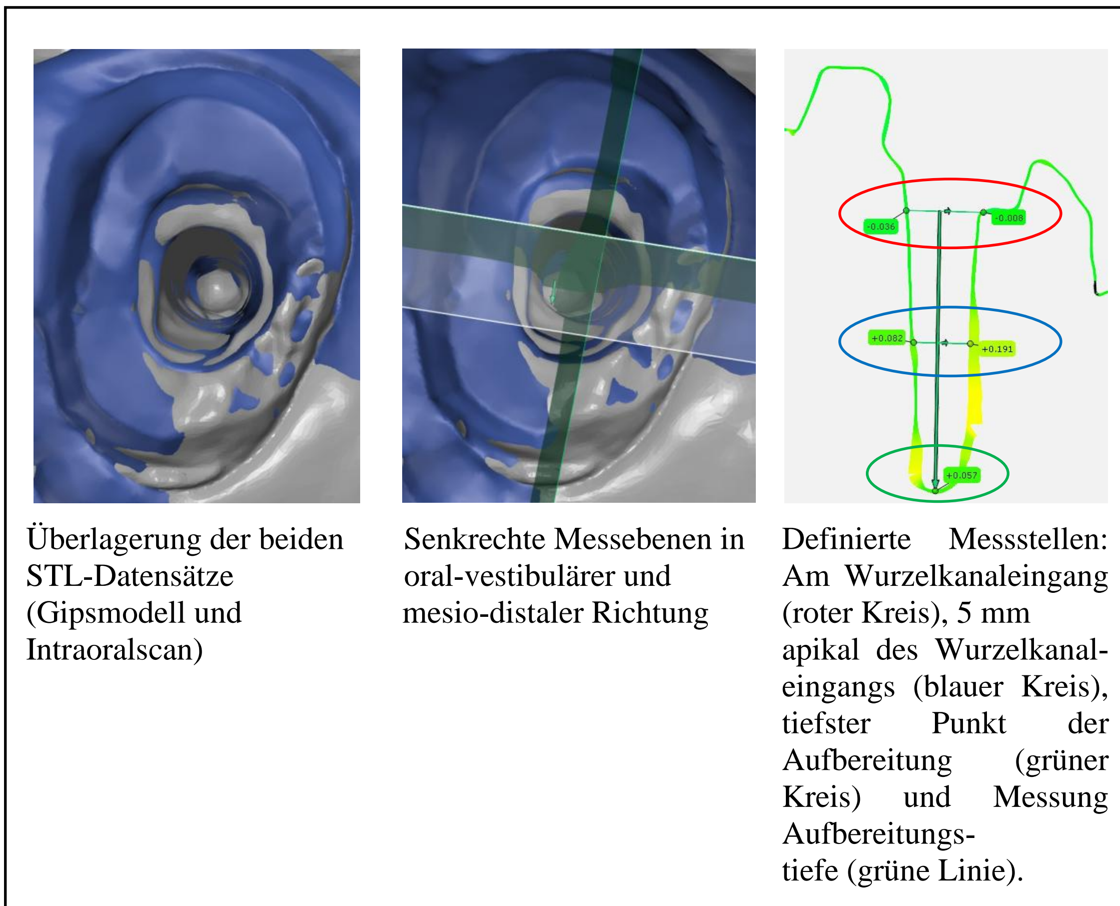


Abbildung 17: Überlagerung der beiden STL Datensätze (Gipsmodell: Blau und Intraoralscan: Grau) in der externen Analysesoftware zur Messung der Abweichung und der Aufbereitungstiefe.

Nach der Anprobe und Bestimmung der Passgenauigkeit wurde in allen 30 Fällen der gegossene Stiftaufbau eingesetzt, da dieser Bestandteil des individuellen Therapieplanes des Patienten war. Entsprechend des etablierten, klinischen Vorgehens wurde anschließend jeweils eine Zahnfilmröntgenaufnahme durchgeführt, um die Passgenauigkeit radiologisch zu überprüfen und eventuelle Perforationen und Frakturen auszuschließen.

Die maximale Aufbereitungstiefe der in dieser Studie untersuchten Zähne lag bei 15,4 mm. Alle Stiftbettpräparationen konnten sowohl konventionell, als auch digital

abgeformt werden, wobei die digitale Stiftabformung höchst signifikant ($p<0.001$) leichter durchzuführen war. Die Auswertung der standardisierten Fragebögen hinsichtlich der Passgenauigkeit der hergestellten Stiftaufbauten zeigte, dass die gefrästen, glasfaserverstärkten CAD/CAM-Komposit Stumpfaufbauten, die nach dem rein digitalen Workflow hergestellt wurden, eine signifikant bessere Passgenauigkeit aufwiesen, als die konventionellen, gegossenen Stiftaufbauten auf Grundlage des analogen Workflows. Darüber hinaus zeigten die gegossenen Stiftaufbauten eine größere Streubreite in den Ergebnissen, als die gefrästen Stiftaufbauten, was die vorhersagbarere Passgenauigkeit der Stiftaufbauten aus dem rein digitalen Workflow verdeutlicht. Die Abbildung 18 stellt die beschriebenen Passgenauigkeitsergebnisse beider Stiftaufbauvarianten in einem Box-Plot Diagramm gegenüber.

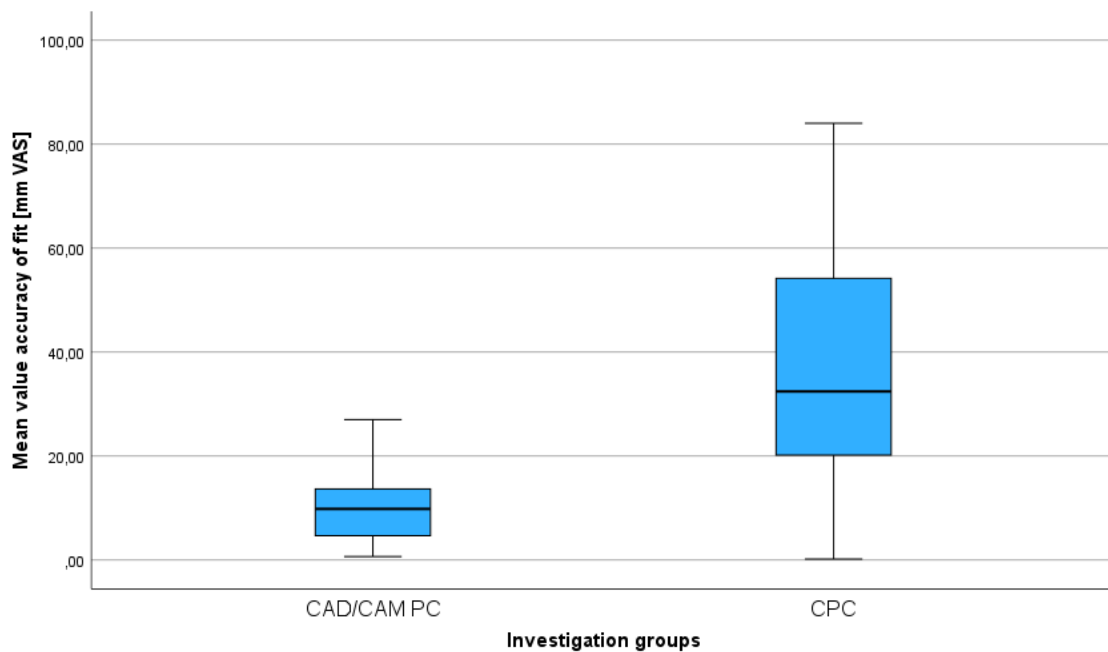


Abbildung 18: Box-Plot Diagramm der VAS-Passgenauigkeitswerte der gefrästen (CAD/CAM PC) und gegossenen (CPC) Stiftaufbauten.

Die Überlagerung der Datensätze der beiden Stiftabformungsvarianten ergab die größten Abweichungen im apikalen Bereich der Stiftbettpräparation, wobei die Zahnfilmröntgenaufnahmen nach der Insertion der gegossenen Stiftaufbauten in vielen Fällen eine schlechte Passgenauigkeit im apikalen Bereich zeigte. Der Datensatz des Intraoralscans zeigte in diesen Fällen apikal ein größeres Lumen als das Gipsmodell der konventionellen Stiftabformung, sodass geschlussfolgert werden kann, dass die Stiftaufbauten, die im rein digitalen Workflow hergestellt werden apikal eine bessere Passgenauigkeit zeigen. Die

Abbildung 19 verdeutlicht das Beschriebene anhand einer Zahnfilmröntgenaufnahme und der dazugehörigen Überlagerung der beiden STL-Datensätze.

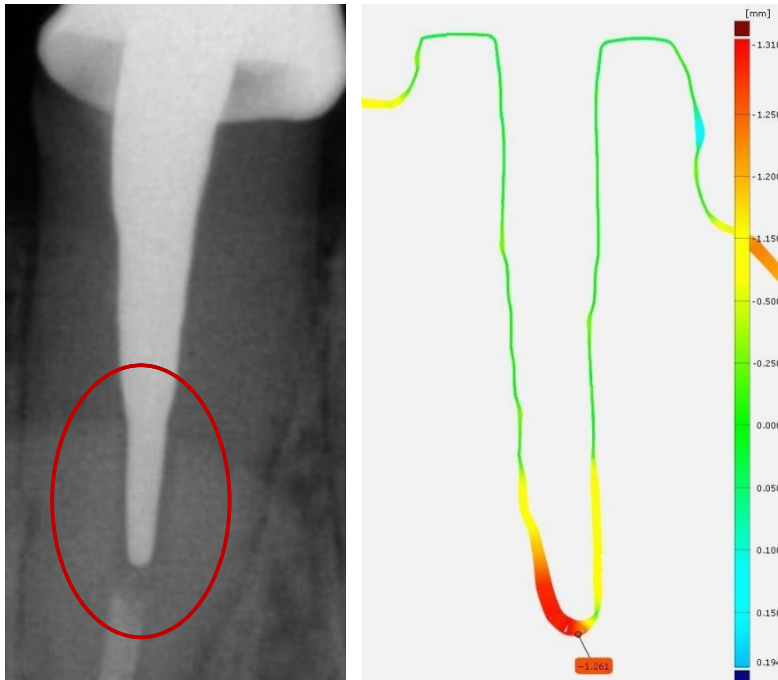


Abbildung 19: Die Zahnfilmröntgenaufnahme (links) zeigt eine schlechte Passgenauigkeit des gegossenen Stiftaufbaus im apikalen Bereich des Wurzelkanals (roter Kreis), während die Überlagerung der dazugehörigen Datensätze der konventionellen und digitalen Stiftabformung (rechts) im apikalen Bereich ein größeres Lumen in dem Datensatz der digitalen Stiftabformung zeigt.

Ein Grund für die apikale Passungenauigkeit der gegossenen Stiftaufbauten, die in dem konventionellen Workflow hergestellt werden, könnte sein, dass das plastische Abformmaterial nicht jeden Bereich der apikalen Stiftbettpräparation erreicht, dies jedoch klinisch während der Abformung nicht überprüft werden kann. Dagegen kann bei dem Intraoralscan die Vollständigkeit der Stiftabformung auf dem Bildschirm überprüft und gegebenenfalls vervollständigt werden.[88] Die apikale Passgenauigkeit von Stiftaufbauten ist dahingehend von großer klinischer Relevanz, da die Kaukräfte nur bei einer guten Passgenauigkeit homogen in die Wurzel weitergeleitet werden könne und anderenfalls das Wurzelfrakturrisiko steigt.[42-45] Darüber hinaus führt ein Spalt zwischen dem Stiftaufbau und dem Wurzelkanallumen im apikalen Bereich zu einer Schwachstelle in der apikalen Versiegelung und steigert damit das Risiko für eine bakterielle Besiedelung und damit einhergehend einem Misserfolg der Restauration durch die Entwicklung einer periapikalen Entzündung.[130-133] Dies steht im Einklang mit den Ergebnissen der retrospektiven Überlebenszeitanalyse von Zähnen mit Stiftaufbauten, die nach dem konventionellen Workflow hergestellt wurden (siehe Kapitel 2.1.4), da die häufigsten Extraktionsursachen in den ersten 5 Jahren nach Insertion, Wurzelfrakturen oder periapikale

Entzündungen waren.[111] Auch stimmen die Ergebnisse der hier vorgestellten in vivo Studie mit der in Kapitel 2.2.1 beschriebenen Laborstudie überein, bei der die Zahnfilmröntgenaufnahmen ebenfalls im apikalen Bereich eine schlechtere Passgenauigkeit bei den gegossenen Stiftaufbauten im Vergleich zu den gefrästen Stiftaufbauten zeigten. Die digitale Stiftabformung in Verbindung mit dem beschriebenen rein digitalen Workflow zur Herstellung von gefrästen, CAD/CAM-Komposit Stiftaufbauten hat daher das Potenzial die postendodontische Versorgung unserer Patienten mittels Stiftaufbauten signifikant zu verbessern.

Stellt man die Ergebnisse der hier beschriebenen Studie mit den bereits publizierten Daten anderer Autoren in der wissenschaftlichen Literatur gegenüber, so sind diese vergleichbar. *Elter et al.* und *Emam et al.* beschreiben in Laborstudien ebenfalls, dass die Abweichungen zwischen der konventionellen und der digitalen Stiftabformung, mit dem gleichen Scansystem wie in der hier vorgestellten Studie, im apikalen Bereich am größten sind, untersuchten jedoch nicht die tatsächliche Passgenauigkeit von hergestellten Stiftaufbauten im Wurzelkanal.[92, 95] Aus diesem Grund ist auf der Grundlage dieser Studien keine Aussage darüber möglich, ob die konventionelle oder die digitale Abformung zu passgenaueren Stiftaufbauten führt. Darüber hinaus verwendeten die Autoren eine ältere Softwareversion, was die größeren Abweichungen als in der hier vorgestellten Studie erklären könnte.[92, 95] Die Tatsache, dass somit durch ein Softwareupdate selbst unter klinischen Bedingungen, bei denen durch den Einfluss von Speichel und die räumliche Enge der Mundhöhle das Scanergebnis beeinträchtigt wird,[164] bessere Ergebnisse erzielt werden können, als mit einer älteren Softwareversion unter idealen Laborbedingungen, verdeutlicht die rasante Weiterentwicklung der digitalen Technologien und deren Potenzial zu Verbesserung der Behandlungsoptionen in der Zahnmedizin.

2.2.3 *Anwendung des digitalen Workflows zur Versorgung von frakturierten Teleskoppfeilerzähnen mit glasfaserverstärkten CAD/CAM-Komposit Stiftaufbauten.*

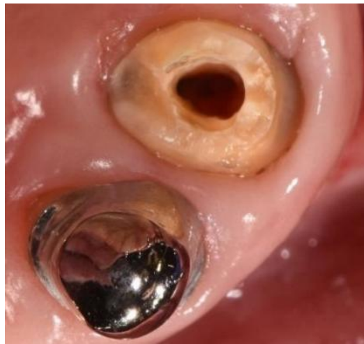
Sowohl in der wissenschaftlichen Literatur,[6, 143] als auch in den im Rahmen dieser kumulativen Habilitation durchgeführten retrospektiven Analysen,[79, 109, 111] die in Kapitel 2.1 beschrieben werden, zeigen Stiftaufbauten und Pfeilerzähne die schlechtesten Überlebensraten, wenn sie zur Verankerung von Teleskopprothesen verwendet werden. In diesem Zusammenhang konnte die fokussierende Untersuchung der Stiftaufbauten unter Teleskopprothesen (siehe Kapitel 2.1.3) zeigen, dass hierbei zu unterscheiden ist, ob der Stiftaufbau bereits zum Zeitpunkt der Eingliederung der Teleskopprothese in situ war, oder nachträglich zur Wiederbefestigung einer Teleskopkrone nach einer Pfeilerzahnfraktur inseriert wurde. Bei Letzteren wurden höchst signifikant schlechtere Überlebensraten festgestellt, weshalb vor allem hierbei eine Optimierung des Behandlungskonzeptes nötig ist. Gleichzeitig stellt diese Indikation den größten Anteil der Stiftaufbauten in Verbindung mit Teleskopprothesen dar, weil es durch nicht axiale Kräfte und eine im Rahmen der Teleskopversorgung invasive Präparation im Verlauf häufig zu einer Fraktur des Pfeilerzahnes kommt.[86, 119, 123, 124] Hierbei ist die Passgenauigkeit des Stiftaufbaus noch entscheidender, als bei anderen Indikationen, da dieser sowohl im Wurzelkanal, als auch unter die Teleskopkrone exakt passen muss, um eine Änderung des Sitzes der Prothese zu vermeiden. Aus diesem Grund ist es bei der Herstellung von individuellen gegossenen Stiftaufbauten nach dem konventionellen Workflow nötig, die Stiftabformung mit der Prothese und der Primärkrone durchzuführen. Durch die anschließenden zeitaufwendigen, analogen Arbeitsprozesse im zahntechnischen Labor ist es daher unvermeidlich, dass der Patient in dieser Zeit auf die Prothese verzichtet, was zu ästhetischen und funktionellen Einschränkungen führt.[6, 12] Zwar wäre es möglich konfektionierte Stifte in einer einzigen Sitzung zu inserieren und damit die Einschränkungen für den Patienten zu vermeiden,[12] jedoch besteht, abgesehen von der schlechteren Passgenauigkeit im Vergleich zu gegossenen Stiftaufbauten, bei konfektionierten Stiften die Limitation, dass nach einer Teleskoppfeilerzahnfraktur in der Regel ein solch großer Defekt besteht, dass diese nicht mehr indiziert sind.[12, 32, 33]

In diesem Zusammenhang können durch die Verwendung moderner, digitaler Technologien erstmals chairside individuelle Stiftaufbauten hergestellt werden, ohne dass der Patient auf die Prothese verzichten muss. Der Grund hierfür ist, dass in einem rein digitalen Workflow physische Gipsmodelle durch digitale, virtuelle Modelle in Form von

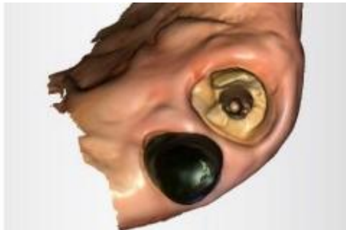
Datensätzen ersetzt werden. Die nachfolgend beschriebene Studie beschreibt den Behandlungsablauf zur Wiederbefestigung von Teleskopkronen nach einer Pfeilerzahnfraktur durch eine Erweiterung des in Kapitel 2.2.1 beschriebenen rein digitalen Workflows. Hieraus ist folgende Veröffentlichung entstanden und zur internationalen Publikation, simultan in englischer und deutscher Sprache, im *International Journal of Computerized Dentistry* angenommen worden:

J.A.H. Vogler, K.A. Walther, P. Rehmann, B. Wöstmann, CAD/CAM Post and Core for telescopic crowns after fracture, Int J Comput Dent (2024) (Zur Puklikation angenommen am 20.10.2024) (IF 2024: 1,8)

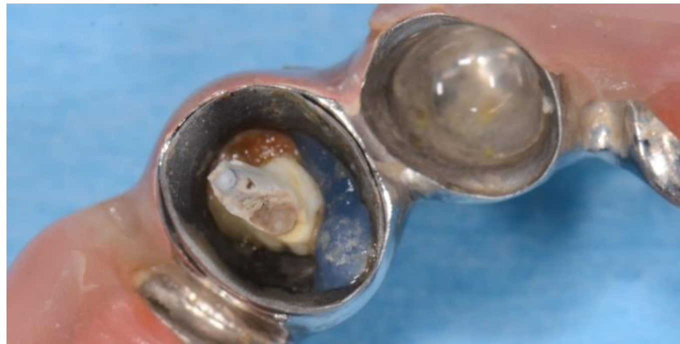
Im Rahmen der Studie wurde bei zwölf Patienten ein glasfaserverstärkter CAD/CAM-Komposit Stiftaufbaut inseriert, um die Teleskopkrone nach einer Pfeilerzahnfraktur wiederzubefestigen. Hierzu werden zunächst nach der Aufbereitung des Wurzelkanals die Stiftbettpräparation gescannt und als digitales Gegenkiefermodell die Teleskopprothese mit der Teleskopkrone von okklusal und basal mit dem Intraoralscanner digitalisiert. Die beiden erzeugten Datensätze werden anschließend durch Einsetzen der Prothese im Mund des Patienten, in einem dritten Intraoralscan einander zugeordnet. In der scannerimmanenten Software wird der Stiftaufbau virtuell so konstruiert, dass der Stiftanteil in das Lumen des aufbereiteten Wurzelkanals und der Stumpfanteil unter die Teleskopkrone passt. Im nächsten Schritt wird der Stiftaufbau virtuell in dem CAD/CAM-Block positioniert, sodass die Glasfasern entlang der Längsachse des Stiftanteils verlaufen, da somit die Biegefestigkeit des Materials um den Faktor 2,5 im Vergleich zu einer anderen Orientierung gesteigert werden kann.[99] Anschließend wird der Stiftaufbau auf einer systemkompatiblen Fräseinheit in weniger als 10 Minuten chairside ausgefräst und kann unmittelbar mit einem adhäsiven Einsetzkomposit in den Wurzelkanal und unter die Teleskopkrone eingesetzt werden. Die Abbildung 20 zeigt den modifizierten Workflow zur Herstellung individueller Stiftaufbauten aus glasfaserverstärktem CAD/CAM-Komposit, anhand eines zuvor dezementierten konfektionierten Stiftaufbaus in Verbindung mit einer partiellen Pfeilerzahnfraktur.



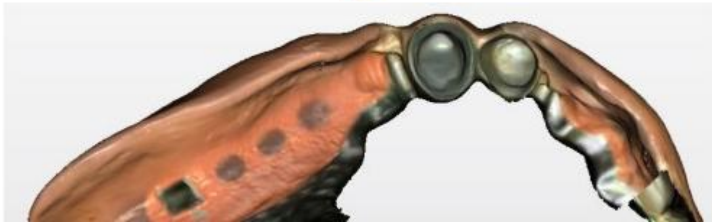
Frakturierter Teleskop-pfeilerzahn



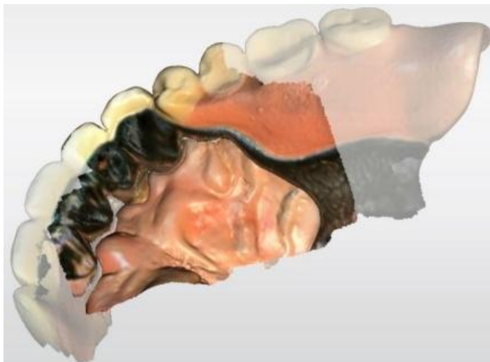
Digitale Stiftabformung



Dezementierter, konfektionierter Stift mit Zahnfragment in der Teleskopkrone

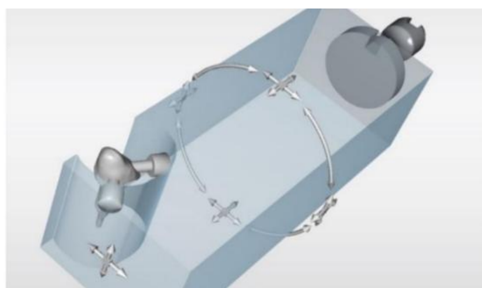


Digitale Abformung der Teleskopprothese und -krone

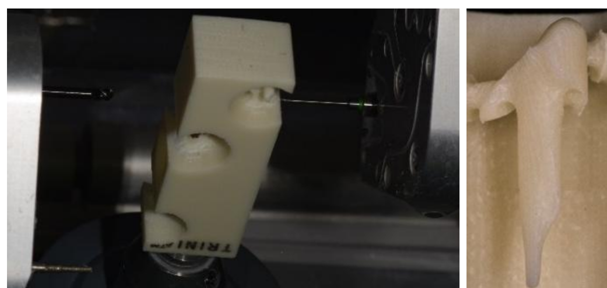


Datensatzzuordnung durch Scan der eingesetzten Prothese

Virtuelle Konstruktion des Stiftaufbaus in der Scannersoftware



Positionierung des Stiftaufbaus im CAD/CAM Block



Herstellung aus glasfaserverstärktem Komposit in weniger als 10 Minuten

Abbildung 20: Modifizierter Workflow zur Herstellung von glasfaserverstärkten CAD/CAM-Komposit Stiftaufbauten zur Wiederbefestigung von Teleskopkronen nach einer Pfeilerzahnfraktur.

Durch die Verwendung des in dieser Studie vorgestellten volldigitalen Workflows können individuelle Stiftaufbauten mit einem dentinähnlichen Elastizitätsmodul chairside eingesetzt werden und somit die Versorgung von frakturierten Teleskoppfeilerzähnen durch den Einsatz moderner, digitaler Technologien verbessert werden. Hierdurch wird nicht nur der Patientenkomfort, sondern auch die Rentabilität dieser Behandlung für den Zahnarzt gesteigert, da die Behandlungszeit auf eine einzige Sitzung reduziert werden kann. Darüber hinaus konnte in der in Kapitel 2.2.2 beschriebenen Studie gezeigt werden, dass durch die digitale Abformung die Passgenauigkeit der Stiftaufbauten verbessert wird, was wie oben beschrieben in besonderem Maße bei Stiftaufbauten unter bereits vorhandenen Teleskopprothesen von herausragender klinischer Relevanz ist. Durch die dentinähnlichen, mechanischen Eigenschaften der glasfasverstärkten CAD/CAM-Komposit Stiftaufbauten könnten zudem das Wurzelfraktur- und Dezementierungsrisiko auch bei Teleskoppfeilerzähnen reduziert werden, da die in Kapitel 2.2.1 beschriebenen Ergebnisse unter nicht axialer Krafteinwirkung auf Teleskoppfeilerzähne übertragbar sind.

3 Fazit und Ausblick

Die in Kapitel 2.2 beschriebene Weiterentwicklung der postendodontischen Versorgung mittels Stiftaufbauten durch den Einsatz digitaler Technologien ist in der Zahnmedizin von höchster klinischer Relevanz, da durch die Primärüberlebenszeitanalyse der Stiftaufbauten an unserer Poliklinik im Rahmen dieser kumulativen Habilitation gezeigt werden konnte, dass aktuell statistisch gesehen nach 10 Jahren 50% der Restaurationen einen Misserfolg erlitten haben. Diese Überlebensrate liegt deutlich unter dem im Allgemeinen in der zahnärztlichen Prothetik angestrebten Zielwert von circa 1% Misserfolg pro Jahr (~10% nach 10 Jahren). Zwar zeigen die in Kapitel 2.1 beschriebenen retrospektiven Überlebenszeitanalysen, dass die vorhandenen und klinisch etablierten Stiftaufbausysteme zwar bei festsitzendem Zahnersatz, kleinen koronalen Defekten und axial einwirkenden Kräften gut funktionieren, jedoch sind die meisten Stiftaufbauten bei herausnehmbarem Zahnersatz, großen koronalen Defekten und nicht axial einwirkenden Kräften notwendig. Hierbei können durch den Einsatz digitaler Technologien zum einen die Passgenauigkeit der Stiftaufbauten verbessert und zum anderen durch moderne Werkstoffe das verloren gegangene Dentin im Sinne eines „Restitutio ad similem“ ersetzt werden. Auch wenn für diese modernen Werkstoffe noch keine klinischen Langzeitdaten vorliegen können, da diese noch nicht lange genug auf dem Dentalmarkt verfügbar sind, ist der in Kapitel 2.2.1 und als Modifikation für frakturierte Teleskoppfeilerzähne in Kapitel 2.2.3 beschriebene Workflow selbstreden auch für alle anderen etablierten Werkstoffe anwendbar, die sich in einem CAD/CAM-Prozess verarbeiten lassen.

Vor dem Hintergrund der rasanten Entwicklung der Digitalisierung in der Zahnmedizin, konnte bereits durch die in Kapitel 2.2.2 beschriebenen Studienergebnisse im Vergleich zu der Literatur der letzten 5-10 Jahre gezeigt werden, dass die digitale Stiftabformung bereits heute der Konventionellen überlegen ist. Auch die Tatsache, dass die glasfaserverstärkten Komposite schon seit Jahrzehnten in der Luftfahrtindustrie mit großem Erfolg eingesetzt werden, hierbei die einwirkenden Kräfte um ein Vielfaches höher sind als bei Stiftaufbauten und bereits zahlreiche positive Studienergebnisse aus anderen zahnmedizinischen Bereichen vorliegen, lässt auch für die postendodontische Versorgung mittels Stiftaufbauten vielversprechende klinische Langzeitergebnisse erwarten. Auch auf dem Gebiet der präklinischen Werkstoffkundeprüfung bietet die Digitalisierung ein großes Potenzial, da bereits heute schon in Finite-Elemente-Analysen mithilfe von Computersimulationen mechanische Belastungsprüfungen rein digital durchgeführt werden können.

Hierbei werden jedoch bisher noch Umgebungsstrukturen, wie der Kieferknochen und die Zähne, als homogene Körper modelliert, weshalb die Simulation damit der in vivo Situation nur angenähert ist. Aus diesem Grund kann nach aktuellem Stand der Technik noch nicht auf Kausimulationen im Labor und klinische Langzeitstudien verzichtet werden. In diesem Zusammenhang ist jedoch zu erwarten, dass die Simulationen mithilfe von künstlicher Intelligenz in Zukunft soweit verbessert werden, dass aufgrund einer Finite-Elemente-Analyse das klinische Verhalten eines Werkstoffs in der individuellen intraoralen Situation exakt vorhergesagt werden kann. Dies würde die werkstoffkundliche Weiterentwicklung enorm beschleunigen, da klassische Laboruntersuchungen und langwierige klinische Studien verzichtbar wären. Beispielsweise könnten durch den Einsatz von 3D-Druckern in Zukunft Stiftaufbauten hergestellt werden, bei denen der Verlauf der Glasfasern individuell an die Belastung aus der Finite-Elemente-Analyse angepasst wird. Auf diesem Gebiet sind in Zukunft noch viele Optimierungen der zahnärztlichen Behandlungsoptionen zu erwarten, da die zugrundeliegenden Techniken bereits verfügbar sind, jedoch in ihrem Zusammenspiel noch optimiert und weiterentwickelt werden müssen.

4 Zusammenfassung

Im Rahmen dieser kumulativen Habilitation wurde eine Weiterentwicklung der postendodontischen Versorgung mittels Stiftaufbauten unter Verwendung moderner, digitaler Technologien vorangetrieben. Durch die Einführung der Adhäsivtechnik in der Zahnmedizin ist zwar nicht mehr bei jedem endodontisch behandelten Zahn ein Stiftaufbau notwendig, jedoch kann auch heute in Fällen mit großen koronalen Zahnhartsubstanzdefekten noch nicht darauf verzichtet werden.[5, 7] Grundsätzlich unterscheidet man in der wissenschaftlichen Literatur zwischen individuellen und konfektionierten Stiftaufbauten,[12] wobei die Individuellen sich durch ihre gute Passgenauigkeit im Wurzelkanal und ihre hohe mechanische Belastbarkeit auszeichnen,[12, 28, 57] während die Konfektionierten in einer einzigen Sitzung eingesetzt werden können und Systeme verfügbar sind, deren Elastizitätsmodul mit dem des Dentins vergleichbar ist.[27, 32]

Stiftaufbauten sind eine in der zahnärztlichen Praxis häufig verwendete postendodontische Versorgungsoption,[11] deren überlebenszeitbeeinflussende Parameter jedoch in der wissenschaftlichen Literatur, aufgrund der Vielfalt der Systeme sowie Materialien und damit einhergehenden Heterogenität der Studien, kontrovers diskutiert wird.[6, 77-79] Um die Versorgung mit Stiftaufbauten an unserer Klinik zu evaluieren, wurden im Rahmen dieser kumulativen Habilitation zunächst in retrospektiven Überlebenszeitanalysen die Risikofaktoren dieser Behandlung identifiziert. Hierdurch sollte im zweiten Schritt eine zielgerichtete und evidenzbasierte Weiterentwicklung unter Verwendung moderner, digitaler Technologien ermöglicht werden.

Es zeigte sich, dass Stiftaufbauten und die damit versorgten Zähne vor allem in Verbindung mit nicht axial einwirkenden Kräften (wie bei Frontzähnen und Teleskopprothesen) und rigiden Materialien (gegossene, individuelle Stiftaufbauten) eine reduzierte Überlebenswahrscheinlichkeit haben. Die häufigste Misserfolgsursache der Restauration war ein Retentionsverlust, bei dem auch die Verwendung eines haftstärkeren, adhäsiven Einsetzkomposites keine Abhilfe schaffen konnte. Der häufigste Zahnextraktionsgrund war eine Wurzelfraktur. Hieraus konnte geschlussfolgert werden, dass eine Optimierung der postendodontischen Versorgung mittels Stiftaufbauten auf eine Verbesserung der Passgenauigkeit (Senkung des Retentionsverlustrisikos) und damit die Herstellung eines individuellen Stiftaufbaus mit dentinähnlichen, mechanischen Eigenschaften (Senkung des Wurzelfrakturrisikos) abzielen sollte.

Im zweiten Schritt wurde ein rein digitaler Workflow entwickelt, bei dem die

Stiftbettpräparation mittels Intraoralscanner digital abgeformt und ein individueller Stiftaufbau aus einem glasfaserverstärkten CAD/CAM-Komposit mit einem dentinähnlichen Elastizitätsmodul hergestellt und in einer einzigen Sitzung eingesetzt werden kann. Somit konnten die Vorteile der individuell gegossen, mit denen der konfektionierten Stiftaufbauten in einem Stiftsystem verbunden und gleichzeitig die Nachteile der beiden etablierten Varianten eliminiert werden.

In einer Laborstudie wurde anschließend das mechanische Verhalten dieser Stiftaufbauten im Vergleich zu konventionellen, gegossenen Stiftaufbauten in einer Kausimulation überprüft. Es zeigten sich signifikant weniger Wurzelfrakturen und Dezementierungen mit den neuartigen Stiftaufbauten. Darüber hinaus wurde die Passgenauigkeit der nach dem entwickelten rein digitalen Workflow hergestellten Stiftaufbauten mit der von konventionellen, gegossenen Stiftaufbauten in einer in vivo Studie vergleichend gegenübergestellt. Die digitale Stiftabformung führte hierbei zu signifikant besser passenden Stiftaufbauten, als die Konventionelle.

Zusammenfassend stellt die Optimierung der postendodontischen Versorgung durch die Verwendung moderner, digitaler Technologien im Rahmen dieser kumulativen Habilitation eine Verbesserung sowohl für den Patienten, als auch für den Zahnarzt dar. Durch die Reduktion der Behandlungszeit für die Herstellung individueller Stiftaufbauten steigt der Patientenkomfort, einhergehend mit einer Verbesserung der Biomechanik durch die Insertion eines Stiftaufbaus mit dentinähnlichen, mechanischen Eigenschaften. Gleichzeitig steigt die Rentabilität der Behandlung für den Zahnarzt, da die Behandlungszeit reduziert wird.

5 Summary

As part of this cumulative habilitation, a further development of postendodontic treatment with post and core using modern, digital technologies was advanced. Although the introduction of the adhesive technique in dentistry means that a post and core is no longer necessary for every endodontically treated tooth, but it is still necessary in cases with large coronal defects. [5, 7] In the scientific literature, a basic distinction is made between individual and prefabricated post and core,[12] whereby the individual ones are characterized by their good accuracy of fit in the root canal and their high mechanical stability,[12, 28, 57] while the prefabricated ones can be inserted in a single session and systems are available whose modulus of elasticity is comparable to that of dentin[27, 32].

Post and core are a frequently used postendodontic treatment option in dental practice,[11] but their parameters influencing survival time are controversially discussed in the scientific literature due to the variety of systems and materials and the associated heterogeneity of the studies.[6, 74-76] In order to evaluate the treatment with post and core at our clinic, the risk factors of this treatment were first identified in retrospective survival time analyses as part of this cumulative habilitation. The second step was to enable targeted and evidence based further development using modern, digital technologies. It was shown that post abutments and the teeth restored with them have a reduced survival probability, especially in cases with non-axial forces (such as in anterior teeth and telescopic prostheses) and rigid materials (cast, individual post and core). The most common cause of failure regarding the restoration was loss of retention, which could not be remedied by the use of a stronger adhesive luting composite. The most common reason for tooth extraction was a root fracture. From this, it could be concluded that an optimization of the postendodontic restoration by means of post and core should aim at improving the accuracy of fit (decreasing the risk of decementation) and thus the fabrication of an individual post and core with dentin-like mechanical properties (decreasing the risk of root fracture).

In the second step, a purely digital workflow was developed in which the post space preparation was digitally imprinted using an intraoral scanner and an individual post and core made of a glass-fiber-reinforced CAD/CAM composite with a dentine-like modulus of elasticity could be fabricated and inserted in a single session. This made it possible to combine the advantages of individually cast and prefabricated post and core in a single system and at the same time eliminate the disadvantages of the two established variants.

In a laboratory study, the mechanical behavior of these post abutments was then tested in a chewing simulation in comparison to conventional, cast post and core. Significantly fewer root fractures and decementations were observed with the new post and core. In addition, the accuracy of fit of the post and core fabricated according to the purely digital workflow was compared to that of conventional, cast post and core in an in vivo study. The digital post impression resulted in significantly better accuracy of fit than the conventional impression.

In summary, the optimization of postendodontic treatment through the use of modern, digital technologies in the context of this cumulative habilitation represents an improvement for both the patient and the dentist. The reduction in treatment time for the fabrication of individual post and core increases patient comfort, accompanied by an improvement in biomechanics through the insertion of a post abutment with dentine-like mechanical properties. At the same time, the profitability of the treatment increases for the dentist, as chair time is reduced.

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7 Anhang

7.1 Abbildungsverzeichnis

- Abbildung 21: Frakturierter Frontzahn mit unzureichender Retentionsfläche für eine Einzelkronenversorgung (links), bei dem ein Stiftaufbau zur Vergrößerung der Retentionsfläche gesetzt wurde (Mitte und rechts).
- Abbildung 22: Design der ursprünglichen „Richmond Krone“ nach C. M. Richmond, 1880. Quelle: *Principles and practice of crowning teeth: a practical, systematic and modern treatise upon the requirements and technique of artificial crown work, including some incidental reference to bridgework. - Hart John Goslee, 1903*
- Abbildung 23: Konfektionierter Stift, bei dem der Stumpf mit Komposit ergänzt wird (links) und individueller Stiftaufbau, bestehend aus einem zusammenhängenden Stift- und Stumpfanteil (rechts). Bei dem konfektionierten Stift besteht im Bereich des Wurzelkanaleingangs ein Spalt zwischen Zahn und Stift, der die schlechtere Passgenauigkeit verglichen mit einem individuellen Stiftaufbau verdeutlicht (roter Pfeil).
- Abbildung 24: Konventionelle Abformung der Stiftbettpräparation durch den Zahnarzt (oben) und anschließende Gipsmodellherstellung, Wachsmodellation und Guss des individuellen Stiftaufbaus im zahntechnischen Labor (unten).
- Abbildung 25: Direkte, digitale Stiftabformung mittels Intraoralscanner.
- Abbildung 26: Kumulative Kaplan-Meier Kurve aller Stiftaufbauten mit einem prognostizierten Misserfolg bei der Hälfte aller Versorgungen nach circa 10 Jahren (schwarze und grüne Markierung).
- Abbildung 27: Kaplan-Meier Kurven der Stiftaufbauten zur Wiederbefestigung einer Teleskopkrone nach Pfeilerzahnfraktur (blaue Kurve) und der Stiftaufbauten, die zum Zeitpunkt der Eingliederung der Teleskopprothese bereits in situ waren (rote Kurve) mit einem prognostizierten Misserfolg bei der Hälfte aller Versorgungen nach circa 4 bzw. 10 Jahren (schwarze und grüne Markierungen).
- Abbildung 28: Balkendiagramm der Extraktionsgründe in Abhängigkeit von der Überlebenszeit des Zahnes.

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7.2 Publikationsverzeichnis

7.2.1 Primärüberlebenszeitanalyse aller Stiftaufbauten

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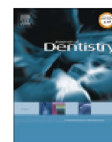
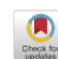


Survival time of post and cores: A 16 year retrospective follow-up study



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ABSTRACT

Objectives: The retrospective survival study (1995–2004) by Balkenhol et al. [1]. led to changes in the decision-making process for treatment with post and cores (special focus on the covering prosthetic restoration while deciding for treatment with post and cores, high primary friction at the try-in stage for conventional cementation, only indirect fabrication technique, no semi-precious alloy) in our clinic. The aim of this study was to examine the influence of these changes on the survival probability.
Materials and Methods: In the observation period (2004–2020) 653 patients received in total 953 post and cores. The patient files were analysed due to the parameters: Type of covering prosthetic restoration, location, type of tooth, luting material, post and core material, bone attachment, therapist and cause of failure. According to the previous study the survival probability was assessed using Kaplan-Meyer analysis. Cox regression was used to assess the risk of failure and identify possible covariates.
Results: The average survival time of the post and cores was 10.9 years. The cumulative failure rate was 28.2%. A significant influence on the survival time (Kaplan-Meyer analysis) could be found for the parameters: Type of covering prosthetic restoration, location, type of tooth, post and core material and bone attachment. The multifactorial survival analysis (Cox regression) showed a significant influence of the age of the patient at the time of fitting the post, the type of covering prosthetic restoration and the bone attachment.
Conclusions: The changes in the decision-making process did not lead to a better survival probability.
Clinical significance: The conclusions stated in the previous study were not strict enough. Treatments with post and cores should be critically scrutinized on the basis of covering prosthetic restoration and bone attachment. Post and cores under primary crown retained RPDs should be avoided because of the bad survival probability.

1. Introduction

The most common factor to describe the clinical success of a prosthetic treatment is the survival [2]. Therefore Balkenhol et al. investigated the survival of post and cores in their retrospective study by means of patients of our clinic between 1995 and 2004 and published their data in this Journal in 2006 [1]. They concluded that the indication should be mainly determined on the basis of the type of covering prosthetic restoration and showed accordance with serval authors in dental literature [3–5]. Furthermore Balkenhol et al. stated that a low friction at the try-in stage cannot be compensated by the use of glass ionomer cement and the indirect fabrication technique should be recommended. Post and cores in their study had been manufactured out of high-gold-content and semi-precious alloy whereas semi-precious alloy showed significantly lower survival probability [1]. These conclusions led to changes in the decision-making process for treatment with post and core in our clinic after 2004.

Even in the recent past survival of teeth treated with post and cores is frequently analysed in systematic reviews published in dental literature [6–10]. Marchionatti et al. described that the survival rates varied from 71 to 100% within the included studies but there is a need for studies with longer follow-up [6]. In this context Soares et al. described that the cumulative survival rate over the included studies decreased from 94.6% after 5 years to 60.4% after 18 years [7]. Torbjörner et al. recorded survival rates between 90 and 100% within 17 included studies but the follow up time was only 1 to 4 years [9]. In the review by Heydecke et al. an overall survival analysis was not possible. The reason for this were differences in data reporting between the included studies [8]. The meta-analysis by Creugers et al. reported survival rates from 77.6% after 5.2 years to 98.6% after more than 10 years. They also described that an overall survival analysis was not meaningful because of the heterogenic study characteristics [2]. Figueiredo et al.

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distinguished between metal-based posts and fibre reinforced posts. The pooled survival rate for metal-based posts was 90% and 83.9% for fibre reinforced posts. They also reported significant heterogeneity between the studies and described that there is a need for clinical studies with comparable setups [10].

Besides that many authors investigated the influence of cofactors on the survival time. They depicted significant influences of cofactors like the type of covering prosthetic restoration, the type of tooth or the restoration material [1, 3, 11]. A systematic review by Naumann et al. investigated the influence of the ferrule design and the type of post and core. They showed a significant influence of the ferrule design whereas the type of post did not have any significant influence [12]. Garcia et al. pointed out that there were no significant differences in the survival rate between anterior and posterior teeth amongst the studies included in their systematic review. They also criticized the short follow-ups and the bad comparability because of the heterogeneous setups between the studies [13].

The aim of this retrospective study was therefore to examine the influence of cofactors on the survival of post and cores under the same study characteristics as described by Balkenhol et al. [1]. A special attention was on the influence of the changes in the decision-making process of treatment with post and cores after 2004 in our clinic (special focus on the covering prosthetic restoration while deciding for treatment with post and cores, high primary friction at the try-in stage for conventional cementation, only indirect fabrication technique, no semi-precious alloy).

2. Materials & methods

2.1. Data acquisition

All Patient files from 2004 until 2020 were digitally scanned for post and cores that have been fitted during the observation period. Hence there were no overlapping in data between the present and the previous study. In total 668 patients received a post and core treatment throughout this period. These patient files were manually investigated for lack of data and unstandardized workflow. Also patients suffering from serious general or systemic illnesses were not included in this study.

653 Patient files with overall 923 post and cores fulfilled the inclusion criteria and were analysed due to the same standardised case report form as used in the previous study [1]. The following information was recorded for statistical analysis along with general demographic data (age and gender of the patients):

- Observation period (date of cementation/date of the final observation or failure)
- Status (success/failure)
- In the case of failure (see below for definition): type of failure
- Location (upper/lower jaw)
- Type of tooth (anterior/premolar/molar)
- Bone attachment (physiological:>75%/pathological:<75%)
- Type of covering prosthetic restoration (crown/bridge/primary crown retained RPDs)
- Luting material used (conventional cement/ adhesive cement)
- Post and core material (high-gold-content alloy/non-precious alloy/ fibre reinforced)
- Therapist (dentist/student)

2.2. Patients population

The analysed patient collective (653) was distinguished in 350 (53.6%) male and 303 (46.4%) female. The average age of the patients was 59.0 years with a range from 21 to 82 years. In line with the previous study the patients were treated by students in the Department of Prosthetic Dentistry under strict supervision of experienced dentists or by the dentists themselves following a standardised procedure. Table 1 illustrates the distribution of the post and cores (N = 953) on the patients. Mostly one post and core was inserted (70.0%).

2.3. Post and cores

In line with the previous study root canal treatment on teeth to be fitted with a post and core had been carried out a maximum of 3 months before cementation of the posts. The same clinical (prosthetic viability of the tooth, degree of tooth movement, percussion test, probing depth) and radiological (absence of periapical inflammation) criteria as used by Balkenhol et al. were applied [1]. The basis for the decision which post option had to be fitted in each case was the size of the defect and especially the remaining cavity walls as described by Creugers et al. [14]. and Fokkinga et al. [15].. fibre reinforced material had been used if there were at least three of four walls left. In cases with extensive loss of tooth structure (two or less cavity walls) cast post and cores had been fitted. Regarding the different alloys non-precious post and cores had only been used if the covering prosthetic restoration was also made of non-precious alloy to prevent corrosion of the post. In all other cases a high-gold-content alloy was used. The preparation of the root canal and the impression for cast posts was performed according to a standardised procedure. This procedure was described in the previous study [1]. The cast posts were fabricated either in a high-gold-content (N = 555/58.2%) or non-precious alloy (N = 247/25.8%). In contrast to the previous study no semi-precious alloy had been used. The prefabricated fibre reinforced posts (N = 151/15.8%) had been fitted directly into the root canal and the core was built up with composite intraorally.

The posts and cores were permanently cemented in the root canal after try-in and minor adjustments. The dentist evaluated the friction of the post in the root canal during try-in. Only cast posts with high friction had been fitted permanently with conventional cement (N = 653/ 68.5%). Totally non fitting cast posts with low friction had been remade. In those cases with extensive loss of coronal tooth structure and associated frictional surfaces mainly inside of the root canal the friction of the post could not be as high as in cases with remaining coronal tooth structure and friction also on remaining cavity walls. In these cases the friction was evaluated as "low". If the friction of cast posts was low or a prefabricated fibre reinforced material was chosen the post had been fitted with adhesive cement (N = 300/31.5%).

In this context the umbrella term "conventional cement" includes only luting materials that provide retention mainly over wedging of its particles between micro rough surfaces. The umbrella term "adhesive cement" includes only resin composites in combination with bonding agents.

Table 2 illustrates the distribution of post and cores for different types of teeth and location (upper/lower jaw).

2.4. Prosthetic treatment

After cementation of the post and core, the abutment tooth was prepared as described in the previous study [1]. A special focus was on the placement of preparation margin 1.5–2 mm apically to the post and core/tooth interface. According to the systematic review by Naumann et al. this ferrule design is proven to be the predominant factor for

Table 1
– Destribution of post and cores on patients.

Number of post and core	Number of patients	Percentage
one	455	70.0%
two	123	18.8%
three	49	7.5%
four	14	2.1%
five and more	2	0.3%
N = 953	N = 653	100.0%

Table 2
– Type of tooth and location with post and core (number/percentage).

Type of tooth	Upper jaw	Lower jaw	Total
Anterior	319/33.5%	134/14.1%	453/47.6%
Premolar	148/15.5%	193/20.3%	241/35.8%
Molar	65/6.8%	94/9.8%	159/16.6%
	532/55.8%	421/44.2%	953/100%

survival of endodontically treated teeth [12].

According to the previous study the covering prosthetic restorations were: Crowns, bridges and primary crowns for double crown retained prostheses (RPDs). All bridges included in this study were non-cantilever bridges. The primary crown retained prostheses had at least two abutment teeth and the primary crowns were parallel milled. All patients participated in a strict recall program which is known to be the predominant factor for survival of these restorations [16]. Table 3 illustrates the distribution of covering prosthetic restoration.

2.5. *Statistical analysis*

In line with the previous study the survival probability was assed using Kaplan-Meyer analysis [17]. In order to provide the best comparability between the two studies the criteria for "censored cases" (post in situ at the final examination without any adjustments = success) and "termination due to failure" (any type of complication including loss of retention with recementation = failure) remained unchanged. In order to provide the best comparability also the statistical tests used by Balkenhol et al. (log rank test, cox regression) were selected equal in the present study. The significance level for the log rank test to estimate differences between the individual sub-groups/covariates was determined at $p = 0.05$.

The following variables were defined as possibly influencing covariates:

- Location (upper/lower jaw)
- Type of tooth (anterior/premolar/molar)
- Bone attachment (physiological:>75%/pathological:<75%)
- Type of covering prosthetic restoration (crown/bridge/primary crown retained RPDs)
- Luting material (conventional cement/ adhesive cement)
- Post and core material (high-gold-content alloy/non-precious alloy/ fibre reinforced)
- Therapist (dentist/student)

In line with the previous study the influence of covariates was evaluated by forward stepwise logistic regression method based on the likelihood ratio. This method only included covariates in the analysis that had significant influences (x^2: $p = 0.05$) on the failure probability.

3. Results

The observation period of post and cores included in this retrospective study ranged from twelve days to 16.33 years with a mean of 4.3 years. The overall average survival time of all 953 post and cores without distribution in subgroups was 9.5 years with a standard error 0.3 years. Fig. 1 illustrates the overall Kaplan-Meyer survival-curve for all post and cores.

Failures were recorded in 269 cases at the final examination which results in a failure rate of 28.2%. In line with Balkenhol et al. also post and cores which could have been recemented were rated as failure so this does not mean that all 269 cases needed to receive a new restoration. According to this the loss of retention was the most common failure in the present study. 119 cases with a rate of 44.2% had been reported. Table 4 illustrates the distribution of causes of failures. For reasons of clarity a breakdown in years had not been carried out but 39.0% of failures arose during the first two years after the post and core had been fitted.

Fig. 2 illustrates the influence of the covering prosthetic restoration and the p-values after log rank testing. The influence was highly significant (log rank test: $p < 0.001$) and the survival probability was greatest in cases with crowns and bridges.

Also the type of teeth and the location showed a significant influence on the survival time (log rank test: $p < 0.05$) (Fig. 3 and 4). The survival curves distinguished by the type of restoration material led to significant differences with best results for fibre reinforced material. No significant difference was found between the investigated alloys for cast post and core (Fig. 5). Additionally the bone attachment had a highly significant influence (log rank test $p < 0.001$) on the survival time (Fig. 6) whereas the different luting materials did not lead to statistically significant differences (log rank test $p > 0.05$). Besides that the therapist and the gender had also no significant influence on the survival time (log rank test $p > 0.05$). Table 5 gives an overview on the mean survival times of post and cores distinguished by the investigated variables.

In line with the previous study a multifactorial cox regression analysis was used to investigate differences amongst all the defined covariates. The age of the patient at the time of fitting the post and core as well as the covering prosthetic restoration and the bone attachment showed a significant influence (Chi-square test: $p<0.05$). Table 6 illustrates the results of the Cox regression analysis. The missing subgroup in the table was chosen as reference variable.

The results showed that the risk of failure increased with the age of the patient at the time of post and core fitting by 3.1% per year. Also the bone attachment had a significant influence. Pathological conditions (<75%) led to an increasing risk of failure by 80% compared to physiological bone attachment (>75%). Post and cores under crowns and bridges did not differ significantly with regard to the risk of failure. Though the subgroup "Primary crown retained RPDs" had a significantly higher risk of failure than the subgroup "crowns" (increase factor of 2.5). The luting material did not have any significant influence on the risk of failure. All other investigated covariates did not have a significant influence on the risk of failure ($p>0.05$).

Table 3
– Type of covering prosthetic restoration with regard to the type of tooth.

Type of tooth	Crown	Bridge	Primary Crown (RPDs)	Total
Anterior	146/ 15.3%	51/5.4%	256/26.9%	453/ 47.6%
Premolar	178/ 18.7%	61/6.4%	102/10.7%	341/ 35.8%
Molar	104/ 10.9%	50/5.2%	5/0.5%	159/ 16.6%
	428/ 44.9%	162/ 17.0%	363/38.1%	

4. Discussion

4.1. *Method*

According to the previous study the data had been acquired retrospectively by using a standardised protocol. Since 2004 all patient files were recorded digitally so the data could be searched computer-assisted. This simplified the data acquisition and avoided human mistakes in the present study. In line with Balkenhol et al. it can be assumed that the data is representative and comparable. As described frequently in the literature there is a problem of comparability between the results of different studies when the design and the procedure of data acquisition differed [2, 8, 10, 12, 13]. It can be assumed that the data of the previous and the present study is comparable because the study characteristics remained unchanged. Therefore in the following discussion a special attention was on the comparison between the present and the previous

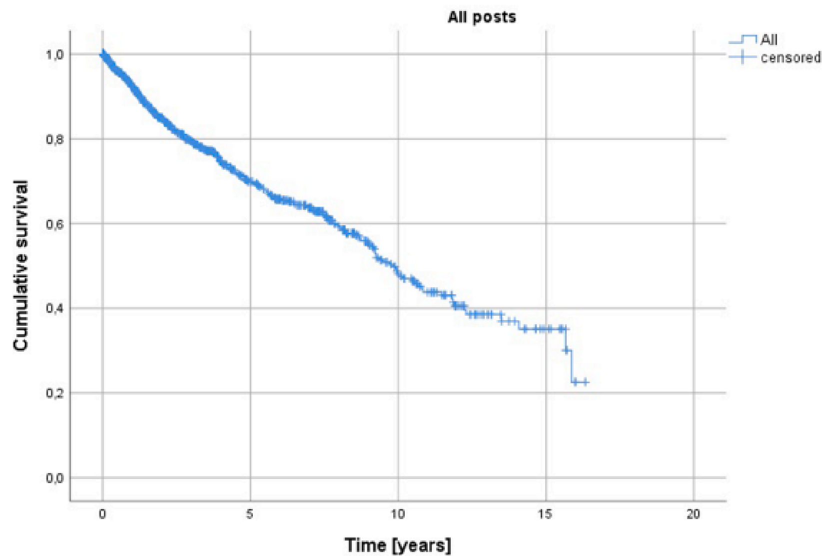

Fig. 1. Kaplan-Meyer survival-curve for all post and cores ($N = 953$).

Table 4
– Amount, Frequency and type of failure in relation to the total number of failures (results of the previous study).

Type of failure	Cases	Percentage
Loss of retention (post)	119 (39)	44.2% (43.3%)
Periapical inflammation	48 (14)	17.8% (15.6%)
Loss of periodontal attachment	35 (9)	13.0% (10.0%)
Secondary caries	26 (6)	9.7% (6.7%)
Fracture (root or crown)	34 (18)	12.7% (20.0%)
Post fracture	7 (3)	2.6% (3.3%)
Other	0 (1)	0.0% (1.1%)
Total	269 (90)	28.2% (11.2%)

study.

To follow on from the previous retrospective investigation a prospective study design would have been suitable to examine the influence of the changes in the decision making process. Accompanying a prospective design the patients had to be mandatory randomized into groups of different post options. However, these options were predefined by the size of the defect and a randomization would not have been in line with the patient's interest. Therefore the authors chose again a retrospective study design but it has to be noted that the data was documented prospectively since our working group has established a highly standardized documentation system in our clinic since 2004.

4.2. Results

Table 7 gives a Comparison of the reported data between the present study and the previous study.

The mean survival time in the present study without distinguishing between types of covering restorations was 9.5 years. The authors of the previous study recorded a mean survival time of 7.3 years. The reason for the increase might be the longer absolute observation period (16.33 years compared to 9.51 years). Moreover the average observation period in the present study was more than two times longer (4.3 years compared to 2.1 years). Garcia et al. and Marchionatti et al. denounced in their systematic reviews that there is a need for studies with longer follow-ups in order to gain a better knowledge about long-term survival of post and cores, but the literature with observations periods lasting more than 10 years is scarce [6, 13]. Only a few authors evaluated the survival of post and cores in a period of more than 10 years [15, 18, 19]. As described by Balkenhol et al. only a limited comparison to other studies with different characteristics can be made [1]. Nevertheless the mean survival time found in the present study is in the range that is reported in dental literature with follow-ups longer than 10 years [19].

The recorded cumulative failure rate was 28.2% in contrast to 11.2% in the previous study. One reason for this might be that Balkenhol et al. did not evaluate the bone attachment before treatment with post and cores. Because of improving periodontal treatment techniques, today more and more people maintain teeth with lower bone level over a longer period of time [20]. Against this background it is plausible that from 1995 until 2004 more teeth with physiological bone attachment received a treatment with post and cores but retrospectively this cannot be figured out undoubtedly. Another reason for this increase in failure rate might be the longer follow-up in the present study. Soares et al. described in his review over the relevant literature a decrease in the survival rate from five to 18 years follow up. [7] This concurs with the present results. Even if the observation period in the present study is almost seven years longer than in the previous study the recorded cumulative failure rate is still in the range of acceptance (13–30%) described by Torbjörner et al. for follow ups with 6–8 years [9]. To our knowledge, there is a lack of comparable data in dental literature for follow-ups longer than 10 years.

In line with the previous study the most common cause of failure was the loss of retention of the post. Moreover the percentage (44.2% compared to 43.3%) is comparable. The loss of retention of the post as the most common cause of failure is frequently described in the recent literature [4, 14, 19, 21]. Even if this should be regarded as a relative failure it has to be presumed that the use of adhesive cement cannot

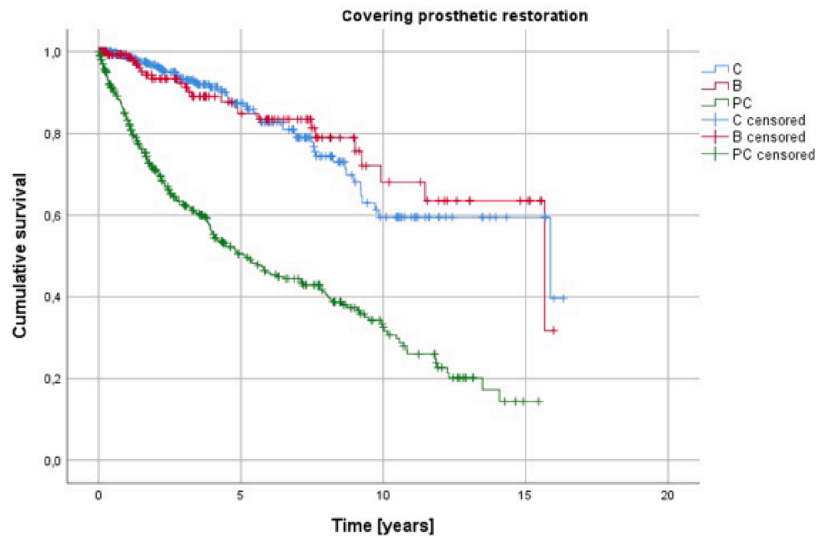

Fig. 2. Kaplan-Meyer survival-curves and p-values of the log rank test for the post and cores in relation to the covering prosthetic restoration. C: Crowns (blue); B: Bridges (red); PC: Primary Crown retained RPDs (green).

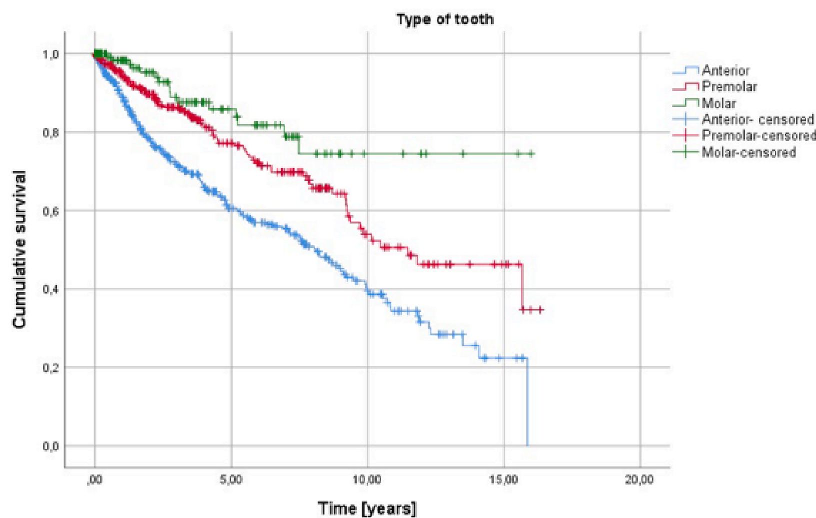

Fig. 3. Kaplan-Meyer survival-curves and p-values of the log rank test for the post and cores in relation to the type of tooth: Kaplan-Meyer survival-curves and p-values of the log rank test for the post and cores in relation to the type of tooth: Anterior (blue), Premolar (red), Molar (green).

compensate a low friction at the try-in stage. In contrast to Balkenhol et al. the luting material had no significant influence on the survival rate. This indicates that adhesive cementation tends to have an advantage over conventional cementation because adhesive luting materials had only been used in posts with low friction. In this context it should be clarified that Balkenhol et al. only used glass ionomer cement when the friction at the try-in stage was low.

Furthermore the percentage of tooth fractures had been reduced by 7.3% in comparison to the previous study. On the one hand a reason for this might be the inclusion of fibre reinforced post materials in the

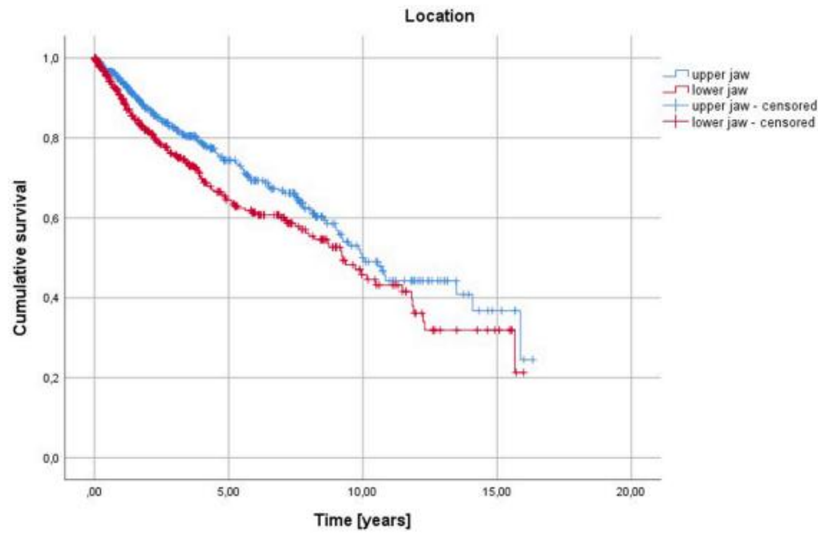

Fig. 4. Kaplan-Meyer survival-curves and p-values of the log rank test for the post and cores in relation to the location. Upper jaw (blue), lower jaw (red).

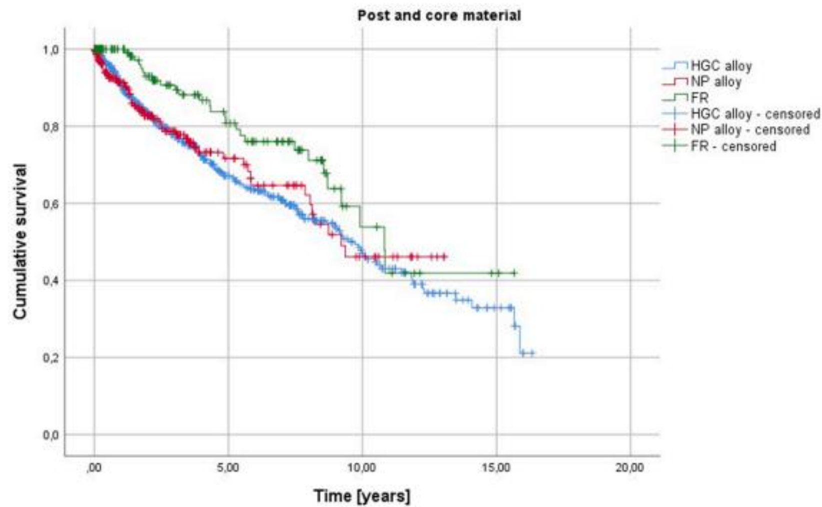

Fig. 5. Kaplan-Meyer survival-curves and p-values of the log rank test for the post and cores in relation to post and core material. High-gold-content (blue), NP: Non-precious (red), FR: fibre reinforced (green).

present study which have an elastic modulus similar to dentine [10]. On the other hand the influence of fibre reinforced material is highly speculative because the statistical analyses of the present study showed no significant influence of any investigated variable concerning the incidence of root fractures. The question whether these materials have an advantage over metal posts when it comes to tooth fractures is discussed controversially in dental literature [8, 10, 22, 23]. The percentages of the other causes of failure are comparable to the results of the previous study.

At this point it has to be noted that fibre reinforced material had only been used if the size of the defect was small. In cases with extensive loss of coronal tooth structure cast post and cores had been fitted. This might be a weakness of the present study because the post options had not been randomized independently. This has to be kept in mind when it comes to

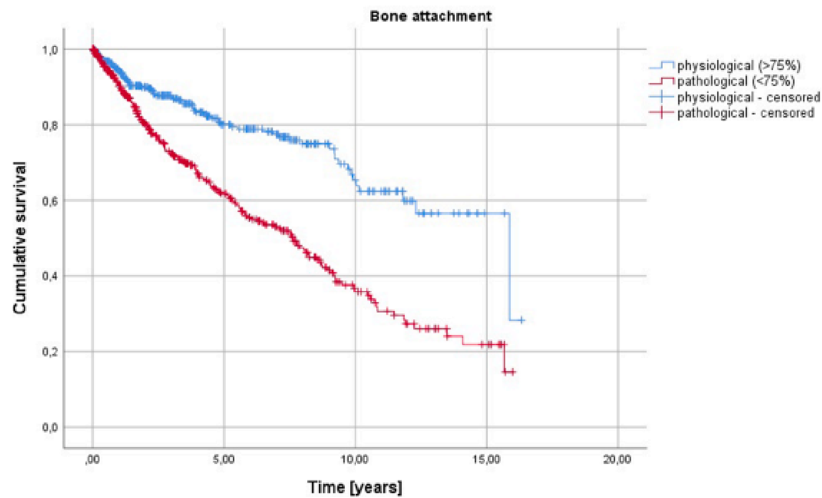

Fig. 6. Kaplan-Meyer survival-curves and p-values of the log rank test for the post and cores in relation to the bone attachment. Physiological (blue), pathological (red).

Table 5
– Mean survival time in years, standard error and confidence interval.

Subgroup	Mean survival time (years)	S.E.	95% Confidence interval : Upper / Lower	
Upper jaw	10.07	0.40	10.85	9.29
Lower jaw	8.94	0.42	9.76	8.12
Anteriors	8.14	0.37	8.86	7.41
Premolars	10.70	0.49	11.66	9.74
Molars	12.98	0.71	14.37	11.60
Bone attachment (>75%)	11.81	0.44	12.67	10.94
Bone attachment (<75%)	7.94	0.35	8.63	7.25
Crowns	12.20	0.49	13.15	11.24
Bridges	12.43	0.64	13.68	11.18
Primary Crown retained RPDs	6.72	0.35	7.40	6.04
Conventional cement	9.37	0.34	10.04	8.70
Adhesive cement	10.04	0.56	11.12	8.92
High-gold-content alloy	9.29	0.35	9.98	8.61
Non-precious alloy	8.52	0.49	9.48	7.55
Fibre reinforced	10.65	0.74	12.10	9.21
Dentist	9.80	0.55	10.87	8.72
Student	9.49	0.34	10.16	8.82
All posts	9.54	0.29	10.17	9.02

Table 6
– Result of the Cox regression analysis.

Predictor variables	B	p-value.	Exp(B)	95% Confidence interval of Exp (B): Upper / Lower	
Female	-0.01	0.94	0.99	1.27	0.77
Age at time of fitting	0.03	<0.001[a]	1.03	1.04	1.02
Lower jaw	0.11	0.42	1.11	1.44	0.86
Prmolars	-0.26	0.09	0.78	1.04	0.58
Molars	-0.17	0.56	0.84	1.50	0.47
Bone attachment (<75%)	0.60	<0.001[a]	1.82	2.39	1.38
Bridges	-0.22	0.40	0.80	1.33	0.48
Primary crown retained RPDs	0.93	<0.001[a]	2.52	3.57	1.79
Adhesive cement	0.05	0.76	1.05	1.48	0.75
Non-precious alloy	-0.07	0.67	0.93	1.27	0.69
Fibre reinforced	0.57	0.58	1.77	1.30	0.24
Dentist	-0.05	0.74	0.95	1.26	0.72

B=coefficient; Exp(B)=hazard. Reference for the hazard is the respective missing subgroup.[a] =Significant influence.

Table 7
– Comparison between the previous and the present study.

	Present Study	Previous Study
Observation period	12 d - 16.33 y	30 d – 9.51 y
Mean Observation period	4.3 y	2.1 y
Average age of patients	59.0	50.1
Number of post and cores	953	802
Average survival time (Standard error)	9.5 y (0.3 y)	7.3 y (0.2 y)
Number of failures	269	90
Failure rate	28.2%	11.2%
Number and rate of losses of retention	119 (44.2%)	39 (43.3%)
Percentage of Failures in the first 2 years	39.0%	47.8%

evaluation of the results since Neumann et al. showed that the loss of coronal tooth structure is a predominant factor of survival of post and cores [12]. Another possible weakness of the present study is that occlusal forces have not been included in the evaluation of the data. Garcia et al. showed in a systematic review over the relevant literature that occlusal forces might have an influence on the survival of post and cores throughout long-term follow-ups [13].

In line with Balkenhol et al. the Cox regression analysis showed a significant influence for the type of covering prosthetic restoration. Post and cores under primary crown retained RPDs had a 2.5 times higher risk of failure compared to single crowns. Single crowns and bridges did not differ significantly. Balkenhol et al. assumed an intermitted or lost load equilibration between tooth and support of the saddle on the edentulous alveolar ridge for the increase in the risk of failure. Despite that after the change in the decision making process for treatment with post and core (only teeth that were rated with a good prosthetic viability received a post and core under a primary crown retained RPDs) the risk of failure is still on a high level and the reported survival times in the

present and the previous study are comparable. Moreover all patients with RPDs included in the present study participated on a strict recall program which is known to have a considerable impact on the long-term success of primary crown retained RPDs [16]. During the aftercare a special focus was on the load equilibration between tooth and support of the saddle on the edentulous alveolar ridge so this could be excluded to be casual for the bad survival probability for post and cores under primary retained RPDs. Therefore it has to be determined that the conclusion stated in the previous study is too weak and a treatment with post and core in combination with primary crown retained RPDs should be avoided.

Furthermore the Cox regression analysis showed a significant influence on the covariates "age of the patient at the time of fitting the post" and "bone attachment". Pathological conditions (<75%) led to an increasing risk of failure by 80% compared to physiological bone attachment (>75%). These covariates had not been investigated in the previous study. A correlation of these variables can be assumed, since the loss of bone attachment increases with the age of the patient [20]. Martino et al. reported that the survival of post and cores is significantly more likely if the tooth root is surrounded by greater than 75% of bone tissue which concurs with the results of the present study [24]. To the best knowledge of the authors the study by Martino et al. is the only one that investigated the influence of bone attachment on the survival of teeth restored with post and cores. Therefore the data in dental literature is scarce and there is a need for more clinical evaluations on this.

The Kaplan-Meyer curves for the type of tooth, the location and the post and core material showed a significantly decreasing survival probability from molar to premolar to anterior, from upper to lower jaw and from fibre reinforced to non-precious alloy to high-gold-content alloy. Contradictory to this but in line with the previous study the Cox regression analysis showed no significant influence of these covariates. Therefore it can be assumed that there is no significant influence of the type of tooth, the location and the post and core material when all investigated variables had been taken into account in only one statistical analysis (Cox Regression). Therefore it can be assumed that all investigated post materials in the present study are suitable for the use as post and cores in every tooth of the upper and lower jaw. In contrast to the previous study no cast post and cores of semi-precious alloy had been included in the present study. Reason for this were the bad results for survival probability reported in the previous study [1].

5. Conclusion

The changes in the decision making process of treatments with post and cores after 2004 did not lead to significantly longer survival times or better survival probabilities. Post and cores should be scrutinised on the basis of the covering prosthetic restoration, the bone attachment and in conjunction to this the age of the patient. Also a low friction at the try-in stage is worrying because this cannot be compensated by the use of adhesive cement. Less crucial is the choice of the post and core material because all investigated materials in the present study showed comparable results when it comes to survival and success. amongst the investigated materials only semi-precious alloy should be avoided for use as cast post and cores.

Against the background of the bad results for post and cores under primary crown retained RPDs in the present and the previous study it has to be assumed that this treatment should be avoided. Even a strict recall program with a special focus on the load equilibration between tooth and edentulous alveolar ridge cannot increase the survival probability.

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Informed consent

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CRediT authorship contribution statement

Jonas Adrian Helmut Vogler: Writing – original draft, Writing – review & editing, Visualization, Validation. **Moritz Lehmann:** Investigation. **Peter Rehmann:** Conceptualization, Methodology, Project administration. **Bernd Wöstmann:** Supervision.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.
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7.2.2 Fokussierende Untersuchung des Retentionsverlustes als häufigste Misserfolgsursache der untersuchten Stiftaufbauten.

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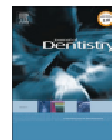

Short communication

Survival time of post and cores after recementation: A 16-year retrospective study with special focus on loss of retention

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ABSTRACT

Objectives: Numerous studies investigating the survival time of post and cores have found that loss of retention is the most common cause of failure Nevertheless, investigations focusing on decementation, survival after recementation, and the influencing parameters in a large number of patients with long follow-up periods are lacking. Therefore, the aim of this short communication article is the survival analysis of post and cores after recementation and repeated loss of retention.

Materials and Methods: During the observation period (2004–2020), 653 patients received 953 post and cores. From these, 112 post and cores which suffered loss of retention were selected. The patient files were analysed for the following parameters: Type of covering prosthetic restoration, location, type of tooth, luting material, post and core material, bone attachment and therapist. The survival time until loss of retention or repeated decementations after recementation was documented. Survival probability was assessed using Kaplan–Meier and Cox regression analyses.

Results: The average time until decementation was 13.33 years. The cumulative decementation rate was 11.8%, while in 42.0% of the cases, post and cores showed multiple losses of retention. A significant influence (Kaplan–Meier analysis) was recorded for the type of covering prosthetic restoration, type of tooth, luting material, post and core material and bone attachment. The multifactorial survival analysis (Cox regression) showed a significant influence of patient's age and the type of covering prosthetic restoration.

Conclusions: Once decementation occurs, recementation neither guarantees definitive fit nor necessarily predetermines repeated decementations.

Clinical significance: Post and cores should be avoided under primary crown-retained removable partial dentures (RPD). If this treatment is inevitable, a continuous follow-up is necessary to check the denture for proper fit to the tissues to prevent overloading on the post and core.

1. Introduction

Loss of retention has been described as the most common cause of failure in studies investigating the survival time of post and cores [1,2, 4-6]. However, as in many cases, the post and cores can be recemented without any additional effort [7–10] the Consequence of failure does not necessarily include extraction of the tooth. Therefore, Balkenhol et al. described loss of retention as a 'relative cause of failure' [5]. Kramer et al. distinguished between 'success' and 'survival' of post and cores: The time until decementation was described as 'success' and the time until extraction of the tooth or renewal of the post and core was called 'survival' [9]. Despite that the loss of retention should not be trivialised because an undetected partial decementation can lead to microleakage and secondary caries or root fracture which inevitably leads to tooth loss [11,12]. Moreover, there is lack of clinical data in dental literature regarding the clinical performance of a recemented post and core whether it remains fitted or loses retention again. Therefore, a high risk of multiple decementations would consequently lead to a higher risk of tooth loss. Thus, the parameters that influence the loss of retention of post and cores are of high clinical relevance.

Unfortunately, only a few studies describe the cause of failure of post and cores and allow for an evaluation of the decementation rate. Therefore, a comparison between studies focusing on the survival of post and cores is aggravated [13–16]. Table 1 gives an overview of the same.

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Table 1

. Data concerning 'loss of retention' from selected studies.

Study	Total number of post and cores (mean observation period)	Prosthetic restoration	Rate of decementation	Proportion of decementation for all causes of failure
Balkenhol et al. [5]	802 (5 years)	C, B, PC	4.8%	43.3%
Cagidiaco et al. [7]	240 (3 years)	C	23.3%	100%
Ferrari et al. [8]	200 (4 years)	C	0.0%	0.0%
Gomez-Polo et al. [1]	112 (10 years)	C, B	3.2%	46.0%
King et al. [17]	23 (7.25 years)	C	21.7%	100%
Naumann et al. [18]	78 (2 years)	C, B, PC	2.1%	16.7%
Sarkis-Onofre et al. [19]	183 (5 years)	C	2.7%	21.7%
Schmitter et al. [20]	81 (5 years)	C, B, PC	14.8%	37.5%
Wegner et al.	864 (1.88 years)	C, B, PC	10.3%	76.1%

C = Crowns. B = Bridges. PC = Primary Crowns for double crown retained protheses.

The rate of decementation varies between 0.0% and 23.3%. The proportion of decementation for all causes of failure ranges from 0.0% to 100%. However, no parameters influencing the loss of retention are mentioned. Furthermore, to the best of our knowledge, no studies which investigate the survival of post and cores after recementation or repeated losses of retention after recementation are available.

Thus, the aim of this study was to consecutively follow-up cases restored with post and cores, where after first loss of retention, the restoration was recemented.

2. Materials and methods

The study was approved by the ethics committee of the Justus-Liebig- University, Giessen, Germany (Reg No. 164/11.). Data acquisition was performed as described in detail by Balkenhol et al. [5]. Overall, 653 patient files with 953 post and cores were analysed. From this analysis, 841 cases which did not report decementation were considered as "censored cases" in the analysis. A total of 112 post and cores showed at least one decementation. The possibly influencing parameters on loss of retention were selected following the findings of other studies investigating the survival time of post and cores [1,4-6,21]. Table 2 illustrates the distribution of post and cores which suffered loss of retention on the investigated parameters and the general framework conditions of this study.

For this study, files of patients in which loss of retention of post and cores occurred were evaluated for multiple decementations. Therefore, the survival analysis was extended over the recementation of the post and core to evaluate the survival probability in relation to repeated losses of retention and influence of the investigated parameters.

3. Results

The overall average survival time until the first loss of retention of the post and cores was 13.33 years with a standard error of 0.3 years. A total of 112 cases of decementation were documented during the observation period (mean observation period, 4.26 years). The cumulative decementation rate was 11.8%, while 58.0% lost retention once and remained fitted after recementation until the end of the observation period. The rate of multiple decementations in all investigated post and cores was 4.9%, while the risk of losing retention again after recementation was 42.0%. Table 3 shows the frequency of multiple losses of retention.

Table 2

Parameters and general framework conditions.

Parameters	Subgroup	Distribution (n = 112)
Location	upper/lower jaw	54/58
Type of tooth	anterior/premolar/molar	87/25/0
Bone attachment	physiological:>75%/ pathological:<75%	36/75
Prosthetic restoration	crown/bridge/primary crown retained RPDs	10/1/101
Luting material used	conventional cement/multi-step adhesive cement	97/15
Post and core material	high-gold-content/non-precious/ prefab. fibre post	84/26/2
Therapist	dentist/student	29/83
Gene ral framework conditions:		
Number of patients	653	
Total number of investigated post and cores	953	
Number of decementations	112	
Average age of the patients	59.0 years	

The Kaplan-Meier survival analyses showed a significant influence of the following parameters: Type of covering prosthetic restoration, type of tooth, luting material, post and core material and bone attachment on the risk for decementation of post and cores. Multifactorial Cox regression analysis found a significant influence of the patient age when the post was fitted, and the type of covering prosthetic restoration. With increasing age, the risk of loss of retention increased by 4.4% per year. Moreover, post and cores under primary crown RPDs had 5.1 times higher risk for decementations than the reference category of post and cores under single crowns. Table 4 illustrates the significant influences in the Kaplan-Meier and Cox regression analyses.

4. Discussion

The data in this study were retrospectively acquired using a standardised protocol [5,6]. Since 2004, all patient files in our department are recorded digitally, allowing a digital search of the data. A randomised study design comparing different post options would have been desirable to analyse the survival probability after recementation of post and cores. However, as the aim of this study was to analyse the performance of a post and core after recementation, a randomised design is challenging to set up because in the beginning of the treatment, it is unknown whether the respective restoration will lose retention during its time of use. Thus, we opted for a retrospective study design, and the data were documented prospectively since our working group had

Table 3

. Multiple losses of retention.

Loss of retention	Number of post and cores	Proportion in all post and cores	Proportion in all losses of retention
Once	65	6.8%	58.0%
Twice	27	2.9%	24.1%
Three times	12	1.3%	10.7%
Four times	3	0.3%	2.7%
Five times	2	0.2%	1.8%
More than five times	3	0.3%	2.7%
Total	112	11.8%	100%

Table 4
Significant influences in the Kaplan–Meier and Cox regression analyses.

Kaplan-Meier analysis Parameters	Subgroup	P-value of log rank test		Mean survival time
Type of covering Prosthetic restoration	Crown (C)	0.083 (B)	<0.001 (PC) [a]	15.19 years
	Bridge (B)	0.083 (C)	<0.001 (PC) [a]	10.24 years
	Primary Crown (PC)	<0.001 (C) [a]	<0.001 (B) [a]	10.24 years
Type of tooth	Anterior (A)	<0.001 (P) [a]	<0.001 (M) [a]	11.57 years
	Premolar (P)	<0.001 (A) [a]	0.001 (M) [a]	14.45 years
Molar (M)	Molar (M)	<0.001 (A)[a]	0.001 (P)[a]	no decem.
Luting material	Conventional	<0.001[a]		12.74 years
	Multi-step adhesive			14.67 years
Post and core Material	High-gold cont. (HG)	0.752 (NPA)	<0.001 (FR)[a]	12.82 years
	Non-precious (NPA)	0.752 (HG)	<0.001 (FR) [a]	10.87 years
	prefab. fibre post (FR)	<0.001 (HG) [a]	<0.001 (NPA) [a]	15.51 years
Bone attachment	Physiological	0.001[a]		14.44 years
	Pathological			12.18 years

Cox regression analysis

Predictor variables	B	p-value.	Exp(B)	95% Confidence interval of Exp(B) Upper	Lower
Age at the time of fitting	0.043	<0.001 [a]	1.044	1.064	1.024
Bridges	−1.715	0.103	0.180	1.411	0.023
Primary crown retained RPDs	1.841	<0.001 [a]	6.132	11.959	3.144

B=coefficient; Exp(B)=hazard. Reference for the hazard is the respective missing subgroup.
[a] =Significant influence. RPD= removable partial denture.

established a highly standardised documentation system in our clinic since 2004. This simplified the data acquisition process and minimised human errors. As described frequently in the literature, there is a problem of comparability between the results of different studies when the design and procedure of data acquisition differ [13-15,22,23]. Moreover, we do not know of any clinical study involving a large number of patients with long follow-up, which focusses on the loss of retention of post and cores and the influence of clinical parameters. Beyond that, data concerning the survival of post and cores after recementation are lacking. Therefore, in the following discussion, the results could only be compared to those of studies that investigated decementation as one of the many causes of failure. For clarity, in the following the results of the present study are shown in brackets. Wegner et al. described in their retrospective survival analysis of 864 post and cores that loss of retention was the most common cause of failure. They recorded a decementation rate of 10.3% (11.8%) which accounted for 76.1% (82.0%) of all failure causes. The results of Wegner et al. are comparable to the findings of the present study; however, the mean observation period was only 1.88 years (4.26 years) [3]. Wegner et al. also reported a significantly higher risk of failure when the post and core was placed under a primary crown-retained RPD [3]. This finding is consistent with that of the present study. In contrast to the results of the present study, Ferrari et al. investigated the survival probability of 200 prefabricated fibre post and did not record any loss of retention of the posts [8]. One reason for this might be that prefabricated fibre posts with composite build-ups are mainly used in teeth with a low grade of coronal destruction. [3,24] Naumann et al. identified the amount of coronal destruction as one of the main influencing factors on the survival probability of post and cores [23]. Linked to that the tooth size could be an explanation for the better results of premolars and molars in contrast to anterior teeth, as the amount of hard tissue increases from anterior to posterior. Moreover, Ferrari et al. investigated only posts under single crowns [8]. In the present study, the risk of decementation was 5.1 times higher when the post and core was fitted under a primary crown-retained RPD. This could be another reason for the difference in results compared to those of the present study.

5. Conclusion

The results of the present study show that the first loss of retention of a post and core does not necessarily predetermine repeated decementations or a continuous fit after recementation. However, post and cores should be avoided in primary crown-retained RPDs owing to their poor results in such cases. If the treatment is inevitable, a continuous follow-up is necessary to check the denture for proper fit to the tissues to avoid overloading of the post and core. These conclusions are corroborated by the findings of other studies [3,5,6], and can therefore be regarded as a recommendation for daily clinical work.

Credit author statement

Jonas Adrian Helmut Vogler : Writing, Visualization, Validation. **Moritz Lehmann :** Investigation. **Maximillane Amelie Schlenz :** Resources. **Karina Zierden :** Methodology. **Peter Rehmann :** Conceptualization, Methodology Development. **Bernd Wöstmann :** Supervision, Project administration.

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Ethical approval

Processing data of patient files (Reg. No. 164/11)
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Declaration of Competing Interest

The authors declare that they have no conflict of interest.
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Data availability

Data will be made available on request.

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Compliance with Ethical Standards and Declaration of Interest.

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7.2.3 Fokussierende Untersuchung der Überlebenszeit in Verbindung mit Teleskopprothesen als häufigste prothetische Versorgungsart der untersuchten Stiftaufbauten mit der gleichzeitig schlechtesten Prognose.

J.A.H. Vogler*, W. Abrahamian, S. Reich, B. Wöstmann, P. Rehmann, Post and Core Treatment to Refit Telescopic Crown-Retaindes Dentures after Abutment Tooth Fracture: An Evaluation of Therapy by Retrospective Survival Analysis, *Dentistry Journal (Basel)* 12(7) (2024). (IF 2024: 2,5) doi: https://doi.org/10.3390/dj12070224

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Post and core to refit telescopic crown retained dentures after abutment tooth fracture – An evaluation of therapy by retrospective survival analysis.

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Abstract: Post and core (PC) treatment shows the worst survival probability if the tooth is used as an abutment for telescopic crown retained dentures (TCD). Due to the extra axial forces, abutment tooth fracture is a common cause of failure for TCD, thus PC is often in need to refit the existing telescopic crown (TC). However, there is no clinical survival data whether the PC is used to refit TC after abutment tooth fracture (PC2) or PC was already fitted at the time of TCD treatment (PC1). 246 patients with 399 PC were retrospectively evaluated for follow ups up to 17.33 years. The files were analysed for PC1 and PC2. Furthermore, the influence of the jaw, type of tooth, luting material, PC material, bone attachment, therapist and cause of failure was recorded. For statistical analysis Kaplan-Meier and Cox regression analysis was conducted. PC2 showed highly significant lower survival probabilities than PC1 (p<0.001). Moreover, the bone attachment and the age of the patient at the time of fitting PC had an influence on the survival (p<0.001). Therefore, PC2 should be avoided if possible and PC1 should be favoured in endontontically treated abutment teeth for TCD.

Keywords: Post and core, Telescopic denture, Survival time, Cox regression, Kaplan-Meyer analysis, Retrospective study

1. Introduction

Telescopic crown retained dentures (TCD) are a frequently used treatment option for patients with few remaining teeth.[1, 2] Survival probability of PC under TCD) is the worst compared to all other types of covering prosthetic restorations.[3-5] In this context, fracture of abutment teeth is frequently described as one of the most common causes of failure with TCD.[6-8] Due to extra axial forces when TCD is removed and inserted incorrectly[3] or when the long denture saddle does not fit the edentulous jaw areas[8], risk for abutment tooth fracture increases because of its rigid connection to the denture.[6, 8] Thus, patients treated with TCD need to follow a strict aftercare program in order to avoid early failures leading to bad survival probability.[7, 8] Fortunately, abutment tooth fracture is not always mandatorily connected to extraction of the tooth.[9] Since for TCD comparably much coronal hard tissue has to be removed,[10] fracture often occurs within the area of the preparation for telescopic crown (TC) resulting in an insufficient coronal height to reattach the existing TC without additional effort.[11] In these cases tooth preservation is possible but in order to refit the existing TC, post and core (PC) after endodontic treatment is mandatory.[12] The precondition for this is, that the fracture line is at least 2 mm above the preparation margin of TC because this ferrule is known to be the predominant factor for long term success of both the tooth and the PC.[11]
Furthermore, TCD fabrication is associated with high costs for the patient because of the technically complex workflow.[6, 8, 13] Therefore, refitting of an existing TC after

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abutment tooth fracture is economically advantageous because the friction of TC in the secondary crown of TCD is hardly adjustable, thus expensive and time consuming if fabrication of a new TC is needed.[13] Moreover, for renewal of TC the patient has to renounce TCD for adjustment which is associated to a decrease in both aesthetics and chewing comfort. Nevertheless, abutment tooth fracture can also be associated with microcracks in the root dentine which in some cases can be undetectable by visual examination.[14] Against the background of extra axial forces on the abutment teeth for TCD, microcracks as well as the accuracy of fit of PC can have an increased influence on survival because a large cement gap is associated to an increase in microleakage[15] and polymerization shrinkage of the resin composite[16]. This can lead to an uneven transmission of force into the root, thus enlargement of microcracks into catastrophic root fractures making extraction of the abutment tooth inevitable.[17, 18] Moreover, bad accuracy of fit of PC is associated to an increased risk for decementation of PC, which can lead to secondary caries, thus an increased risk for tooth loss.[4, 19]
Besides that, the influence of co-parameters (e.g. the type of treated tooth or the PC material) on survival, are inconsistently described by different studies.[11, 20, 21] *Garcia et al.* reported that there were no significant differences in the survival rate between anterior and posterior teeth,[22] whereas *Dittmann et al.* found better survival probabilities for anterior teeth.[23] However, both investigators agreed on the need for more evidence by more studies with longer follow-ups and larger sample sizes.[22, 23] Furthermore, many studies considered the type of covering prosthetic restoration on the survival of PC and found significantly lower survival rates when PC was fitted under TCD than under fixed dental prostheses.[3-5] However, the authors did not consider if PC was fitted before treatment with TCD or after fracture of an abutment tooth to refit an existing TC. Therefore, one cannot evaluate the treatment of reattaching TC with PC by the results of these studies. To the best knowledge of the authors there is no analysis on this in scientific dental literature considering possibly influencing co-parameters on the basis of a large sample size with long follow-ups. Since abutment tooth fracture is one of the most common complications with TCD,[6-8] an evaluation of this treatment option is of high clinical relevance. Therefore, the aim of this study was to investigate the survival probability of PC fitted before treatment with TCD (PC1) and to compare it to PC refitting an existing TC after abutment tooth fracture (PC2).

2. Materials and Methods

This study was approved by the ethics committee of the [*removed for anonymity reasons*] *(Reg No.…).* The observation period for the present study was defined from 2004 until 2023. All patient files within this period were digitally documented, so that an automatized search for PC treatment could be conducted. Since 2004 every patient in our clinic is documented using the same software with standardised and unchanged characteristics. Therefore, the documentation is concordant between the different users throughout the whole observation period.
Initially, all patients with PC treatment between 2004 and 2023 (N=1661) were filtered. The files were then manually searched for different covering prosthetic restorations than TCD, lack of data, unstandardized PC workflow and serious systemic illnesses possibly influencing the survival of PC. Subsequently, these files were excluded from further investigation and from the data acquisition for the present study.
Finally, 246 Patient files with overall 399 PC fulfilled the inclusion criteria and were analysed according to a standardised evaluation sheet including the following information and general demographic data such as age and gender of the patients:

- Date of cementation/ Date of the final observation or failure
- Reason for failure
- Time of fitting PC (before treatment for TCD/reattaching TC after tooth fracture)

- Jaw (upper/lower jaw) 97
- Type of tooth (anterior/premolar/molar) 98
- Bone attachment (physiological:>75%/pathological:<75%) 99
- Luting material (conventional cement/ adhesive cement) 100
- PC material (high-gold-content alloy (hg) /non-precious alloy (np) /fibre reinforced (fr)) 101 102
- Therapist (dentist/student) 103

The patient cohort (n=246) included 133 (54.1%) male and 113 (45.9%) female with an average age of the patient at the time of fitting PC of 67.48 years (±10.45 years). The majority of treatments for PC were conducted by students under strict supervision of experienced dentists (n=314, 78.7%). Fewer treatments were conducted by the dentists themselves (n=85, 21.3%). Both groups of therapists followed the same standardised workflow which is described in detail in the following and by other authors as well.[3, 4] 267 (66.9%) PC were fitted after a fracture of an abutment tooth in order to reattach the existing TC (PC2), while 132 (33.1%) teeth were already treated with PC before preparation for TCD (PC1). 104 105 106 107 108 109 110 111 112

PC treatment was only performed if the tooth was free of symptoms indicating an inflammation or a root fracture.[3] Moreover, a sufficient circumferential ferrule of at least 2 mm of TC was mandatory.[11] The decision whether a prefabricated fiber reinforced post (PFRP) or a cast PC (CPC) was fitted was determined by the amount of remaining dentine and existing cavity walls.[24, 25]. PFRP had been used if there were at least three walls left and CPC if the coronal destruction was more severe. Post space preparation and impression for CPC was performed according to a standardised and clinically established procedure.[3, 4] In cases of PC2, the impression was taken using TCD and TC as an impression tray in order to fix the position of TC in relation to the abutment tooth. Regarding the different alloys, non-precious PC had only been fitted if TC was also made of non-precious alloy in order to prevent from corrosion of PC. In all other cases a high-gold-content alloy was used. Before fitting of PC, the therapist evaluated the friction in the root canal and decided if a conventional cement (high friction of CPC) (N=286/71.7%) or an adhesive cement (low friction of CPC/every PFRP according to the manufacturers advise) (N=113/28.3%) was used. In total, 190 (162 anterior teeth, 27 Premolars and one Molar) of the included PC were fitted in the upper jaw, whereas 209 (122 anterior teeth, 82 Premolars, five Molar) teeth were treated in the lower jaw. 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129

Kaplan-Meier and cox regression analysis were used to investigate the survival probability as well as possibly influencing co-parameters. Univariate influences were investigated by Kaplan-Meier and multivariate influences by cox regression analysis in which a reference variable is predefined in order to consider multiple influences on one co-parameter.[26] Significant differences between the subgroups of possibly influencing co-parameters were assessed by means of the log rank test[27] with a significance level of $p<0.05$. The evaluation was conducted by forward stepwise logistic regression method based on the likelihood ratio, meaning that only parameters that had significant influences (x^2: $p<0.05$) on the failure probability were included in the analysis. Multiple PC in the same patient was statistically considered using "shared frailty".[28] 130 131 132 133 134 135 136 137 138 139

3. Results 140

The overall average survival time of all cases included in this study was 6.96 years with a standard deviation (SD) of 0.36 and a 95% confidence interval (CI) of 6.25 - 7.67. The most common cause of failure was loss of retention (N=121/30.3%) followed by root fracture (N=29/7.3%), periapical inflammation (N=25/6.3%), secondary caries (N=20/5.0%), periodontal bone loss (N=20/5.0%) and post fracture (N=6/1.5%). Root fracture was only recorded with CPC, whereas post fracture occurred solely with PFRP. Furthermore, 141 142 143 144 145 146

decementation of PC was most frequently reported with PFRP. 147
The overall mean observation period was 4.13 years (SD=4.04) with a maximum of 17.33 years. Distributing the cases according to the time of fitting PC, the mean survival time for PC1 was 9.85 years (SD=0.61; CI=8.65 - 11.05), whereas PC2 survived 5.35 years (SD=0.41; CI=4.56 - 6.15). The Log-rank test recorded highly significant differences ($p<0.001$) between these two investigation groups (Table 1). Furthermore, the statistical analyses showed highly significant influences ($p<0.001$) on the survival regarding the parameters "age of the patient at the time of fitting PC" as well as the "bone attachment" (Table 1 and Table 2). In detail, the risk for failure increased by 4.2 % each year that the patient was older at the time of fitting PC and the survival probability was inferior with pathological bone attachment. Figure 1 illustrates the Kaplan-Meier curves of the influencing parameters "Time of fitting PC" (left) and "Bone attachment" (right). 148–158

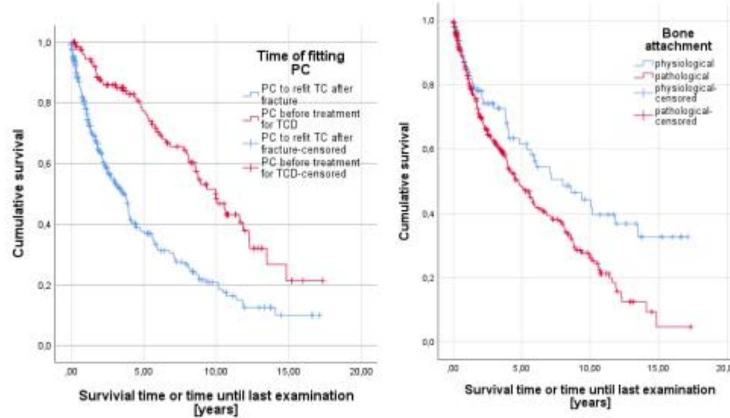

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Figure 1. Kaplan-Meier survival curves of the significantly influencing parameters: Time of fitting PC (left) and Bone attachment (right). 160–161

All other investigated co-parameters showed no significant influence ($p>0.05$). Table 1 illustrates the results of the Log-rank tests between the subgroups of the co-parameters. 162–163

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Table 1. Results of the Log-rank tests between the subgroups of the co-parameters 165

Co-parameter	Log-rank test between subgroups	p-value
Time of fitting PC	PC1 /PC 2	<0.001*
Gender	female / male	0.355
Jaw	upper / lower	0.405
Type of tooth	anterior / premolar	0.168
	premolar / molar	0.342
	anterior / molar	0.586
Bone attachment	>75% / <75%	<0.001*
Luting material	conventional / adhesive	0.502
PC material	hg / np	0.217
	hg / fr	0.345
	np / fr	0.467
Therapist	dentist / student	0.791

* significant difference 166

Table 2 illustrates the results of the multivariate cox regression analysis. The predefined reference variables of the co-parameters are written in brackets. 167 168

Table 2. Results of the multivariate cox regression analysis (reference variable), 169

Co-parameter	Subgroups (reference variable)	p-value
Time of fitting PC (PC1)	PC 2	<0.001*
Gender (female)	male	0.630
Age at the time of fitting PC	/	<0.001*
Jaw (upper)	lower	0.754
Type of tooth (anterior)	premolar	0.510
	molar	0.540
Bone attachment (>75%)	<75%	<0.001*
Luting material (conventional)	adhesive	0.309
PC material (hg)	np	0.352
	fr	0.980
Therapist (dentist)	student	0.489

* significant difference 170

4. Discussion 171

The data had been automatically acquired by using a standardised protocol and a Software, avoiding human mistakes and improving data correctness. Therefore, one can assume that the data is representative as well as comparable and it can be used to take a stand on the treatment option of fitting PC to reattach TC after abutment tooth fracture (PC2) by comparison to the survival of PC that have been fitted before treatment for TCD (PC1). Furthermore, a survival analysis including a large sample size with comparably long observation periods up to 17 years as the present study, would have been hardly possible in a prospective study. One reason for this is that it would have been ethical worrying to renounce PC treatment before fitting TCD and wait for abutment tooth fracture in order to fit PC reattaching TC. That is why we chose a retrospective study design which is comparable to similar survival analyses in scientific dental literature as well.[3, 5, 29] The present study resulted in highly significant lower survival rates, when PC was fitted to reattach TC after tooth fracture (PC2) in comparison to PC that have been fitted before treatment for TCD (PC1). One reason for this might be possible microcracks in the root dentine in consequence of the previous abutment tooth fracture. Even if every tooth was visually checked for cracks, the dentist cannot exclude intraorally undetectable microfractures which could enlarge during wear of the TCD after PC fitting. This enlargement of cracks could even be increased with rigid CPC, because of unmatching mechanical properties to dentine or PC with bad accuracy of fit. In both cases the extra axial forces on the abutment tooth with TCD result in an uneven transmission of force into the dentine leading to an increased risk for decementation and root fracture.[15-18] This is in line with the results of the present study because decementation and root fracture were the most common causes of failure and root fracture was only reported with CPC. On the other hand, post fracture was solely observed with PFRP. One reason for this might be the reduced mechanical forces of PFRP compared to CPC which in connection with the extra axial forces can lead to higher post fracture rates.[16, 18] Recent studies using CAD/CAM technology described customized PC fabricated out material with matching mechanical properties to dentine,[30-32] which reduce the risk for root fracture under extra axial load.[31] This can be a promising treatment option for TCD as well because these PC can combine the advantages of CPC and PFRP.[31] Nevertheless, this should be further investigated in future studies. *Rottner et al.* described a new PC technique consisting of a prefabricated PC with a ball attachment connection in order to reattach TCD on a fractured abutment tooth renouncing the existing TC. They pointed out that the costs and the treatment time for PC with their technique are less than for cast PC and comparable to established prefabricated post systems.[9] Nevertheless, the observation period in this study was only three years and therefore not comparable to the long-term results of the present study. To the best knowledge of the authors, this is the only other survival analysis investigating PC survival after abutment tooth fracture for TCD. Another disadvantage related to the technique described by *Rottner et al.* is that the ball attachment is limited to a strictly rigid connection to TCD, transmitting occlusal forces only onto the tooth. Though, TCD can be modified in order to transmit occlusal forces onto both the gingiva and the abutment teeth, which can be advantageous for tooth preservation especially in patients with few remaining teeth.[7] Furthermore, the present study recorded significantly lower survival rates with pathological bone attachment and elderly patients at the time of fitting PC. A correlation of these parameters can be assumed, since the periodontal bone loss increases with the age of the patient.[33] In line to the results of the present study, *Martino et al.* described that the survival of PC is significantly more likely if the bone attachment is greater than 75%.[34] 172–219

5. Conclusions 220

The results of the present study show that PC to refit TC after abutment tooth fracture (PC2) should be avoided because of the poor survival probability. If an abutment tooth is 221–222

of high prosthetic value for TCD treatment, the dentist should carefully discuss with the patient to fit PC before TCD treatment (PC1) in order to increase the survival probability. Moreover, the bone attachment and the age of the patient should be considered in this decision-making process. In any case, one can lead from literature and the results of the present study that patients treated with TCD should follow a strict aftercare program in order to prevent abutment teeth from excessive extra axial forces because of incongruent denture saddles decreasing survival. Furthermore, PC treatment options in connection to TCD should be further developed because new digital technologies have already shown promising results which might be transferable to TCD. 223 224 225 226 227 228 229 230 231

Supplementary Materials: The following supporting information can be downloaded at: www.mdpi.com/xxx/s1, Figure S1: title; Table S1: title; Video S1: title. 232 233

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William Abrahamian: Investigation; formal analysis
Sarah Marie Reich: Data curation; validation
Bernd Wöstmann: Software; supervision; resources
Peter Rehmann: Conceptualization; methodology
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. 249

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7.2.4 Untersuchung der Überlebenswahrscheinlichkeit des mit einem Stiftaufbau versorgten Zahnes bis zur Extraktion.

J.A.H. Vogler*, A.L. Stummer, K.A. Walther, B. Wöstmann, P. Rehmann, Survival of teeth treated with post and core - A retrospective study of more than 1000 cases with observation periods up to 18 years, *Journal of Dentistry* 138 (2023) 104723. (IF 2023: 4,4) doi: 10.1016/j.jdent.2023.104723

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Survival of teeth treated with post and core - A retrospective study of more than 1000 cases with observation periods up to 18 years

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ABSTRACT

Objectives: Even if survival of post and core (PC) itself was frequently investigated in recent literature, clinical data concerning the risk for extraction of teeth restored with PC is still scarce. Since most authors found the loss of retention of refitable post and cores as the most common cause of failure, it is impossible to draw a conclusion on tooth survival on the results of those studies. Therefore, the aim of the present study was to improve the clinical evidence on the survival of teeth treated with post and cores on a large number of cases over a long observation period.

Materials and methods: 735 patients were treated with 1053 post and cores in the observation period (2004–2022) and could be included in the study. The patient files were analysed due to the parameters: Type of covering prosthetic restoration, location, type of tooth, luting material, post and core material, bone attachment and therapist. The survival probability was assessed using Kaplan-Meyer analysis. Cox regression was used to assess possible multifactorial influences.

Results: The overall average survival time until necessary extraction of a tooth restored with a post and core was 11.74 years. A root fracture in primary crown retained removeable partial dentures (RPDs) during the first five years was the most common reason for extraction in this study. A significant influence on the survival time of teeth restored with post and cores was found for the type of covering restoration, bone attachment, age of the patient and post and core material.

Conclusions: Post and core restored teeth should be avoided as abutments for primary crown retained RPDs.

Clinical significance: If it is inevitable to utilise post and core restored teeth for primary crown retained RPDs, post and core materials with matching mechanical properties to that of dentine should be preferred.

1. Introduction

Due to the advancements of the adhesive technique in dentistry post and core (PC) is no longer necessary for all teeth with loss of coronal tooth structure, but it is still indispensable in cases with extensive defects [1,2]. In former decades it was the prevailing opinion in scientific dental literature that insertion of PC stabilises the tooth and therefore increases the survival probability of endodontically treated teeth [3]. This opinion was refuted in the following years by many studies because the necessity of post space preparation weakens the tooth structures which means that for example risk for root fractures increases [4,5]. That is why *Naumann* et al. claimed in a their review over the relevant literature that PC should only be fitted when the remaining tooth structure provides insufficient adhesive surface for a filling because there is no evidence for a positive effect of post placement neither for survival of indirect nor direct restorations [2].

The most common criteria in literature to investigate the clinical success of a treatment is the survival of the restoration [6]. Nevertheless, in the particular case of PC this is not an irrevocable indicator for tooth survival because loss of retention is frequently described as the most

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common cause of failure, [7–10] but at the same time in many cases the PC can be recemented without any additional effort [11–13]. Therefore, loss of retention does not necessarily lead to the extraction of the tooth. *Balkenhol* et al. described loss of retention as a 'relative cause of failure' [7]. *Kramer* et al. agreed to that and distinguished in their prospective observational study between 'success' and 'survival' of PC, meaning that the time until decementation was described as 'success' and the time until extraction of the tooth or renewal of PC was called 'survival' [12]. However, there is evidence that this 'relative cause of failure' should not be trivialised because an undetected microleakage caused by partial decementation can lead to secondary caries or root fracture which consequently increases the risk for extraction of the tooth [14–16]. Thus, loss of retention of PC can secondarily be related to a higher risk for extraction. Another frequently described cause of failure which is not obligatorily related to tooth loss is the post fracture [17,18]. Especially, treatment with prefabricated fibre reinforced posts can easily be revised after post fracture and the tooth does not need to be extracted [19,20].

Unfortunately, not in every study investigating the survival of PC the cause of failure is described in detail [12,21]. That is why it is impossible to draw a conclusion on the survival of the tooth itself on the basis of the results of these studies.

Even if the survival of PC has been investigated frequently in recent scientific literature, the influence of parameters such as the type of tooth or the type of covering restoration was described inconsistently by different authors [22–24]. *Figueredo* et al. reported that there is significant heterogeneity between the studies leading to a limitation of comparability [24]. Other authors concluded that there is a need for more clinical survival analysis with long follow-ups on the basis of a large number of cases to give the dentist an evidence based recommendation for treatment with PC [1,25].

Summarising the already published data, well-structured long term studies of teeth treated with PC focusing on the survival until necessary extraction are lacking. Therefore, the aim of this retrospective study was to investigate the survival time as well as the influencing parameters on the survival of PC restored teeth until extraction in a more than 1000 cases over an observation periods of 18 years.

2. Materials & methods

2.1. Data acquisition

Data acquisition was conducted in a software that was programmed especially for the standardisation of dental treatment documentation at university clinics (Multizentrische Dokumentation, MZD) and was used in our department since 2004. The study was approved by the ethics committee of the *[removed for reasons of anonymity]* (Reg No.…). All Patient files from 2004 until 2022 were digitally and automatically searched for treatment plans with PC that have been issued during the observation period. As a primary result of the retrospective data acquisition 962 patients received a treatment plan for PC within this period. These patient files were manually investigated for actual procession of the treatment plan, lack of data and unstandardised workflows or treatments. Moreover, patients suffering from serious general or systemic illnesses possibly influencing the environmental factors of the oral cavity were excluded from further investigation.

Finally, 735 Patient files with overall 1053 PC fulfilled the inclusion criteria and were analysed due to the standardised evaluation criteria described below. This procedure is well-established and was used in previous studies [7,10,16]. Thus, the following information was recorded for statistical analysis along with general demographic data (age and gender of the patients):

- Observation period (date of cementation/date of the extraction of the tooth or final examination).
- In the case of extraction: Reason for extraction.
- Location of PC treated tooth (upper/lower jaw).
- Type of tooth (anterior/premolar/molar).
- Bone attachment (physiological:> 75 %/pathological:< 75 %).
- Type of covering prosthetic restoration (crown/bridge/primary crown retained RPDs)
- Luting material used (conventional cement/ adhesive cement)
- PC material (high-gold-content alloy/non-precious alloy/fibre reinforced).
- Therapist (dentist/student).

2.2. Patients population

The patients included in the study (735) were distributed to 391 (53.2 %) male and 344 (46.8 %) female. The average age of the patients at the time of fitting PC was 58.7 years with a range from 17 to 92 years. Treatment for PC was processed by students in the Department of Prosthetic Dentistry under strict supervision of experienced dentists or by the dentists themselves following a standardised procedure [7]. Table 1 illustrates the distribution of PC ($N = 1053$) on the patients included in the study. In the majority of the patients only one PC was fitted (71.8%).

2.3. Teeth treated for PC

Only teeth in which the endodontic treatment has been processed successfully have been included in the study. Therefore, before post space preparation each tooth was checked according to established clinical (prosthetic viability of the tooth, degree of tooth movement, percussion test, probing depth) and radiological (absence of periapical inflammation) criteria [7,10,16]. The decision whether a cast PC (CPC) or a chairside treatment with prefabricated fibre reinforced post and a composite core build-up (PFRP) was fitted has been taken according to the size of the defect and the remaining cavity walls [8,26]. PFRP had been used if there were at least three walls left providing sufficient adhesive surface for the composite core build-up ($N = 167/15.86$ %). In cases with extensive defects (two or less cavity walls) CPC had been fabricated out of non-precious ($N = 308/29.2\%$) or high-gold-content ($N = 578/54.9$ %) alloy fitting to the material of the covering prosthetic restoration. The preparation of the post space, the impression and the fabrication workflow for CPC was performed according to a standardised procedure [7].

CPC were permanently cemented in a second appointment after try-in and possible minor manual adjustments. The dentist evaluated the friction of CPC against pull out in the root canal during try-in to decide whether an adhesive or conventional cement was used for fitting, meaning that for CPC with high friction a conventional cement ($N = 705/67.0$ %) was used while all other CPC and PFRP were fitted with a resin composites in combination with bonding agents ($N = 348/33.0$). In this context "conventional cement" includes only luting materials that provide retention mainly over wedging of its particles between micro rough surfaces. "Adhesive cement" stands for resin composites in combination with bonding agents. Totally non-fitting CPC with low friction had been remade after revision of the post impression. In cases with extensive defects and only small frictional surfaces mainly inside of the root canal (no cavity walls) the friction of CPC could obviously not be as high as in cases with remaining cavity walls. In these cases, the friction

Table 1
Destribution of PC on patients.

Number of PC	Number of patients	percentage
one	528	71.8 %
two	133	18.1 %
three	53	7.2 %
four	11	1.5 %
five and more	10	1.4 %
$N = 1053$	$N = 735$	100.0 %

was evaluated as “low” and an adhesive cement was used.

In Table 2 the distribution of PC on the investigated different type of tooth as well as the location (upper/lower jaw) is illustrated.

2.4. *Covering prosthetic restoration*

Subsequently after fitting of CPC or PFRP, a preparation for the covering prosthetic restoration (crown, bridge and primary crown retained RPDs) was conducted according to established preparation rules [7]. Only teeth in which a circumferential ferrule with a preparation margin 1.5–2 mm apical of the PC/tooth interface was possible were included in this study [2]. PC under cantilever bridges as well as single tooth retained primary crown retained RPDs were excluded from further investigation. The primary crowns were parallel milled from non-precious or high-gold-content alloy and all patients participated in a regular aftercare program which is known to be the predominant factor for survival of these restorations [27]. Therefore, all patients included in this study were contacted for an appointment by phone call or letter at least once a year. In order to avoid human mistakes, the software automatically gives a memory to the user if the last recall was more than one year ago.

Table 3 illustrates the distribution of covering prosthetic restorations on the type of tooth.

2.5. *Statistical analysis*

The survival probability was assed using Kaplan-Meier and cox regression analysis. For pairwise comparison the log rank test was conducted and the significance was determined at $p < 0.05$.

By means of the log rank test and cox regression analysis the following parameters were investigated for possible influences on the survival of the tooth treated with PC:

- Location (upper/lower jaw).
- Type of tooth (anterior/premolar/molar).
- Bone attachment (physiological:> 75 %/pathological:< 75 %).
- Covering prosthetic restoration (crown/bridge/ primary crown retained RPDs).
- Luting material (conventional cement/adhesive cement).
- PC material (high-gold-content alloy/non-precious alloy/fibre reinforced).
- Therapist (dentist/student).

The influence of parameters was evaluated by forward stepwise logistic regression method based on the likelihood ratio. This method only included covariates in the analysis that had significant influences (x^2: $p < 0.05$) on the failure probability.

3. Results

The mean observation period of teeth treated with PC in the present study was 4.73 years (standard deviation= 4.34 years (SD)). The first tooth extraction was twelve days after fitting of PC and the longest recorded survival time was 18.41 years. The shortest observation time without the need for an extraction was eight days, whereas the longest was 18.01 years. Fig. 1 gives an overview of the observation periods distributed to the number of cases.

Table 2
Type of tooth and location of PC (number/percentage).

Type of tooth	Upper jaw	Lower jaw	Total
Anterior	343 / 32.6 %	140 / 13.3 %	483 / 45.9 %
Premolar	171 / 16.2 %	211 / 20.0 %	382 / 36.3 %
Molar	78 / 7.4 %	110 / 10.5 %	188 / 17. 9%
	592 / 56.2 %	461 / 43.8 %	1053 / 100 %

Table 3
Type of covering prosthetic restoration distributed to the type of tooth.

Type of tooth	Crown	Bridge	RPDs	Total
Anterior	163 / 15.5 %	52 / 4.9 %	268 / 25.5 %	483 / 45.9 %
Premolar	209 / 19.8 %	68 / 6.5 %	105 / 10.0 %	382 / 36.3 %
Molar	125 / 11.9 %	57 / 5.4 %	6 / 0.6 %	188 / 17.9 %
	497 / 47.2 %	177 / 16.8 %	379 / 36.0 %	1053 / 100 %

The overall average survival time of all 1053 teeth treated with PC was 11.74 years (SD = 0.31) with a 95 % confidence interval 11.12 – 12.35 (CI). The cumulated survival rate of all teeth treated with PC after 10 years was 58.98 % which is illustrated in Kaplan-Meier survival-curve in Fig. 2.

In total 245 out of 1053 teeth included in the present study had been extracted during the observation period (23.3 %). In the majority of 134 cases (54.7 %) the tooth extraction was necessary within the first five years after PC cementation, whereas in the observation period of five to ten years 78 teeth (31.8%) and after ten years only 33 teeth (13.5 %) had been extracted. Fig. 3 shows the decrease in the number of cases over the survival time intervals. In Table 4 the reasons for extraction are illustrated. These were documented in the patients file of MZD.

In Fig. 3 the reasons for extraction distributed to the survival time intervals 0–5, 5–10 and >10 years are illustrated. Most tooth fractures and periapical inflammation occurred within the first five years after PC insertion. The main reason for extraction between five and ten years of survival time was the periodontal bone loss. After more than ten years mainly secondary caries occurred, whereas the other reasons for extraction have rarely been recorded.

In Fig. 4 the reasons for extraction distributed to the covering prosthetic restoration are illustrated. The majority of teeth had been extracted in connection with primary crown retained RPDs (in total 150 cases / 61.2 %) and mainly due to a fracture of the tooth (60 cases / 24.5 %). For teeth as abutments for crowns (in total 66 cases / 26.9 %) and bridges (in total 29 cases / 11.8 %) less extractions were recorded.

The analysis of parameters possibly influencing the survival of the teeth treated with PC showed highly significant influences for the bone attachment ($p < 0.001$) as well as the covering prosthetic restoration ($p < 0.001$) and slightly significant influence of the PC material ($p = 0.045$). Figs. 5–7 illustrate the Kaplan-Meier survival curves of these parameters with the corresponding p-values calculated in the log-rank test. All other investigated parameters showed no significant influence ($p > 0.05$) on the survival until extraction of the teeth treaded with PC. Table 5 gives an overview over the mean survival times and the 10-year survival rates with the corresponding standard deviations and 95 % Confidence intervals of teeth treated with PC distributed to the investigated parameters and subgroups.

There was also no significant difference in the survival probability between multiple and single PC treatment in one patient ($p = 0.872$). Therefore, independence of the investigated cases was assumed even if 28.2 % of the patients received more than one PC.

The multifactorial cox regression analysis was used to investigate differences taking all investigated parameters into account. In line with the results of the pairwise comparison (log rank test) the bone attachment and the covering prosthetic restoration showed a significant influence in the multifactorial analysis as well. Table 6 illustrates the results of the Cox regression analysis meaning that the missing subgroup in the table was chosen as reference variable.

The results showed that the risk for tooth extraction increased by the age of the patient at the time of fitting PC by 2.9 % per year. Regarding the bone attachment pathological conditions (< 75 %) led to an increasing risk for extraction by 133% compared to physiological conditions (> 75%). Teeth restored with PC under primary crown retained RPDs had a 63 % higher risk for extraction compared to teeth under crowns while subgroups “bridges” and “crowns” did not differ significantly. All other investigated parameters did not have a significant

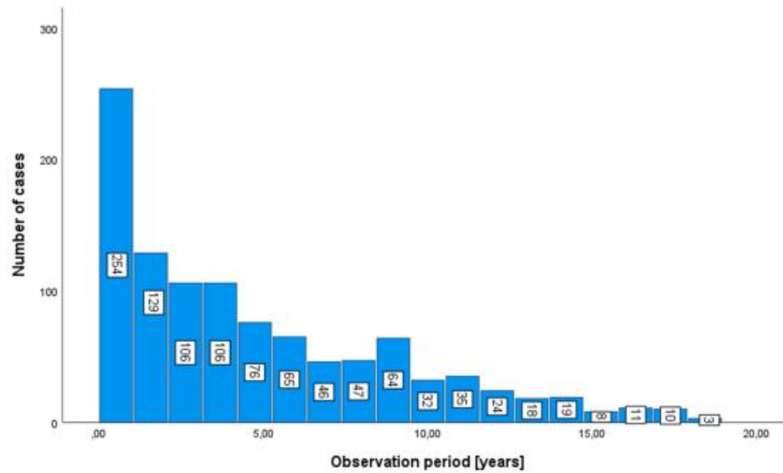


Fig. 1. Distribution of observation periods to the number of cases (one bar stands for one year of observation).

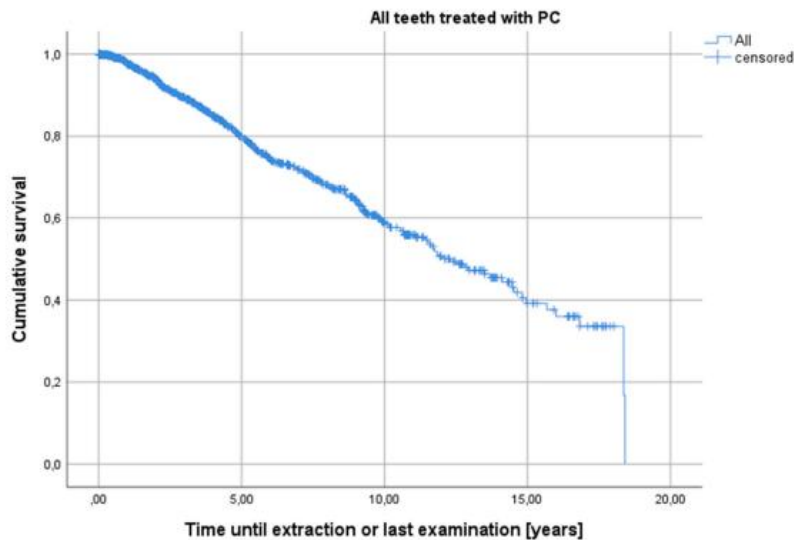


Fig. 2. Kaplan-Meier survival-curve for teeth treated with PC ($N = 1053$).

influence on the risk for extraction in the cox regression analysis ($p > 0.05$).

4. Discussion

4.1. Method

Retrospective study designs are frequently described in scientific dental literature when it comes to long term survival analysis with large sample sizes [7,10,21,28]. One reason for this might be that even if a randomised controlled prospective survival analysis can be standardised to a higher degree than a retrospective study, it is hardly practicable for a sample size of over 1000 cases and an observation period up to 18 years. Moreover, with a randomisation the patients would have been mandatorily assigned into groups of different PC options. Though, this would not have been in line with the patient's interest because these options were predefined by the size of the defect and the covering prosthetic restoration.

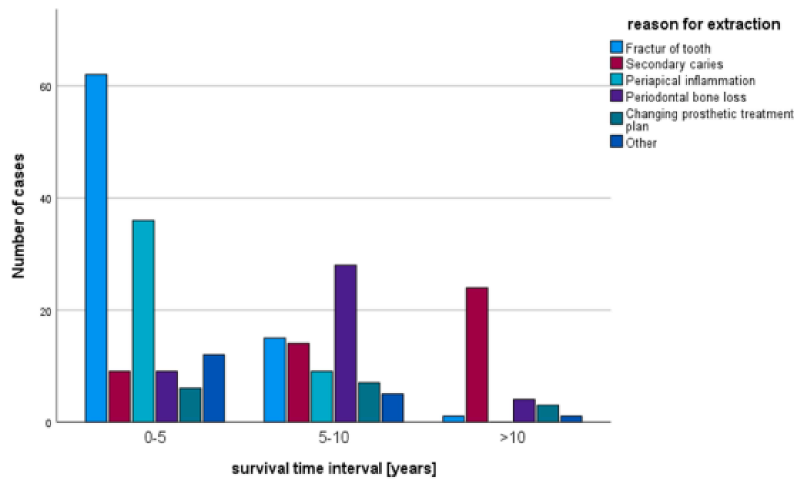


Fig. 3. Bar diagram of reasons for extraction distributed to the survival time intervals.

Table 4
Reasons for extraction of teeth treaded with PC with number of cases and percentage.

Reason for extraction	Cases	Percentage (*- in all included teeth)*
Fracture of tooth	79	32.2 % *(7.5 %)*
Secondary caries	46	18.8 % *(4.4 %)*
Periapical inflammation	45	18.4 % *(4.3 %)*
Periodontal bone loss	41	16.7 % *(3.9 %)*
Changing prosthetic treatment plan	16	6.5 % *(1.5 %)*
Other	18	7.4% *(1.7%)*
Total	245	100% *(23.3%)*

The data of the present study has been acquired retrospectively by using a consistent standardised protocol since 2004. All patient files were recorded digitally which enables a computer-assisted data search avoiding human mistakes and simplifies data acquisition. Therefore, it can be assumed that the data is as representative and conclusive as that of a prospective investigation but a possible limitation concerning the retrospective study design has to be mentioned anyways.

Many authors described that there is a problem of comparability between the results of different survival analysis when the procedure of data acquisition differed [6,24,25]. Since the data acquisition of this retrospective study was standardised to the highest possible degree it can be assumed that the results are comparable and representative. Nevertheless, the inevitable limitations of comparability to other studies

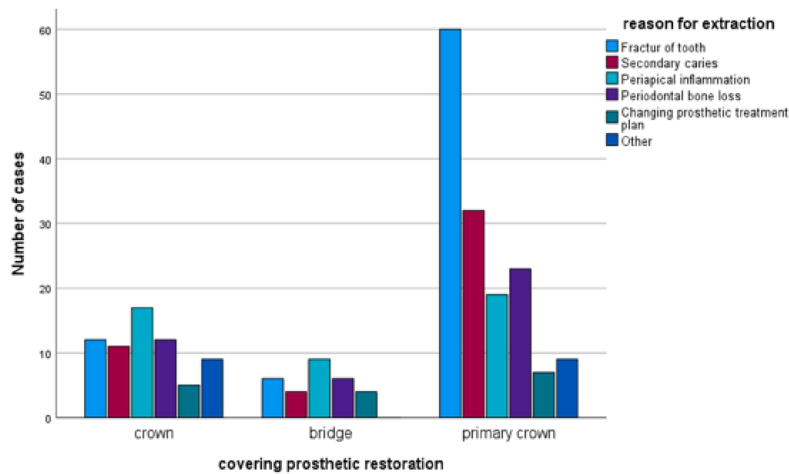
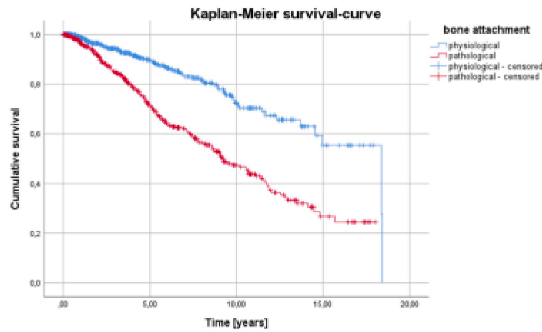
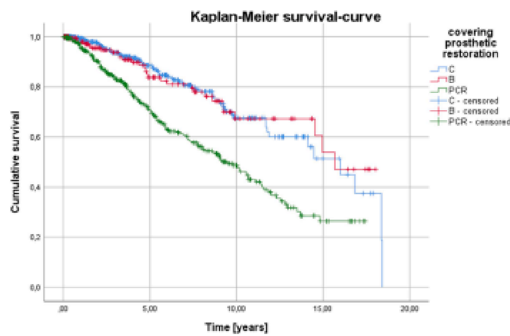


Fig. 4. Bar diagram of reasons for extraction distributed to the covering prosthetic restoration.



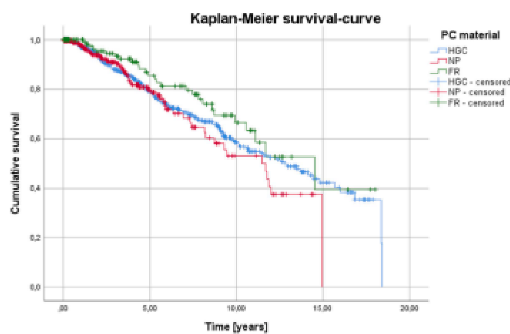
Log rank test (p-values)
physiological / pathological
<0.001

Fig. 5. Kaplan-Meier survival-curve with the corresponding p-values distributed to the bone attachment. (Physiological (blue); Pathological (red)).



Log rank test (p-values)		
C / B	B / PC	C / PC
0.950	**<0.001**	**<0.001**

Fig. 6. Kaplan-Meier survival-curve with the corresponding p-values distributed to the covering prosthetic restoration. (C: Crowns (blue); B: Bridges (red); PCR: Primary Crown retained RPDs (green)).



Log rank test (p-values)		
HGC / NP	NP / FR	HGC / FR
0.768	**0.045**	0.152

Fig. 7. Kaplan-Meier survival-curve with the corresponding p-values distributed to the PC material. (HGC: High-gold-content alloy (blue), NP: Non-precious alloy (red), FR: Fiber reinforced (green)).

with different frameworks (e.g. different PC-materials or different covering prosthetic restorations) has to be kept in mind when it comes to interpretation of the results. In particular, there is weak clinical survival data regarding the tooth itself which was treated with PC since many authors did not distinguished between different causes of failure and focused on the PC survival [1,6,24]. Many authors described the loss of retention of PC as the most common cause of failure which in many cases is relative because PC can be refitted without any additional effort or a new PC can be fitted preventing from tooth loss [7,11,13]. Therefore, clinicians should carefully distinguish between survival of teeth treated

Table 5
Mean survival time, 10-year survival rate, standard deviation and 95% confidence interval distributed to the investigated parameters.

Parameters	Subgroup	Mean survival time (years)/10-year survival rate (%)	S.D.	95% confidence interval	
				Lower	Upper
Location	Upper jaw	12.08 / 60.23	0.42	11.25	12.90
	Lower jaw	11.14 / 57.49	0.45	10.26	12.01
Type of tooth	Anteriors	11.08 / 55.09	0.43	10.24	11.93
	Premolars	12.15 / 61.72	0.50	11.12	13.12
	Molars	12.41 / 66.61	0.80	10.84	13.99
Bone attachment	Physiological	14.07 / 72.56	0.47	13.15	14.98
	Pathological	9.91 / 47.40	0.39	9.15	10.67
Covering	Crowns	13.26 / 67.59	0.52	12.23	14.29
prosthetic	Bridges	13.40 / 61.25	0.70	12.04	14.76
restoration	Primary crown retained RPDs	9.67 / 48.65	0.40	8.88	10.45
Luting	Material Conventional Cement	11.76 / 57.93	0.85	10.97	14.28
	Adhesive cement	11.51 / 58.55	0.55	10.44	12.60
PC material	High-gold-content alloy	11.80 / 58.66	0.38	11.06	12.55
	Non-precious alloy	9.97 / 53.05	0.52	8.94	10.99
	Fibre reinforced	12.51 / 66.52	0.84	10.87	14.16
Therapist	Student	11.44 / 66.55	0.36	10.73	12.15
	Dentist	12.41 / 56.13	0.61	11.21	13.60
All teeth restored with PC		11.74 / 58.98	0.31	11.12	12.35

Table 6
Result of the Cox regression analysis.

Parameters	B	p-value.	Exp (B)	95%Confidence interval of Exp (B)	
				Lower	Upper
Female	−0.106	0.427	0.900	0.693	1.168
Age at time of fitting PC	0.028	<0.001 [a]	1.029	1.016	1.042
Lower jaw	−0.002	0.988	0.998	0.758	1.313
Premolars	−0.010	0.947	0.990	0.729	1.344
Molars	0.324	0.209	1.383	0.834	2.293
Bone attachment (<75%)	0.846	<0.001 [a]	2.330	1.743	3.116
Bridges	−0.224	0.341	0.800	0.505	1.267
Primary crown retained RPDs	0.487	<0.001 [a]	1.628	1.163	2.279
Adhesive cement	0.081	0.652	1.084	0.764	1.539
Non-precious alloy	0.120	0.461	1.127	0.819	1.552
Fibre reinforced	0.661	0.517	1.937	0.262	1.392
Dentist	−0.262	0.093	0.770	0.567	1.045

B=coefficient; Exp(B)=hazard. Reference for the hazard is the respective missing subgroup.
[a] =Significant influence.

with PC and survival of PC.

A possible limitation of the study is that independence of the cases was assumed even if not every patient received only one PC. Despite, there was no significant difference in the survival probability of multiple and single PC treatment a bias of the data cannot be completely excluded and has to be kept in mind while interpreting the data.

4.2. Results

The cumulative mean survival time of teeth treated with PC until extraction in the present study was 11.47 years with a 10-year survival rate of 58.98 %. *Kramer* et al. described a failure rate for 'survival' of 4.4 % per year which is comparable to the results of the present study. Nevertheless, 'survival' does only exclude PC decementations and is not equal to extraction of the tooth since also renewal of PC is included in this rate. Moreover, the observation period in the study of *Kramer* et al. was only up to 6.5 years and the sample size was far less ($n = 195$) [12]. Two systematic reviews dealing with survival of PC described that there is a need for studies with longer follow-ups and higher sample sizes in order to improve the evidence about long-term survival [22,25]. Nevertheless, clinical studies with observation periods of more than 10 years are still scarce and only focus on PC and not on tooth survival. To the best knowledge of the authors only five investigations evaluated the survival of PC in comparably long periods as in the present study but with far less cases [7,9,26,28,29]. Moreover, three studies included only PC under single crowns [9,26,28]. and one study no covering prosthetic restoration [29] which could be a reason for the higher 10-year survival rates compared to the present study. *Balkenhol* et al. did consider bridges and primary crown retained RPDs as well but they did not distinguish between causes of failure leading to tooth conservation or extraction. However, the survival rate published by *Balkenhol* et al. is comparable to the results of the present study [7].

The most common reason for extraction of a tooth treated with PC in the present study was the root fracture most frequent under primary crown retained RPDs in the first five years of the observation period. A possible explanation for this may be the resulting extra-axial forces when the RPDs is removed and inserted incorrectly or when the long denture saddle does not fit the edentulous jaw areas [7]. That is why patients with RPDs need to follow a strict aftercare program because an undetected mismatch of the denture saddle can lead to bending forces of PC in the root canal and consequently to tooth fracture [27]. Assuming that many patients do not consequently comply to this strict aftercare this could be the reason for the increased fracture rate in the first five years of the observation period. A possible limitation of the present study is that a regular or irregular recall interval could not be analysed by the data since for Kaplan-Meier analysis only two dates (date of fitting PC / date of last aftercare or extraction) can be considered. Other reasons for extraction such as periodontal bone loss or secondary caries are biological causes of failure and follow a chronical progress leading to a later tooth loss [30,31]. A possible explanation for the frequent periapical inflammations in the first five years of the observation period may be that the endodontic treatment before post space preparation did not sufficiently disinfected the whole root canal system. This can lead to a contemporary exacerbation of the periapical inflammation after PC cementation and consequently to the necessity of tooth extraction.

In the present study teeth restored with PC had a significantly higher risk for extraction when it was used as an abutment for primary crown retained RPDs. This result is in line with other investigations published is scientific dental literature. However, these studies focused on the survival of PC meaning that the extraction of the abutment tooth was one out of many included causes of failure [7,16,32]. *Wöstmann* et al. investigated the survival probability of primary crown retained RPDs and its abutment teeth in a long term retrospective survival analysis and included vital, endodontically treated and PC treated abutment teeth [27]. The authors found significantly higher survival rates for the

abutment teeth than reported in the present study. This indicates that PC treated teeth should be avoided as abutments for primary crown retained RPDs because of the extremely low survival probability [16]

Moreover, in the present study the bone attachment and the PC material had a significant influence on the survival of PC treated teeth. Even if clinical data for the influence of bone attachment is scarce *Martino* et al. confirmed to the findings of the present study [21]. Linked to this, the higher risk for tooth extraction with increasing age of the patient can be explained as well since the loss of bone attachment increases in elder patients [33]. Therefore, one can conclude that clinicians should carefully check the periodontal health of patients before treating with PC but nevertheless more studies are needed to confirm these results. A possible explanation for the better survival probability of teeth treated with PFRP than with CPC made of non-precious alloy may be the matching elastic modulus of PFRP to dentine [24]. An advantage of these materials over alloy because of decreasing stress on the root is controversially discussed by many authors but was mostly investigated for single crowns as covering prosthetic restoration [24,34]. The authors assume that the advantage of matching elastic modulus between PC material and dentine increasingly takes effect with primary crown retained RPDs because of the extra-axial forces on the root dentine [7]. In the present study most abutment teeth for primary crown retained RPDs were restored with CPC in anterior teeth which means that tensile forces increase when chewing force loads on the posterior denture saddle. In those cases, a matching elastic modulus between PC material and dentine might reduce the incidence of root fracture. The results showed no significant difference between CPC made of high-gold-content alloy and PFRP. One reason for this can be that the high-gold-content alloy is known to have better mechanical properties for use as PC material than non-precious alloy, but it is much more expensive [35]. Nevertheless, it has to be pointed out that PFRP have only been used if the size of the defect was small. Teeth with severe coronal defects have been restored with CPC, which might be a limitation of the present study because the post options have not been randomized independently. The Interpretation of the results has to be seen against this background since *Neumann* et al. reported that the size of the coronal defect is a predominant factor for survival [2].

5. Conclusion

Against the background of the large sample size of over 1000 cases and the long observation periods of up to 18 years, the results contribute to improve the knowledge about survival of teeth treated with PC. Within the limitations of this study the risk for extraction of teeth treated with PC is significantly influenced by the type of covering prosthetic restoration, bone attachment, age of the patient and PC material, which should be considered for planning of PC treatment. The most common reason for extraction was the tooth fracture most frequent in primary crown retained RPDs during the first five years after fitting PC. This indicates that PC restored teeth should be avoided as abutments for those dentures. If it is inevitable to renounce these teeth, a strict aftercare is mandatory.

CRediT authorship contribution statement

Jonas Adrian Helmut Vogler: Writing – review & editing, Visualization, Validation. **Anna-Lena Stummer:** Data curation, Investigation. **Kay-Arne Walther:** Resources, Methodology. **Bernd Wöstmann:** Supervision. **Peter Rehmann:** Conceptualization, Methodology, Project administration.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

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7.2.5 Untersuchung der optimalen Stiftaufbereitungstiefe im Hinblick auf den Langzeiterfolg des Stiftaufbaus.

S.M. Reich, K.A. Walther, B. Wöstmann, P. Rehmann, **J.A.H. Vogler***, How long must a post be? A retrospective survival analysis on a large cohort with long follow-ups, *Journal of Dentistry* (2024) 104879. (IF 2024: 4,4) doi: 10.1016/j.jdent.2024.104879

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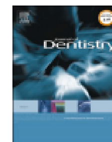

How long must a post be? A retrospective survival analysis on a large cohort with long follow-ups

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ABSTRACT

Objectives: Post and core (PC) is frequently used, but clinical evidence concerning how long a post must be is scarce. Recommendations in dental literature range from half of the root which should be incorporated, to post space preparations conducted as deep as possible increasing the risk for root perforation thus tooth loss. Therefore, the aim of this retrospective survival analysis is to evaluate the post length as well as the post-clinical crown ratio on a large patient cohort with long follow-ups.

Materials and methods: Overall 1026 PC in 731 patients could be included in this study (2004–2023). The files were analysed due to the parameters post length and post-clinical crown ratio on X-Ray. Furthermore, the influence of the type of covering prosthetic restoration, location, type of tooth, luting material, PC material, bone attachment and therapist was evaluated. The statistical analysis was assessed using Kaplan-Meier (univariate influences) and Cox regression (multifactorial influences).

Results: Survival until extraction as well as decementation was significantly influenced by bone attachment and covering prosthetic restoration. Posts reaching the middle third of the root showed highly significant ($p < 0.001$) better survival probabilities than those reaching the coronal or apical third. Regarding the post-clinical crown ratio, no significant difference was found for post = crown/post > crown, whereas post<crown showed highly significant lower survival probabilities ($p < 0.001$).

Conclusions: The post space preparation should not be extended over the middle third of the root, but has to be deep enough to ensure that the post is at least as long as the clinical crown.

Clinical significance: Against the background of the large sample size and the long follow-ups, the results of this retrospective survival analysis are suitable to give general recommendations regarding how long a post has to be in order to ensure the best survival probability for PC treatment.

1. Introduction

The development of the adhesive technique in dentistry made post and core (PC) dispensable for many clinical situation, but it can still be necessary for teeth with severe coronal defects when an endodontical treatment was needed [1,2]. Recent scientific dental literature proclaims that other than assumed by former studies [3], fitting of PC does not reinforce the tooth but increases the risk for root fracture because of the necessity of removing hard tissue during post space preparation [4,5]. Therefore, *Naumann* et al. proposed in a systematic review that PC should only be fitted in cases with insufficient adhesive surface for core reconstruction by filling, since they found no positive effect of post placement on survival [2]. Furthermore, they described that the most important aspect for survival of PC is the presence of a ferrule in which the covering restoration overlaps the margin of PC by at least 2 mm [2].

Even if PC is still a frequently used treatment option, there is still a lack of evidence in recent scientific literature how deep the post space preparation should be conducted. *Baraban* described in a treatment guide report from the 1970s that half of the root should be incorporated but care must be taken to prevent from root perforation [6]. *Perel and Muroff* claimed in their general companion for dentists which is also from the 1970s that the post must be long enough to prevent excessive internal stress on the root. Therefore, at least half of the root that is attached by bone should be included in the post space preparation [7].

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In particular, this rule is hard to follow in teeth with periodontal bone loss, since a remaining apical endodontic filling is obligate in order to prevent from reinfection [8–10]. That is why other authors described in more recent studies a preparation rule for post and core in which the post space preparation has to be conducted as long as possible leaving a minimum of 4 mm of apical seal [11–14]. However, in many cases the preparation depth is limited due to a curved root canal or root retractions [15]. Therefore, in former decades screw retained posts were common for treatment of severely destroyed teeth because of the high retention with short post space preparations [6,7,16]. Nevertheless, threaded posts lead to microcracks in dentin and are therefore no longer recommended in recently published studies [17]. Another recommendation for general post length which is frequently described in scientific dental literature is that the post must be at least as long as the clinical crown [18,19] However, this preparation rule is not applicable for every post material since *Zicari* et al. reported that shorting of post space preparation for fibre reinforced posts can improve the fracture modes compared to rigid materials and therefore can improve the therapy by lowering the perforation risk [20]. Santos-Filho et al. and Kaya et al. agreed to this and described in their in-vitro studies that post length did not influence the survival except for rigid posts in which shorter post space preparations led to a higher risk for root fracture [21,22].

To the best knowledge of the authors there is no recent clinical investigation including modern PC materials and treatment options which evaluates the required depth of post space preparation on the basis of a large cohort with long follow-ups. Therefore, this retrospective study of more than 1000 PC over an observation period up to 19 years aims to enlarge the knowledge about this frequently used but inconsistently described treatment option by evaluating the post length as well as the post-clinical crown ratio. In order to include all causes of failure also decementation of refitable PC was investigated but additionally these cases were analysed until possible extraction of the tooth.

2. Materials & methods

2.1. Data acquisition

The study was approved by the ethics committee of the Justus-Liebig University Giessen, Germany (Reg No. 164/11). The Data acquisition was conducted using a specialised treatment documentation software (Multizentrische Dokumentation, MZD) that was used in our clinic since 2004. Within the oberservation period of 2004 until 2023, all Patient files were digitally and automatically searched for treatment plans with PC. Primarily, 987 patients received a treatment plan for PC. These files were manually analysed for actual procession of the treatment plan, lack of data (especially no X-Ray or not fully imaged PC or covering prosthetic restoration on X-Ray), unstandardised workflows or treatments. Furthermore, patients suffering from illnesses possibly influencing the environmental factors of the oral cavity were excluded from this study.

Finally, 731 patients with overall 1026 PC fulfilled the inclusion criteria. Subsequently, the data acquisition was performed according to the following criteria, along with age and gender of the patient:

- Observation period (date of cementation / date of first decementation, extraction or final examination)
- In case of extraction: Reason for extraction
- Location of PC treated tooth (upper / lower jaw)
- Type of tooth (anterior / premolar / molar)
- Bone attachment (physiological: >75 % / pathological: <75 %)
- Type of covering prosthetic restoration (crown / bridge / RPD)
- Luting material used (conventional cement / adhesive cement)
- PC material (high-gold-content alloy / non-precious alloy / fibre reinforced)
- Therapist (dentist / student)
- Post-clinical crown ratio on X-Ray (post > crown / post = crown / post < crown)
- Post length on X-Ray (reaching coronal / middle / apical third of the root)

The data acquisition for post-clinical crown ratio and post length on the X-Ray was performed by using the measurement tool of an image software (VixWin Pro-VDDS, solution GmbH & Co. KG, Holzgerlingen, Germany) illustrated in Fig. 1.

All patients ($n = 731$) were distributed to 392 (53.6 %) male and 339 (46.4 %) female. The average age of the patients at the time of PC cementation was 59.0 years with a range from 17 to 93 years. PC treatment was conducted by students in the Department of Prosthetic Dentistry under strict supervision of experienced dentists or by the dentists themselves following a standardised procedure [23].

2.2. Treatment

The inclusion criteria regarding the tooth were determined as absence of pain and clinical or radiological signs of inflammation. Moreover, the prosthetic viability of the tooth, degree of tooth movement, percussion and measurement of pocket depth was evaluated before including in this study [23–25]. The type of post system (cast PC (CPC) or fibre reinforced post and a composite core build-up (PFRP)) was chosen according to the size of the coronal defect and the remaining cavity walls [26,27].. PFRP had been fitted if there were ≥3 walls left providing sufficient adhesive surface for the composite core build-up ($N = 155/15.10$ %). In cases with ≤2 remaining cavity walls CPC had been fitted using non-precious ($N = 567/55.27$ %) or high-gold-content ($N = 304/29.63$ %) alloy matching to the covering prosthetic restoration. The depth of post space preparation was strived to the apical third of the root leaving a residual endodontic filling of at least 4 mm for apical seal. In teeth with a curved root canal or root retractions the post space preparation was conducted as deep as possible in order to prevent from perforation. Table 1 shows the distribution of the cases regarding post length on X-Ray reaching the coronal, middle and apical third of the root as well as the post-clinical crown ratio by means of post > crown, post = crown and post < crown.

The impression and the fabrication of CPC was performed according to a standardised procedure described in detail in a previously published study [23].

CPC were permanently fitted in a second appointment after try-in. Depending on the friction of CPC against pull out an adhesive or conventional cement was used, meaning that in the case of high friction a conventional cement ($N = 686/66.9$ %) was used while all other CPC and PFRP were fitted with a resin composites in combination with bonding agents ($N = 340/33.1$ %). Table 2 shows the distribution of PC regarding the type of tooth and the location (upper/lower jaw).

2.3. Covering prosthetic restoration

In every case included in this study the tooth that was treated with PC was prepared for a covering prosthetic restoration (crown, bridge or RPD) according to established preparation rules considering a ferrule of at least 1.5–2 mm [2,23]. Abutment teeth for cantilever bridges as well as single tooth retained RPDs were excluded from this study. All RPDs had parallel milled primary crowns made of non-precious or high-gold-content alloy and all patients participated in a strict aftercare program which is known to be a predominant factor for survival [28]. Therefore, all patients included in this study were asked for an appointment at least once a year. Table 3 illustrates the distribution of covering prosthetic restorations on the type of tooth.

2.4. Statistical analysis

Kaplan-Meier and cox regression analysis were used to assess the survival probability. In order to investigate significant differences between the groups, the log rank test was conducted and the significance

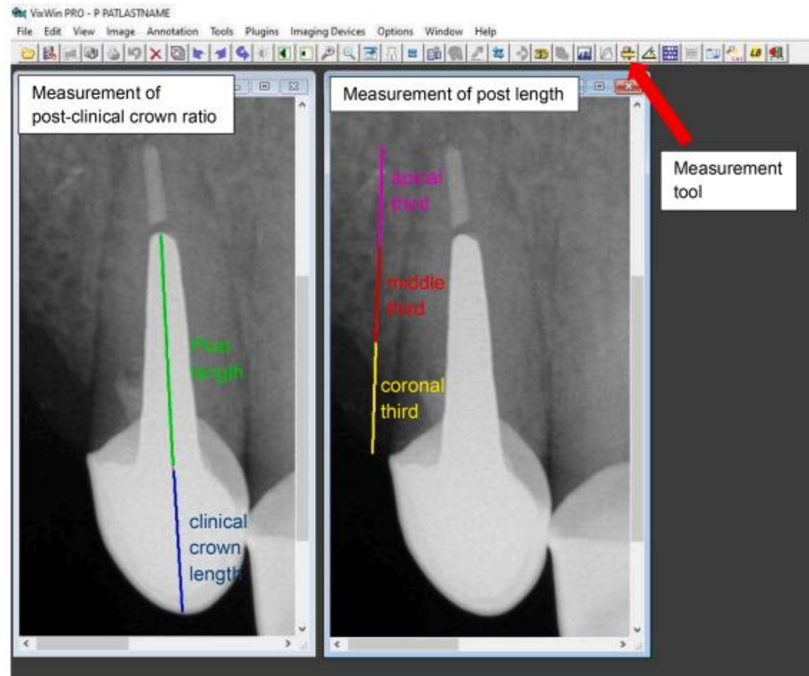

Fig. 1. Measurement of post-clinical crown ratio and post length on X-Ray using the measurement tool of an image software.

Table 1
Destribution of post length and post-clinical crown ratio.

post length on X-Ray	number of PC	percentage
Coronal third	86	8.4 %
Middle third	610	59.5 %
Apical third	330	32.1 %
post-clinical crown ratio	**number of PC**	**percentage**
post>crown	535	52.1 %
post=crown	388	37.8 %
post<crown	103	10.1 %

Table 2
Type of tooth and location of PC (number/percentage).

Type of tooth	Upper jaw	Lower jaw	Total
Anterior	340 / 33.1 %	129 / 12.6 %	469 / 45.7 %
Premolar	168 / 16.4 %	207 / 20.1 %	375 / 36.5 %
Molar	74 / 7.2 %	108 / 10.6 %	182 / 17.8 %
	576 / 56.1 %	450 / 43.9 %	1026 / 100 %

Table 3
Type of covering prosthetic restoration distributed to the type of tooth.

Type of tooth	Crown	Bridge	RPD	Total
Anterior	159 / 15.1 %	51 / 5.0 %	264 / 25.7 %	469 / 45.7 %
Premolar	206 / 20.1 %	65 / 6.3 %	101 / 9.8 %	375 / 36.5 %
Molar	117 / 11.8 %	57 / 5.6 %	6 / 0.6 %	182 / 17.8 %
	482 / 47.0 %	173 / 16.9 %	371 / 36.1 %	1026 / 100 %

was determined at $p < 0.05$. This statistic procedure is particularly suitable for considering unequal group sizes with varying observation periods between the cases and is therefore frequently used in comparable survival analyses as well [23,27,29,30]. Along with cofactors (location, type of tooth, bone attachment, covering prosthetic restoration, luting material, PC material and therapist) the post length on X-Ray as well as the post-clinical crown ratio on X-Ray were investigated for possible influences on the survival. The evaluation was conducted by forward stepwise logistic regression method based on the likelihood ratio, meaning that only cofactors that had significant influences (x^2: $p < 0.05$) on the failure probability were included in the analysis. Multiple PC in one patient was statistically considered using "shared frailty" [31].

3. Results

The mean observation period in the present study was 4.65 years (standard deviation = 4.32 years (SD)) regarding survival until extraction and 3.64 years (SD = 3.83) regarding survival until decementation. Fig. 2 illustrates the distribution of observation periods to the number of cases reagrding both target events for survival analyses (extraction: green diagram, decementation: blue diagram).

Table 4 shows the minimum and maximum values for the observation period as well as the first and latest recorded extraction and decementation.

The overall average survival times until extraction were 13.89 years (SD = 0.36) (95 % confidence interval of 13.19 – 14.58 (CI)) and until decementation 12.52 years (SD = 0.32) (CI = 11.93 – 12.16), showing that the cumulative survival probability in both analyses are almost matching. Therefore, one can assume that the conclusions of one

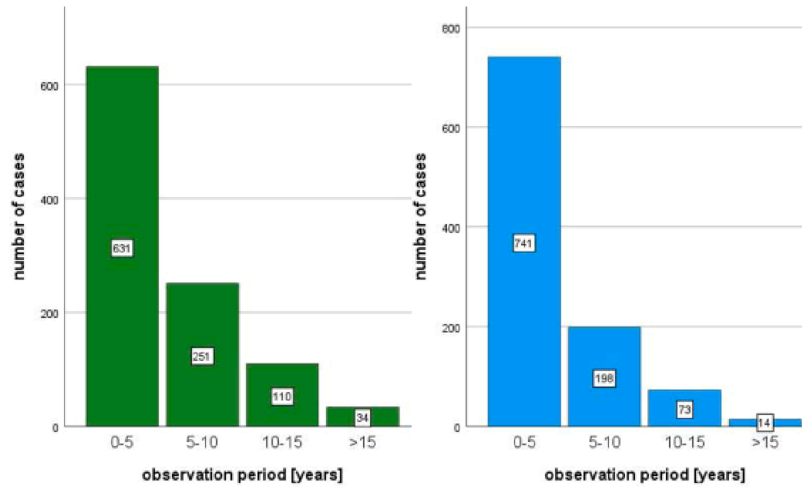

Fig. 2. Distribution of observation periods to the number of cases for survival until extraction (green diagram) and until decementation (blue diagram). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

Table 4
Range of observation period for survival until extraction and survival until decementation [years].

	Survival until extraction	Survival until decementation
Minimum observation period	0.03	0.01
Maximum observation period	19.02	17.70
First recorded target event	0.03	0.01
Latest recorded target event	18.41	14.09

analysis is transferable to the other and the results can be discussed together.

During the observation period 241 of the 1026 investigated teeth had been extracted (23.5 %). The most common reason for extraction was root fracture (n = 86 / 35.7 %) followed by caries (n = 67 / 27.8 %), periodontal bone loss (n = 62 / 25.7 %) and periapical inflammation (n = 26 / 10.8 %). In Table 5 the reasons for extraction with the mean time

Table 5
Reasons for extraction with the mean time of occurrence as well distribution of post length and post-clinical crown ratio.

	Root fracture (n = 86)	Periapical inflammation (n = 26)	Periodontal bone loss (n = 62)	Caries (n = 67)
Mean time of occurrence [years] (SD)	2.80 (0.27)	5.42 (0.73)	7.05 (0.49)	7.61 (0.48)
Post length:				
Coronal third	47	0	3	1
Middle third	6	5	20	26
Apical third	33	21	39	40
Post-clinical crown ratio:				
post>crown	1	14	34	38
post=crown	9	12	28	19
post<crown	76	0	0	10

of occurrence as well as the distribution of post length and post-clinical crown ratio are illustrated. It shows that root fracture occurs much earlier than periapical inflammation, periodontal bone loss and caries. Furthermore, root fracture was least recorded with posts reaching the middle third of the root (n = 6) while periapical inflammation was mainly associated with deep post space preparations reaching the apical third of the root (n = 21). Regarding the post-clinical crown ratio, root fracture was mostly recorded with shorter posts than the clinical crown (n = 76).

Decementation of PC was recorded in 119 cases during the observation period (11.6 %). Table 6 shows the distribution of decementation on the post length and post-clinical crown ratio. It shows that the highest percentage of decementation was recorded with post space preparations reaching the coronal third of the root as well as when the clinical crown is longer than the post.

The pairwise comparisons of possibly influencing parameters for both, the survival until extraction as well as decementation, showed highly significant influences for the bone attachment, the covering prosthetic restoration, the post length as and the post-clinical crown ratio ($p < 0.001$). There was no significant influence ($p > 0.05$) of the other parameters investigated in this study. For reasons of clarity the significant influences in Table 7 were marked in bold and cursive letters. Best survival was recorded in cases in which the post was at least as long as the clinical crown and when the post space preparation reached the middle third of the root. Longer as well as shorter posts showed significantly lower survival probabilities. Figs. 3 and 4 illustrate the

Table 6
Distribution of decementation on post length and post-clinical crown ratio.

post length	number of decementation	percentage
Coronal third (n = 86)	20	23.3 %
Middle third (n = 610)	48	7.9 %
Apical third (n = 330)	51	15.5 %
post-clinical crown ratio	**number of decementation**	**percentage**
post>crown (n = 535)	43	8.0 %
post=crown (n = 388)	49	12.6 %
post<crown (n = 103)	27	26.2 %

Table 7
P-values of the pairwise comparisons (log- rank test) of survival analysis until extraction as well as decementation.

Parameters	Subgroups	P-values (a =Significant influence)	
		extraction	decementation
Location	Upper jaw Lower jaw	$p = 0.173$	$p = 0.240$
Type of tooth	Anteriors (A)	$p = 0.253$ (A/P)	$p = 0.348$ (A/P)
	Premolars (P)	$p = 0.442$ (P/M)	$p = 0.288$ (P/M)
	Molars (M)	$p = 0.332$ (M/A)	$p = 0.409$ (M/A)
Bone attachment	Physiological Pathological	***$p<0.001^{a}$***	***$p<0.001^{a}$***
Covering prosthetic restoration	Crowns (C)	$p = 0.440$ (C/B)	$p = 0.208$ (C/B)
	Bridges (B)	***$p<0.001^{a}$ (B/R)***	***$p<0.001^{a}$ (B/R)***
	RPD (R)	***$p<0.001^{a}$ (R/C)***	***$p<0.001^{a}$ (R/C)***
Luting material	Conventional cement Adhesive cement	$p = 0.549$	$p = 0.205$
PC material	High-gold-content (G)	$p = 0.428$ (G/N)	$p = 0.388$ (G/N)
	Non-precious alloy (N)	$p = 0.136$ (N/F)	$p = 0.209$ (N/F)
	Fibre reinforced (F)	$p = 0.103$ (F/G)	$p = 0.172$ (F/G)
Therapist	Dentist Student	$p = 0.216$	$p = 0.655$
Post-clinical crown ratio	post>crown (>)	$p = 0.070$ (>/=)	$p = 0.067$ (>/=)
	post=crown (=)	***$p<0.001^{a}$ (=/<)***	***$p<0.001^{a}$ (=/<)***
	post<crown (<)	***$p<0.001^{a}$ (</>)***	***$p<0.001^{a}$ (</>)***
Post length	coronal third (C)	***$p<0.001^{a}$ (C/M)***	***$p<0.001^{a}$ (C/M)***
	middle third (M)	***$p<0.001^{a}$ (M/A)***	***$p = 0.004^{a}$ (M/A)***
	apical third (A)	***$p<0.001^{a}$ (A/C)***	***$p<0.001^{a}$ (A/C)***

corresponding Kaplan-Meier curves of post-clinical crown ratio and post length for survival until extraction and decementation in which one can see the statistically expected failure rate at a certain time after fitting of PC [29].

To investigate influences taking all investigated parameters into account a multifactorial cox regression analysis was processed. Confirming the results of the log rank test the bone attachment, the covering prosthetic restoration, the post-clinical crown ratio and the post length had a significant influence in the multifactorial analysis, too. These results were also concordant over the survival until extraction and decementation. All other investigated parameters did not have a significant influence on the risk for extraction or decementation in the cox regression analysis ($p > 0.05$). Table 8 illustrate the results of the Cox regression analysis. The missing subgroup in the table was chosen as reference variable for the analysis. For reasons of clarity the significant influences were marked in bold and cursive letters.

4. Discussion

4.1. Method

In order to analyse a large patient cohort over long observation periods a retrospective study is suitable and frequently used by other authors as well [23,24,30,32]. Since the data acquisition in this study was conducted digitally and according to a standardised protocol for a period of up to 19 years (2004–2023), one can assume that the results are representative and conclusive. Furthermore, by using the computer-assisted data search tool of the software, human mistakes could be avoided and data errors were minimalized. Nevertheless, it has to be stated that a prospective randomised controlled clinical trial would have been also suitable to investigate how deep a post space preparation has to be conducted. However, a sample size of more than 1000 cases with a comparably long follow-up as in the present study would have been hardly possible in a prospective study. Since the data acquisition is standardised to the highest possible level, one can assume that the results are comparable to these of other studies even if the data acquisition differed [8,33,34]. Nevertheless, one has to mention that in the present study not all pairwise comparisons had equally distributed group sizes and matching observation periods. Even if the statistical analysis of the present study is able to consider this kind of data and is commonly used in comparable survival analyses as well, this can still be a possible limitation related to the retrospective study design [23,24,27,29,30]. In particular the unequal distribution of CPC and PFRP related to the size of the defect has to be kept in mind when interpreting the results of the present study, since the amount of residual tooth structure is known to be one of the predominant factors for survival of PC [2].

There is a lack of clinical data concerning the necessary depth of post space preparation because to the best knowledge of the authors the only

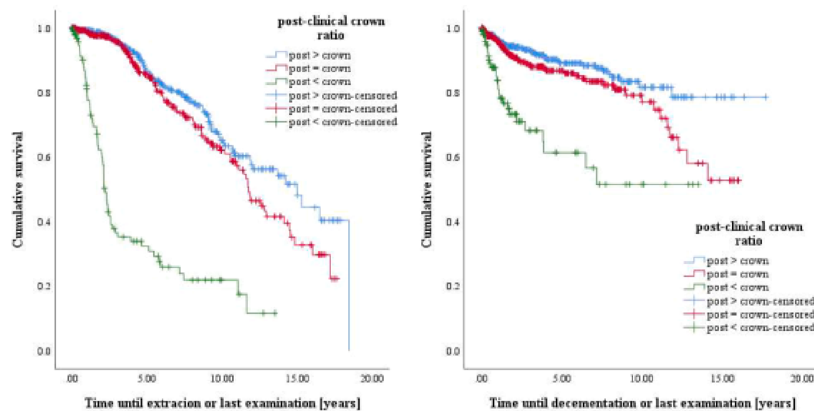

Fig. 3. Kaplan-Meier curves of post-clinical crown ratio for survival until extraction (left) and decementation (right). (post > crown (blue); post = crown (red) post < crown (green)). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

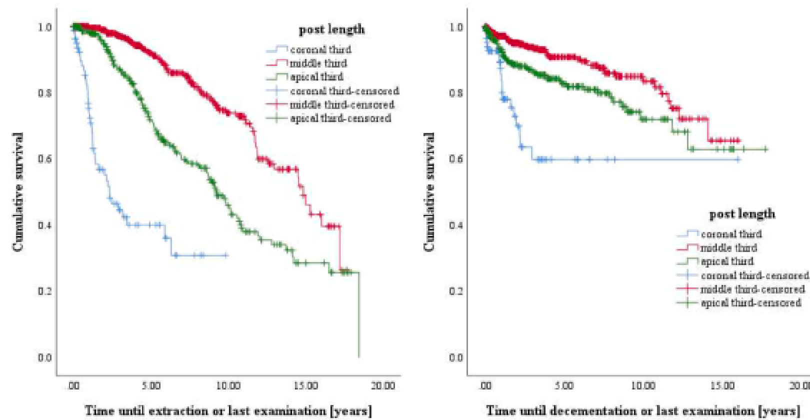

Fig. 4. Kaplan-Meier curves of post length for survival until extraction (left) and decementation (right). (coronal third (blue); middle third (red) apical third (green)). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

Table 8
Results of the Cox regression analysis for survival until extraction and decementation.

Parameters	B	p-value.	Exp (B)	95 %Confidence interval of Exp (B)	
				Lower	Upper
Survival until extraction:					
post=crown	0.635	0.104	1.886	1.346	2.644
post < crown	2.046	***<0.001***[a]	0.741	0.093	1.764
middle third	−1.718	***<0.001***[a]	0.179	0.115	0.280
apical third	−0.046	***0.031***[a]	0.626	0.400	0.982
Lower jaw	−0.157	0.310	0.855	0.632	1.157
Premolars	−0.119	0.485	0.888	0.636	1.239
Molars	0.043	0.873	1.044	0.620	1.756
Bone attachment (<75 %)	0.684	***<0.001***[a]	1.982	1.461	2.690
Bridges	0.086	0.485	1.090	0.685	1.735
RPD	0.297	**<0.001**[a]	1.346	0.933	1.941
Adhesive cement	0.241	0.184	1.273	0.891	1.817
Non-precious alloy	0.090	0.596	0.864	0.297	1.524
Fibre reinforced	1.611	0.270	2.008	1.078	3.266
Dentist	−0.183	0.251	0.833	0.609	1.138
Survival until decementation:					
post=crown	−0.589	0.097	1.407	0.829	2.387
post < crown	0.341	***0.007***[a]	0.555	0.343	0.898
middle third	0.862	***0.005***[a]	2.368	1.295	4.331
apical third	1.507	***0.027***[a]	1.661	1.060	2.601
Lower jaw	0.125	0.531	1.133	0.767	1.675
Premolars	0.435	0.163	1.546	0.977	2.445
Molars	−1.337	0.197	0.263	0.035	1.999
Bone attachment (<75 %)	0.146	***0.016***[a]	1.157	0.762	1.757
Bridges	1.083	0.259	0.952	0.654	1.332
RPD	2.359	***0.001***[a]	1.577	0.252	2.281
Adhesive cement	−0.162	0.535	0.850	0.510	1.419
Non-precious alloy	0.043	0.856	1.044	0.659	1.652
Fibre reinforced	1.768	0.113	2.595	0.738	3.516
Dentist	0.085	0.690	1.089	0.717	1.757

B=coefficient; Exp(B)=hazard. Reference for the hazard is the respective missing subgroup.
[a] =Significant influence.

clinical evaluation dealing with this topic is almost 40 years old [11]. The recommendations given by the authors are obviously no longer up to date because of the advancements associated with new PC materials and the adhesive technique in dentistry. Indeed, there are some recent in-vitro studies investigating the post length [13,14,18,20,22], but those results are not fully transferable to the clinical situation because of the ideal ambient conditions in a laboratory [35]. Therefore, a renewal of guidelines concerning the required depth of post space preparation is of high clinical relevance for daily dental practice.

4.2. Results

In the present study the survival until extraction and until first decementation was evaluated separately, since loss of retention has been described as the most common cause of failure in studies investigating the survival time of PC [23,24,26,36,37]. However, PC in some cases is refitable without any additional effort [38–41], thus decementation does not necessarily include extraction of the tooth. Therefore, *Kramer et al.* distinguished between 'success' and 'survival' of PC [40], but these terms are inconsistently defined in literature, since survival can mean extraction of the tooth or renewal of PC [23]. For Kaplan-Meier survival analysis only two dates (date of fitting PC / date of last recall appointment or target event) can be taken into the account. That is why we determined "decementation" as the first loss of retention of PC. Even if PC was refitted, the case was excluded from further investigation regarding decementation in order to prevent from bias by evaluating on PC repeatedly. In order to ensure clarity for the reader and since the results of the survival until extraction and decementation are comparable and almost matching, the discussion in the following refers to both survival analyses. In the present study the survival was significantly lower when PC was fitted in teeth with pathological bone attachment and teeth that were used as abutments for RPD. Indeed, clinical evidence for the influence of bone attachment on survival of PC is scarce, *Martino* et al. confirmed to the findings presented in this article [30]. Also the result of bad survival of PC in connection with RPD is in line with other investigations published in scientific dental literature [23,25,42]. One reason for this may be because of the extra axial forces resulting on the tooth when the RPD is removed and inserted incorrectly or when the denture saddle does not fit the edentulous jaw [23].

Regarding the post length and post-clinical crown ratio in the present study, a root fracture was least recorded with posts reaching the middle third of the root while periapical inflammation was mainly recorded in deep post space preparations (apical third). Furthermore, root fracture occurred mainly in shorter posts than the clinical crown (post < crown). One reason for this may be that in cases with a longer clinical crown than

the post the leverage effect increases the forces on the tooth favouring root fracture. This effect is even bigger in teeth used as abutments for RPD because of the extra axial forces. In cases with deep post space preparations the increase of periapical inflammations might be because of an insufficient apical seal after preparation [11–14]. Even if a residual endodontic filling of at least 4 mm is shown on the X-Ray, it cannot be excluded that a reinfection occurs through a side canal in the apical root causing a periapical inflammation. The result of the present study that root fracture occurs much earlier than periapical inflammation, periodontal bone loss and caries can be explained accordingly: Other than root fracture the other reasons for extraction follow a biological and chronical progression leading to a delayed failure [43,44].

Summarising these results one can recommend for PC treatment guidelines that the post space preparation should not be extended over the middle third of the root but has to be deep enough to ensure that the post is at least as long as the clinical crown. This recommendation is supported by the results of the pairwise comparisons because there was no significant difference between "post > crown" and "post = crown" but significant differences were detected between all other investigation groups for post length and post-clinical crown ratio. Concurrently, the highest survival rate was recorded for posts reaching the middle third of the root.

The results of the present study are comparable to the findings of *Baraban, Perel and Muroff* from the 1970s which is remarkable, because it emphasizes that their outdated recommendations are still valid to present PC treatment options with modern materials and adhesive techniques. Other authors recommended that post space preparation should be conducted as deep as possible, but they performed mechanical behaviour studies with extracted teeth under laboratory conditions [12–14]. These findings are not transferable to the clinical situation, because they did not include biological failures such as periapical inflammation.

5. Conclusion

This retrospective survival analysis investigated a large patient cohort with more than 1000 PC over a mean observation period of 4.65 years (SD = 4.32 years) and a maximum follow-up of 19 years. Therefore, the results are suitable to give general recommendations regarding how long a post has to be in order to ensure the best survival probability of PC treatment. Summarising the results, the post space preparation should not be extended over the middle third of the root, but has to be deep enough to ensure that the post is at least as long as the clinical crown. Moreover, clinicians should critically review PC treatment in teeth with pathological bone attachment and teeth which are used as abutments for RPD because of the bad survival probabilities.

Ethical approval

Processing data of patient files (Reg. No. 164/11).

Informed consent

For this type of study, formal consent is not required.

CRediT authorship contribution statement

Sarah Marie Reich: Data curation, Investigation. **Kay-Arne Walther:** Writing – review & editing, Visualization. **Bernd Wöstmann:** Resources, Methodology. **Peter Rehmann:** Project administration, Methodology, Conceptualization. **Jonas Adrian Helmut Vogler:** Writing – original draft, Validation, Supervision.

Declaration of competing interest

The authors declare that they have no conflict of interest.

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7.2.6 Einfluss glasfaserverstärkter CAD/CAM Komposit Stiftaufbauten auf die Dezementierungs- und Wurzelfrakturgefahr unter Kausimulation.

J.A.H. Vogler*, L. Billen, K.-A. Walther, B. Wöstmann, Fibre-reinforced Cad/CAM post and cores: The new "gold standard" for anterior teeth with extensive coronal destruction?–A fully digital chairside workflow, *Heliyon* (2023) e19048. (IF 2023: 4,0) doi: 10.1016/j.heliyon.2023.e19048

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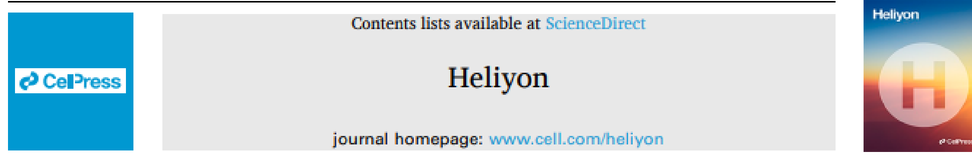

Fibre-reinforced Cad/CAM post and cores: The new "gold standard" for anterior teeth with extensive coronal destruction?–A fully digital chairside workflow

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ABSTRACT

Objectives: Since one-third of persons suffer a dental trauma, treatment of anterior teeth using post and core (PC) is becoming important. In teeth with extensive destruction, cast PC (CPC) remain the "gold standard", even though they lead to aesthetic impairment and have a mismatching elastic modulus to that of dentin. Prefabricated fibre-reinforced posts have elastic modulus similar to that of dentin but the accuracy of fit and mechanical stability are worse. This study was aimed to evaluate the deviation and mechanical performance of fibre-reinforced CAD/CAM PC (FRPC) fabricated in a fully digital chairside workflow, compared to those of CPC.
Methods: On 30 teeth, a PC preparation was conducted, and a conventional and digital post impression were taken with an intraoral scanner. Fifteen teeth each were treated with CPC and FRPC, respectively. The deviation was evaluated by superimposing the datasets of the digitalised stone models and digital post impressions. Decementation and root fracture during chewing simulation were analysed by microscopy and X-ray. Statistical analysis was performed by pairwise comparison and Kaplan-Meier analysis.
Results: The median deviation for the "coronal", "middle" and "apical" were 14.5, 18.0 and 113.7 μm, respectively. The pairwise comparison for "coronal"/"middle" showed no significance ($p = 0.465$), whereas that for "coronal"/"apical" and "middle"/"apical" showed highly significant differences ($p < 0.001$). After chewing simulation, five decementations and two root fractures were detected for CPC. For FRPC, neither decementation nor root fracture were documented.
Significance: Within the limitations of this study, FRPC performed significantly better than CPC.

1. Introduction

Even though the development of the adhesive technique in dentistry means that post and core (PC) is no longer necessary for all the teeth with loss of coronal tooth structure, it is still indispensable for cases with extensive defects [1,2]. Statistically, every third person suffers a dental trauma to the permanent dentition, which in many cases is related to severe damage to the tooth [3]. Thus, the restoration of the upper anterior teeth with PC is becoming important [4–6]. In addition to mechanical stability, aesthetics also play a decisive role with those cases; hence, many patients prefer the use of tooth-coloured and translucent materials in the anterior teeth [7–9]. Customised cast PC (CPC) has a high mechanical stability and is therefore indicated for extensive defects, because of their good

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accuracy of fit and monobloc structure that consists of a core and post components [10–13]. However, due to the lack of translucency, CPC can lead to darkening of the tooth and its surrounding gingiva [9]. Moreover, the failure rate of PC in the upper anterior teeth is significantly higher than that in posterior teeth because of the non-axial masticatory load [14,15]. Therefore, many authors prefer the use of materials with an elastic modulus similar to that of dentin [7,8], to prevent root fracture [16–19]. Other than CPC, prefabricated fibre-reinforced posts (PFRP) have a modulus of elasticity similar to that of root dentin and can positively influence the aesthetic appearance due to their translucency and colour [8,9,20]. Nevertheless, PFRP have a worse accuracy of fit compared to customised PC, and are less mechanically stable because of the interface between the PC parts [7,16,21,22]. Therefore, customised CPC remains the "gold standard" for treating cases of extensive loss of tooth structure [13,16].

Compared to other PC materials, such as metal or zirconia, the mechanical properties of fibre-reinforced composite differ depending on the direction of load to the fibre orientation [23]. PFRP have a unidirectional fibre orientation parallel to the posts long-axis, while recent fibre-reinforced CAD/CAM-materials have a multidirectional fibre orientation [23]. Suzaki et al. reported that the fracture resistance is 2.5 times higher when the direction of load is perpendicular to the orientation of the fibres, which is of high clinical relevance when the material is used for PC [24].

In the conventional workflow, a customized PC is waxed-up on a stone model based on the conventional impression of the prepared root canal and cast in alloy [25]. To use materials with an elastic modulus similar to that of root dentin for producing customized PC, it is necessary to scan the prepared root canal, because these materials are limited to a CAD/CAM workflow [16,26,27]. Recent developments of intraoral scanners (IOS) made it possible to mill customized PC in a fully digital workflow, by using the CAD/CAM-technology [16]. Leven et al. described that the accuracy of fit of CAD/CAM PC is within a clinically acceptable range [26]. Nevertheless, comparative studies between the "gold standard" of CPC and CAD/CAM PC made of a material with a similar elastic modulus to that of dentin, are lacking.

This in-vitro study was aimed to investigate the performance of customised CPC made of non-precious alloy fabricated in a conventional workflow, and fibre-reinforced CAD/CAM PC (FRPC) fabricated in a fully digital chairside workflow. The following null hypothesis were defined.

1. There is no significant difference between the datasets of the digitalised stone model and the digital post impression of the prepared root canal concerning the deviation in the coronal, middle and apical root canal areas.
2. There is no significant difference between the CPC and FRPC concerning root fracture and decementation during chewing simulation with thermocycling.

2. Materials & methods

In order to calculate the statistically significant sample size for the present study a power analysis with a pursued power of 95% was conducted. Due to the lack of similar comparative studies between different materials for PC concerning mechanical behaviour, the basis for this power analysis were the already published data for comparison between digital and conventional post impression [28,

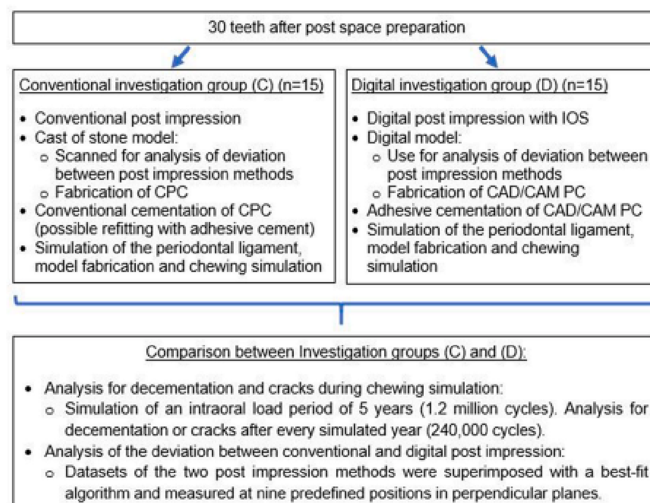

Fig. 1. Schematic diagram of the experimental steps.

29]. The sample size was dependent on the number of measuring points in the root canal so that because of the high deviation in the reference studies in total 13 teeth with 9 measuring points would have allowed for a statistically significant analysis. Due to the scarce clinical data the sample size was increased to 15 teeth each for investigation group (C) and (D) in order to improve the statistical power.

Fig. 1 gives an overview over the experimental steps of the present study which are described in detail in the following sections.

2.1. Tooth preparation

For this study, 30 single-rooted teeth with comparable sizes of 15 mm length and 6 mm width (±1.0 mm) were selected [30,31]. The teeth had been extracted for therapeutic reasons and their use for research purposes was approved by the ethics committee of the Medical Faculty of Justus Liebig University Giessen (Reg. No. 143/09) . The crowns were removed up to 2 mm above the cemen-toenamel junction using a disc grinder with water cooling. Then, a chemo-mechanical endodontic treatment was processed by using 3.0% sodium hypochlorite and a system of rotary files (F-360 ISO 15–45, Komet, Germany). This was followed by filling with gutta-percha (ISO 45, Taper 0.04, Coltène/Whaledent AG, Switzerland) and sealer (AH Plus, Dentsply DeTrey, Germany), using the one-point technique. After the cure time of the sealer (24 h), the post space preparation was conducted using the ER System (ISO 90, Komet, Germany) at a length of 10 mm. Additionally, a rotation lock by means of a 3 mm box at the root canal entrance and a chamfer line was prepared with diamond burs under constant water cooling. Subsequently, the roots were examined, and teeth with infractions, cracks and root caries were excluded. The analysis was carried out under a digital light microscope (Smartzoom 5, Zeiss, Germany) and based on X-ray findings.

2.2. Conventional/digital PC impression and fabrication

On every teeth, one conventional and one digital post impression were taken as described below. Subsequently, the 30 teeth were divided into two investigation groups (conventional and digital): 1. Conventional (C): For 15 teeth, CPC, according to the conventional workflow [25] was fabricated as follows: the conventional post impression was taken using a polyether material (Impregum, 3 M GmbH, Germany) with a resin post (ER CAST-Stift, ISO 90, Komet, Germany). The impression was transferred to a stone model (Implantat-rock, Picodent, Germany) which was subsequently scanned with an IOS (Primescan, Version 5.2.3, Dentsply Sirona, Germany) for the analysis of deviation between the two post impression methods (see chapter 2.6) before using for PC modelling. The gypsum powder was mixed in a vacuum machine for 60 s with distilled water in the ratio that was recommended by the manufacturer. After setting time of the stone model for 24 h the PC modelling was performed by use of a new resin post and wax (Dentaurum, Germany). The core part in all PC was designed with a height of 5 mm. The wax up was embedded in an investment material (Heravest Onyx, Kulzer, Germany) for casting a non-precious alloy PC (Wirobond C, Bego, Germany) by use of the lost wax technique. Fig. 2 shows the conventional workflow for fabrication of CPC.

2. Digital (D): For 15 teeth, FRPC, according to the fully digital chairside workflow was fabricated as follows: the digital PC impression was taken using an IOS. Subsequently, the STL-dataset was used for designing the PC at a core height of 5 mm, using the IOS software, to allow for comparison with CPC for group C during chewing simulation. The cement gap parameter was set to 50 μm in the software. The FRPC was fabricated in <10 min in a fully digital workflow using a milling unit that was developed for chairside restorations (MCXL, Dentsply Sirona, Germany) and a fibre-reinforced CAD/CAM composite with multidirectional orientation of glass fibre mats (Trinia, Bicon Europe Ltd., Germany). To ensure that the direction of load during chewing simulation is perpendicular to the glass fibre mats, the FRPC orientation was rotated by 45° in the CAD/CAM block. Fig. 3 shows the digital workflow for FRPC fabrication and the orientation of fibres (green lines) in relation to the direction of load (blue arrow).

Table 1 illustrates the materials with the elastic modulus used for CPC and FRPC fabrication in group (C) and (D), respectively.

2.3. Fitting of PC in the root canal

The PC for both investigation groups were blasted with aluminium oxide and then cleaned in an ultrasonic bath with ethanol (ethanol 70% (V/V) Hofmann's, Hofmann & Sommer GmbH und Co. KG, Germany). The prepared root canal was cleaned with a diamond-coated hand instrument (Aufrauinstrument 196D, ER System, Komet, Germany). The debris was removed by rinsing with 3% sodium hypochlorite solution. Subsequently, the root canal was dried with paper points.

CPC of group (C) were fitted with glass ionomer luting cement (Ketac™ Cem Aplicap™, 3 M GmbH, Germany) according to an

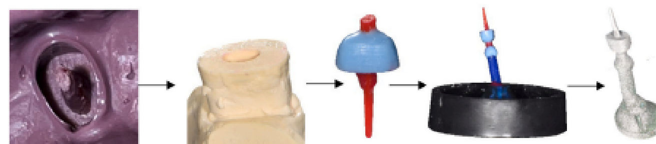

Fig. 2. Conventional workflow for fabricating PC in group C. From left to right: conventional post impression, stone model, wax up of PC, PC modelling embedded, CPC.

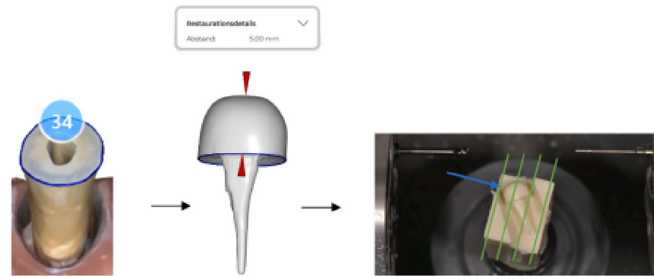

Fig. 3. Digital workflow for FRPC fabrication in group D. From left to right: digital post impression, virtual PC design (red arrows: 5 mm height of the core part), FRPC in the milling unit: Orientation of glass fibre mats in the CAD/CAM block (green lines) perpendicular to the direction of load during chewing simulation (blue arrow).

Table 1
Materials for PC fabrication.

Investigation group	Material	Product name	Product name	Elastic modulus
Conventional (CPC)	non-precious alloy	Wirobond C	Bego	180 GPa
Digital (FRPC)	fibre-reinforced CAD-CAM composite	Trina	Bicon	18.8 GPa

Elastic modulus of dentin: 18.6 GPa [5].

established conventional workflow [25]. The cement was filled into the lumen with a probe and was applied to the post part of CPC. Under constant finger pressure, the CPC was pressed into the final position and held for 7 min of setting time. Subsequently, the excessive cement was removed.

The FRPC of group (D) were fitted with an adhesive cement (PANAVIA V5, Kuraray Noritake, Kuraray Noritake, Japan) according to the manufacturer's instruction [32]. The first primer (CLEARFILTM CERAMIC PRIMER PLUS, Kuraray Noritake, Japan) was applied on the post part of PC. The second primer (PANAVIA V5 Tooth Primer, Kuraray Noritake, Japan) was applied for 20 s on the luting surfaces of the tooth. The excessive primer in the canal was removed with paper points and then dried by a gentle air stream. The adhesive cement (PANAVIA V5 Paste, Kuraray Noritake, Japan) was applied to the post part of PC. Under constant finger pressure, the PC was pressed into the final position and held for 7 min of setting time. Excessive cement was removed with a foam pellet. In addition, a gel (OXYGUARD™, Kuraray Noritake, Japan) was applied circularly to the margins to prevent the formation of an oxygen inhibition layer. Subsequently, all surfaces were light-cured for 20 s, and the gel was removed.

After PC fitting, all 30 teeth were once again examined for infractions and cracks by digital light microscope analysis and X-ray. In addition, the transition area from PC to the tooth was documented by images taken using the digital light microscope software as a reference for the analysis of cracks throughout chewing simulation (T0).

In case of a decementation during chewing simulation, PC and the prepared root canal were cleaned of cement residues and examined for infractions and cracks by microscopic analysis and X-Ray. Teeth with infractions or cracks were excluded from further investigation. If no infraction or crack was detected, CPC of group (C) were adhesively refitted according to the luting protocol described for FRPC in group (D). This procedure is in line with established clinical practice [33].

2.4. Simulation of periodontal ligament, model fabrication and chewing simulation

To simulate the periodontal ligament for chewing simulation, the roots were fixed in a shrink tube (DERAY®-KY 175, SHAWCOR,

Fig. 4. Simulation of periodontal ligament using a shrink tube (a: sample teeth for group C; b: sample teeth for group D).

Canada) that is comparable to the human periodontal ligament regarding thickness and elastic modulus [34,35]. For shrinking, the tube was heated evenly using a hot air dryer, so that the root was covered without any gaps. Subsequently, the tube was cut off at the cementoenamel junction (Fig. 4).

For chewing simulation, all sample teeth were embedded in a block of acrylic resin fitted into the mount of the chewing simulator at an inclination of 45° to the axis of masticatory load. Therefore, the roots were polymerised in the block, up to 2 mm below the cementoenamel junction (Fig. 5). Subsequently, three measurements using *Periotest* (Periotest Classic type 3218, Medizintechnik Gulden e.K., Germany) were processed, to verify that the simulation of the periodontal ligament was equivalent to that of a clinical tooth mobility grade 0. If the mean value was outside the range of −08 to +09, the tooth was excluded from further investigation. Then, the chewing simulation was processed for 1.2 million cycles of load under thermocycling in a water bath (SD Mechatronik Chewing Simulator CS-4.8; SD Mechatronik GmbH, Germany) (Fig. 5), which equals an intraoral load period of 5 years [36].

Table 2 illustrates the set parameters of the chewing simulator.

2.5. Analysis for decementation and cracks during chewing simulation

After every 240,000 cycles of load, simulating 1 year of intraoral loading period (T1-T5), the chewing simulation was stopped and the transition area of the sample teeth was analysed for infractions or cracks using a digital light microscope and X-Ray. In case of an infraction or crack, the sample was classified as "root fracture", the simulated survival time (T1-T5) was documented and the sample was excluded from further investigation. In cases of decementation the survival time (T1-T5) was documented and PC was recemented as described in paragraph 2.3 in order to follow and examine the clinical established practice after loss of retention of PC. After recementation, the chewing simulation was restarted from the beginning for 1.2 million cycles of load. The decementation, infractions or cracks analysis were repeated after every simulated year of intraoral loading period (240,000 cycles of load).

2.6. Analysis of deviation between conventional and digital post impression

For the analysis of deviation between the conventional and digital post impression, the unchanged stone models before PC modelling were scanned using the same IOS that was used for digital post impressions. Subsequently, the corresponding datasets (digitalised stone model and digital post impression of the prepared root canal) were superimposed using a 3D analysis software (Version V8 SR1 2020, GOM inspect, GOM GmbH, Germany) and a best-fit algorithm. The deviation of the datasets was measured at nine predefined points of the root canal using the "measuring flag" function of the analysis software. Therefore, two perpendicular planes were constructed along the lumen of the prepared root canal with the software tool "plane in viewing direction". One plane each was set in mesio-distal (largest diameter of the tooth circumference) and oro-vestibular direction (smallest diameter of the tooth circumference perpendicular to plane in mesio-distal direction), respectively. For each plane, four measurements were taken as follows: two each at the points of intersection with the root canal entrance and with the root canal wall 5 mm apical of the root canal entrance, respectively. Measurement point number nine was the deviation between the datasets at the deepest point of the prepared root canal. Fig. 6 shows an example of the plane construction and measurement of deviation between the two datasets.

2.7. Statistical analysis

IBM SPSS Statistics for Windows, version 26 (IBM Corp., Armonk, NY, USA) was used for statistical analysis. Decementations and root fractures during chewing simulation over a 5-year simulated time of intraoral loading, were assessed using Kaplan-Meier analysis. Cases in which neither decementations nor root fractures occurred were rated as "censored cases". The pairwise comparison between the two investigation groups was assessed using the log-rank test. For statistical analysis of the deviation between the datasets of the conventional and digital post impression, the measuring points at the entrance, 5 mm apical and deepest point of the root canal, were assigned to the "coronal", "middle" and "apical" category, respectively. A pairwise comparison (median test) was performed to investigate significant differences between the three measurement categories. Due to alpha error accumulation, p-values were corrected using the Bonferroni method and level of significance was set at $p < 0.05$.

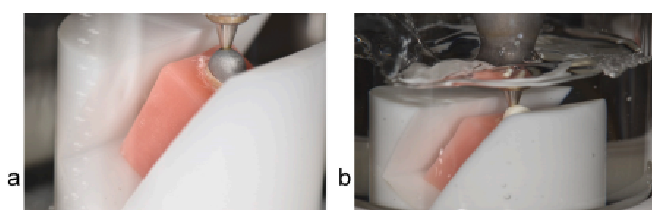

Fig. 5. Chewing simulation (a: CPC of group C in the mount of the chewing simulator at an inclination of 45° to the axis of masticatory load; b: FRPC of group D during chewing simulation under thermocycling in a water bath).

Table 2
Set parameters of the chewing simulator.

Loading force [N]	50
Force frequency [Hz]	1.6
Chewing speed [mm/s]	60
Mouth opening distance [mm]	2.0
Thermocycling temperature	5 °C/55 °C, 95 s each
Antagonist	Stainless steel cone/point radius: 30°/Vickers hardness: 385 R1, SD Mechatronik GmbH, Germany

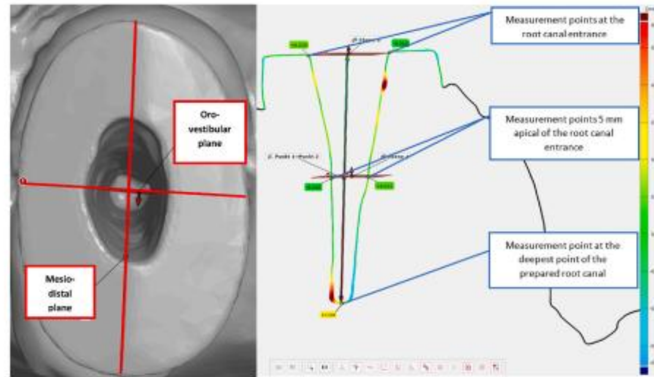

Fig. 6. Left: Mesio-distal (largest diameter of the tooth circumference) and oro-vestibular (smallest diameter of the tooth circumference perpendicular to plane in mesio-distal direction) plane construction. Right: Measuring points of deviation between the da**tasets of the conventional and digital post impression on the oro-vestibular plane.**

3. Results

3.1. Deviation between conventional and digital post impression datasets

The calculated medians of the measurement categories were 14.5, 18.0 and 113.7 μm for "coronal", "middle" and "apical", respectively. The results of the pairwise comparison between "coronal" and "middle" showed no significant difference. However, a highly significant influence was shown for the pairwise comparisons between "coronal" and "apical" as well as "middle" and "apical". The p-values of the pairwise comparisons between the measurement categories and median values with the corresponding standard deviations are illustrated in Table 3.

Moreover, the deviation increased from "coronal" to "apical" with the highest divergence in "apical" category. Fig. 7 is the box-plot diagram of the deviation between the conventional and digital post impression datasets distributed according to the "coronal", "middle" and "apical" measurement categories.

Hence, the first null hypothesis of no significant difference between the digitalised stone model and digital post impression datasets of the prepared root canal regarding the deviation among the coronal, middle and apical root canal areas was partially rejected.

3.2. Decementations and cracks after chewing simulation

In group (D) (FRPC fabricated in a fully digital chairside workflow), neither decementations nor root fractures were detected during the 5-year chewing simulation of 1.2 million cycles. Therefore, the simulated 5-year survival rate in group D was 100%. In group (C)

Table 3
Significant influences of the pairwise comparison (median test).

Deviation between the conventional and digital post impression		
Categories	**Median ± standard deviation [μm]**	**P-value of median test**
Coronal (CO)	14.5 ± 24.8	0.465 (MI) < 0.001 (AP)[a]
Middle (MI)	18.0 ± 21.7	0.465 (MI) < 0.001 (AP)[a]
Apical (AP)	13.7 ± 159.8	<0.001 (CO)[a] <0.001 (AP)[a]

[a] =Significant influence.

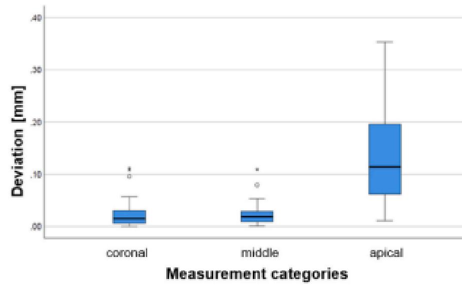

Fig. 7. Box-plot diagram of deviation between the conventional and digital post impression datasets distributed according to the three measurement categories ("coronal", "middle" and "apical").

(CPC fabricated in a conventional workflow), five CPC lost retention during chewing simulation. Three decementations occurred after 240,000 (T1), one after 720,000 (T3) and one after 960,000 (T4) cycles of load. Moreover, two PC in group C showed dentinal cracks after chewing simulation (one each at T1 and T5). Therefore, the simulated 5-year survival rate in group C was 65.0% with a mean survival time of 4.05 simulated years of intraoral loading period (standard deviation = 1.64). For PC after adhesive recementation (five CPC in group C), neither decementations nor dentinal cracks were recorded. Fig. 8 illustrates the Kaplan-Meier survival curve for PC after chewing simulation. The pairwise comparison (log-rank test) showed a significant difference ($p = 0.042$) between groups (C) and (D).

Therefore, the second null hypothesis of no significant difference between CPC and FRPC concerning root fracture and decementation after chewing simulation with thermocycling was rejected.

4. Discussion

The deviation between the two post impression methods and the mechanical behaviour during chewing simulation in a set up that is comparable to that of the clinical treatment of teeth with extensive coronal destruction, was investigated. Especially for anterior teeth, FRPC have the potential to improve dental treatment regarding the aesthetics and mechanical stability because of the translucency and similar elastic modulus to those of dentin. To the best of the authors knowledge, there has been no comparable study in dental literature investigating CAD/CAM PC that combines the advantages of PFRP, that are widely used in dental practice, with those of customised PC, in a fully digital chairside workflow.

4.1. Method

Even though the elastic modulus of alloy used for fabrication of CPC is significantly higher than that of dentin [37,38], customised CPC is still regarded as the "gold standard" for treating teeth with severe coronal destruction because of its excellent accuracy of fit [13,16]. PFRP have a mechanical behaviour similar to that of dentin but are less stable due to the interface between the PC parts and the poor accuracy of fit in the prepared root canal [7,16,21,22,38]. Therefore, to combine the advantages of both types of PC, the accuracy

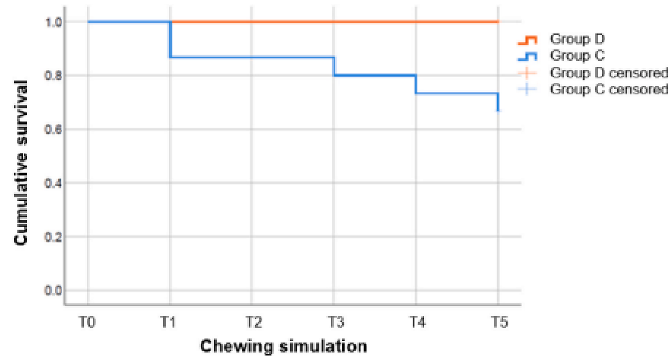

Fig. 8. Kaplan-Meier curve of the chewing simulation: FRPC of group D (orange) and CPC of group C (blue).

of fit has to be a major assessment criterion when it comes to evaluation of further developed PC treatment options. In the present study, the deviation between the two investigated workflows was measured by superimposing the two datasets with a best fit algorithm, which is an established procedure in dental literature [26,28,39–41]. Therefore, the software superimposes the datasets automatically to minimise the discrepancy between the point clouds [42]. *O'Toole* et al. investigated the accuracy of superimposing two datasets using the best fit algorithm, a three-point superimposition and the same coordinate system, for both scans [43]. Although the superimposition of the same coordinate system for both scans resulted in the smallest error, this procedure was described as non-clinically feasible due to the lack of reference structures for the coordinate system. The use of the best fit algorithm led to less discrepancies compared to the three-point superimposition [43]. *Revilla-León* et al. confirmed this conclusion and found the highest accuracy and precision for the best fit algorithm in a clinically feasible set up [42]. Most studies dealing with the evaluation of the accuracy of fit of fixed dental prothesis used the analogue replica technique [44,45] or microcomputed tomography [46] to measure the cement gap. Nevertheless, these techniques are not feasible for PC because of the fragile impression of the cement gap in the prepared root canal and the artefacts caused by X-Ray with alloy restorations [46]. Thus, for evaluating the deviation between the two post impression methods in the present study, the superimposition of the datasets with the best fit algorithm was the most suitable method. To minimise the influence of the scanner system, the stone models were digitalised using the same IOS that was used for the digital post impressions. *Chen* et al. showed for the IOS used in the present study, the highest precision in comparison to that of another IOS and an extraoral laboratory scanner system [47]. *Ender* et al. confirmed these findings in a comparative study between seven different IOS systems [48]. *Primescan* has a higher depth of focus compared to that of other IOS. Therefore particularly suitable for digital post impression in a fully digital chairside workflow for CAD/CAM PC, especially because it is part of an established system that was developed for fabrication of chairside fixed dental protheses [28].

In addition to high accuracy of fit in the prepared root canal, the mechanical behaviour of PC is also non-negligible because the teeth and restorations are exposed to continuous stresses from chewing movements and parafunctions in clinical use [49]. The artificial oral environment and changing temperatures within the oral cavity affect the retention of PC as well as the PC material itself [32,50]. Therefore, preclinical survival simulation in a set up that is comparable to the clinical situation is essential in terms of material fatigue and further development of new treatment options [49]. Thus, many authors in dental literature reported using chewing simulators to analyse the mechanical behaviour of new materials or workflows, similar to those performed in the present study [49,51]. *Rosentritt* et al. described that a simulation of the periodontal ligament is necessary during chewing simulation, since the omission of this resulted in a three times lower susceptibility to fracture, which decreases the comparability to the clinical situation [52]. For this, in many dental literature, a thin layer of impression material with a comparable thickness but different mechanical properties than those of the human periodontal ligament was used [36,52,53]. Moreover these previous studies did not examine the simulation of the periodontal ligament for mobility grade before chewing simulation. In the present study, the artificial periodontal ligament was made of a shrink tube with a thickness and mechanical properties similar to those of the intraoral situation in anterior teeth [34,35]. Moreover, a check using *Periotest* was performed before chewing simulation. Nevertheless, it has to be mentioned that the simulation of the periodontal ligament is still a limitation and a possible influencing factor on the results of the present study. Since the periodontal ligament shows a complex elastic behaviour it is obvious that the simulation with a polymeric shrink tube can only be an approach to the clinical situation but to the best knowledge of the authors there is no better simulation of an artificial periodontal ligament described in dental literature. Another limitation of the present study was that the luting protocol was not the same for both investigation groups at the beginning of the chewing simulation. The reason for this was that the study aimed to compare the conventional workflow for CPC, which includes conventional fitting with glass ionomer cement [25], to the new fully digital chairside workflow for CAD/CAM PC made of *Trinia*. According to the manufacturer's instruction fitting of *Trinia* is limited to adhesive cementation. That is why the luting protocol was not the same at the beginning of chewing simulation. After possible decementation also CPC were refitted adhesively following the protocol of investigation group (D) which is in line with established clinical procedure in our clinic [33]. In order to minimise the influence of chewing simulation before decementation on the mechanical behaviour after refitting of PC the teeth were critically examined for infractions and cracks and excluded if damage was detected. Nevertheless, it has to be mentioned that an influence of chewing simulation before decementation cannot be completely excluded and is therefore an inevitable limitation of the present study.

Many studies investigated the mechanical behaviour of PC using a covering crown since the ferrule effect is a known significant factor for clinical success [2,49]. In the present study, a ferrule design was deliberately omitted to investigate the uninfluenced effect of the material on loss of retention and root fracture. This approach is described by other studies as well [54,55]. In the present study, the evaluation of decementation and root fracture after chewing simulation was analysed using a digital light microscope and X-Ray. *Iemsaengchairat and Aksornmuang* investigated CAD/CAM PC and conventionally CPC and also used microscopic analysis and X-Ray for evaluation, since this approach makes it possible to detect microcracks in root dentin, which can hardly be seen by visual inspection [31].

4.2. Results

In the present study, the median deviation between the two post-impression methods in the “apical” category was 113.7 μm. *Pinto* et al. investigated the accuracy of fit of post impressions using preparation lengths of 8.5 mm–9.8 mm [29]. They described that digital post impression using an IOS led to a 1.83 mm shorter impression depth than a conventional post impression. However, this previous study used an outdated IOS with a smaller depth of focus. *Leven* et al. found a tenfold smaller deviation using the latest generation of a modern IOS [26]. Nevertheless, *Elter* et al. described an apical deviation of 357.1 μm for digital post impression using the *Primescan* compared to a conventional post impression [28]. One reason for the higher deviation compared to that of the present study could be

the software version. *Elter* et al. used *Primescan* version 5.0.0, whereas, in the present study, version 5.2.3 was used. The influence of the IOS software on the precision of digital impressions has been described in dental literature [56]. This indicates that for fabrication of CAD/CAM PC in a fully digital workflow, the IOS needs to have a hardware with a high depth of focus and an updated software version to facilitate good accuracy of fit. In the present study the deviation increased from "coronal" to "apical" within a clinically acceptable range [26]. This result is in line with other authors in dental literature although in the present study, the deviation is to a much smaller extent [26,28]. Another reason for the high divergence in "apical" measurement category values could be because of the vulnerability of the conventional post impression. Since with an analogue impression, the complete representation until the deepest point of the prepared root canal can hardly be checked, whether an impression material did not reach every part of the preparation resulting in a CPC with a large cement gap in the apical area, cannot be excluded. The authors recognised this in some teeth with CPC on the proceeded X-ray. In those cases, the digital post impression might have led to a better accuracy of fit in the apical area; however, since the conventional post impression dataset was set as the "reference" and the pairwise comparison test in the present study was limited to the absolute values, this could not have been taken into the account. The described procedure might be a weakness of the present study and should be further investigated in future studies; however, it was inevitable in the context of investigating the significant differences between the two workflows. Concerning the analysis of decementation and root fracture during chewing simulation with thermocycling in the present study, five CPC lost retention, and two showed dentin cracks in the transition area between PC and root. For FRPC, neither decementation nor root fracture was detected. *Hayashi* et al. investigated the in-vitro fracture resistance of pulp-less teeth restored using PFRP and metallic posts. The inclination of the axis of masticatory load to the axis of the post was 45°, similar to that of the present study. The authors found a significantly higher fatigue limit for teeth restored using fibre-reinforced posts and presumed a similarity of elastic modulus between post and dentin for this result [19]. *Ferrari* et al. compared the clinical survival of CPC and PFRP retrospectively over an observation period of 4 years. CPC showed root fractures in 9% of cases, whereas no fracture occurred in the group of teeth restored using fibre-reinforced posts [57]. Contrary to this, *Altitinchi* et al. found a 100% failure rate because of fractures after chewing simulation with thermocycling for FRPC made of *Trinia*. However, the previous study did not consider the orientation of the fibre mats to the axis of the load and did not rotate PC in the CAD/CAM block, different from that of the present study [49]. *Suzaki* et al. described the significant influence of fibre orientation for fracture toughness especially when the material was used for PC [24]. This could be the reason for the different results of FRPC made of *Trinia* in the present study compared to that by Altinchi et al. Most studies dealing with the survival probability of PC found the loss of retention as the most common cause of failure [7,25,58], which is in line with the results of the present study. Even though the loss of retention is described as a relative cause of failure because PC can often be recemented without additional effort [25], it can still increase the risk for tooth loss. Ona et al. described that the mismatch of the elastic modulus appears to be a factor responsible for decementation of metallic PC from the root canals, with a potential increase in the risk of root fractures. This is in line with the findings of the present study because root fracture was only documented for CPC cemented with glass ionomer cement. After recementation of CPC with an adhesive cement, no root fracture or further decementation was detected. This indicated that adhesive cementation of CPC seems to have an advantage over conventional cementation with regard to the retention in the root canal as well as decreasing risk of root fracture.

5. Conclusion

The fully digital chairside workflow for CAD/CAM PC described in the present study has the potential to combine the advantages of a chairside treatment with PFRP and customised CPC. Within the limitations of this study, the fibre-reinforced CAD/CAM composite (*Trinia*) can be used to fabricate customised PC for anterior teeth with extensive coronal destruction in a fully digital chairside workflow with superior mechanical behaviour and accuracy of fit compared to the "gold standard" of CPC. Moreover, the results showed that even CPC should be cemented adhesively, to decrease the risk for loss of retention and root fracture.

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Ethical approval

Use of extracted teeth for research purposes (Reg. No. 143/09).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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7.2.7 Vergleich der klinischen Passgenauigkeit zwischen glasfaserverstärkten CAD/CAM-Komposit und konventionellen, gegossenen Stiftaufbauten.

J.A.H. Vogler*, L. Billen, K.A. Walther, B. Wöstmann, Conventional cast vs. CAD/CAM post and core in a fully digital chairside workflow - An in vivo comparative study of accuracy of fit and feasibility of impression taking, *Journal of Dentistry* 136 (2023) 104638. (IF 2023: 4,4)

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Conventional cast vs. CAD/CAM post and core in a fully digital chairside workflow – An *in vivo* comparative study of accuracy of fit and feasibility of impression taking[☆]

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ABSTRACT

Objectives: Clinical data for CAD/CAM post and cores (PC) is still scarce, even though developments in digital dentistry have improved dental treatment in many aspects. Therefore, the purpose of this in vivo study was to compare CAD/CAM PC fabricated in a fully digital chairside workflow to conventional cast PC (CPC) according to the accuracy of fit and the impression taking. The null hypothesis was that there is no significant difference between CAD/CAM PC and CPC.
Methods: The study was conducted on 30 teeth in 25 patients receiving a CPC during their prosthetic treatment plan. On each tooth a conventional and a digital post impression were taken. Subsequently, one CPC following a conventional and one CAD/CAM PC following a digital workflow were fabricated. Both PC were tried-in intraorally and assessed according to a standardised evaluation sheet. The deviation between the two impression methods was evaluated by superimposing the datasets in a 3D analysis software. Statistical analysis for pairwise comparison was conducted according to Wilcoxon and median test with a significance level of $p = 0.05$.
Results: CAD/CAM PC performed significantly better compared to CPC according to accuracy of fit ($p = 0.022$) and feasibility of impression taking ($p < 0.001$). The deviation between post impression methods increased from "coronal" to "apical". Between "coronal"/"middle" no significant difference ($p = 0.158$) was detected, whereas the pairwise comparison between the other measurement categories showed significant differences ($p = 0.002$, $p < 0.001$).
Conclusions: The null hypothesis was rejected since CAD/CAM PC performed significantly better and the deviation between the post impression methods showed significant differences.
Clinical significance: By using intraoral scanners (IOS) teeth can be restored with customised CAD/CAM PC in a single session. Within the limitations of this study the fully digital chairside workflow led to superior accuracy of fit of PC and higher feasibility of impression taking than the conventional workflow for CPC.

1. Introduction

In cases with extensive defects of the coronal structure, PC is sometimes the last option to restore an endodontically treated tooth [1]. For many years, CPC fabricated on the basis of a conventional impression of the prepared root canal was the standard therapy of choice for those teeth [2]. It took the development of adhesive technique, leading to the dissemination of prefabricated posts with composite core build-ups in dental practice, to make it possible to restore a tooth with PC in a single session [3]. Therefore, the main advantage of the prefabricated post was the reduced chair time, which makes the treatment more comfortable for the patient and economically attractive for the dentist [4]. Moreover, with prefabricated posts there are fibre-reinforced materials that have an elastic modulus similar to dentin [5,6]. This is clinically relevant because a mismatch of the elastic modulus between post material and dentin is known to be associated with a higher risk of root fracture and decementation of the post [7–10]. Nevertheless, prefabricated posts have worse accuracy of fit in comparison to customised CPC and are less mechanically stable because of the interface between the post and the composite core build-up [7,11–13]. Therefore, CPC are still regarded as

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the "gold standard" and are indicated especially in cases with severe coronal defects, insufficient ferrule design, and flared or elliptical root canals where prefabricated posts fail to adapt to the lumen [7,14–16]. That is why some authors describe the indications of prefabricated posts for cases with moderate defects having a greater amount of remaining coronal dentin and providing sufficient adhesive surface for the composite core build-up [14,17,18].

In order to combine the advantages of customised and prefabricated posts, it is necessary to scan the lumen of the post space preparation because materials that are capable for the production of customised PC and have an elastic modulus similar to dentin are limited to a CAD/CAM workflow [7,19,20]. The latest technical developments have made it possible to digitalise a post space preparation intraorally or on the basis of a stone model providing the basis for fabrication of CAD/CAM PC [7]. Nevertheless, all IOS are optical systems and have therefore limitations, since the light has to reach every part of the post space preparation to provide good accuracy of fit of the PC [21]. That is why the quality of the digital post impression is significantly influenced by hard- and software parameters of the IOS because the depth of focus [22] and the ideal ambient light conditions [23] differ between the systems.

In this context *Pinto* et al. investigated the accuracy of fit of digital and conventional post impressions with different root canal preparation lengths [24]. They reported that digital post impression using an IOS resulted in significantly shorter impression depth than a conventional post impression with silicone. However, the study was published in 2017 and neither the hardware nor the software of the IOS that was used by *Pinto* et al. is comparable to the performance of modern IOS [25]. *Leven* et al. found a tenfold smaller deviation between digital and conventional post impressions using modern IOS hardware and software [19]. *Al-Qarni* has published a review over the published scientific literature concerning CAD/CAM PC [7]. Most of the included studies were laboratory studies or clinical case reports in which a stone model of a conventional post impression was scanned with a laboratory scanner [26–28]. In some other studies, a resin or wax PC was modelled intraorally in the prepared root canal and scanned with a laboratory scanner [12,29,30]. In only three studies, the prepared root canal was directly scanned in a fully digital workflow and the PC was virtually designed and fabricated in a CAD/CAM process. Two of these investigations were conducted *in vitro* under ideal conditions [31,32]. Only one study described a clinical case report in which the root canal was prepared conically and short, favoring scanability for the IOS and did not correspond to a typical clinical situation [33]. *Al-Qarni* concluded that the clinical data is very limited and well-structured *in vivo* studies are needed to confirm the usability of IOS for fabrication of CAD/CAM PC in dental practice [7].

Summarising the already published data concerning CAD/CAM PC one can postulate that technical development of IOS is only recently capable for sufficient digital post impression. Since the digital post impression is the key factor for combing the advantages of prefabricated and customised PC a comparative study between CAD/CAM PC and CPC is of high clinical relevance.

Therefore, the aim of this *in vivo* study was to investigate the accuracy of fit of CPC fabricated in a conventional workflow and CAD/CAM PC fabricated in a fully digital chairside workflow in a clinical setup. Moreover, the deviation between the conventional and digital post impression as well as the feasibility of the two impression methods were assessed. The null hypothesis for the investigation was that there is no significant difference between CAD/CAM PC and CPC.

2. Materials and methods

In order to calculate the statistically significant sample size for the pairwise comparison between digital and conventional post impression a power analysis with a pursued power of 95% was conducted. The basis for this power analysis was the already published data by *Pinto* et al. and *Elter* et al. [22,24]. The sample size was dependant on the number of measuring points in the root canal so that because of the high deviation in the reference studies 13 teeth with 9 measuring points would have allowed for a statistically significant analysis. Due to the scarce clinical data the sample size was increased to 30 teeth in order to increase the statistical power.

The present study was approved by the ethics committee of the *[removed for anonymity reasons]*. The inclusion criteria were determined as follows: Only teeth that were free of symptoms from pain or inflammation in patients whose prosthetic treatment plan included a CPC were included in the study. In the present study treatment with CPC was only conducted if the grade of residual tooth structure was low (one or less remaining cavity wall). In cases with more residual tooth structure a prefabricated post was fitted and the tooth was excluded from further investigation in this study. In teeth with more than one endodontically treated root canal only one root canal was prepared for CPC. In cases where a PC with more than one post part was mandatory, the tooth was excluded from further investigation. The patients agreed, by signature, to participate and were free to withdraw their consent at any time. Initially, 29 patients with 34 teeth were included in the study. After preparation of the root canal for PC four teeth were excluded from further investigation because, in two cases, the root was perforated, thus the tooth had to be extracted, and two patients withdrew their consent for participation. Finally, 30 teeth (16 anterior teeth, 8 premolars, 6 molars) in 25 patients were included in the data acquisition. Fig. 1 gives an overview over the experimental steps of the present study which are described in detail in the following sections.

2.1. Tooth preparation

The treatment was performed in accordance with established and standardised preparation rules in order to minimise the influence of differences in the preparation design on the post impressions and the results of the study. The preparation rules were also consistent over the different types of teeth (anteriors, premolar and molars). The gutta-percha filling of the root canal had to be completed at least 24 h before beginning the post space preparation in order to obtain a sufficient setting time of the endodontic sealer. All existing coronal fillings and carious lesions were removed prior to preparation for PC. Every post space preparation was conducted using the same drillsize of the ER System (*ISO 90, Komet, Germany*) [18] until a depth of two thirds of the root length [34] leaving a minimum of 4 mm of residual endodontic filling in order to achieve apical seal against reinfection [35,36]. If the PC would have been rotatable after post space preparation because of the geometry of the coronal defect (no remaining cavity walls), a rotation fuse of 3 mm was prepared with diamond burs under constant water cooling at the entrance of the root canal [19].

2.2. Conventional / digital PC impression and fabrication

Every step of the present study was conducted by a single investigator. At the first appointment subsequently, after post space preparation, the root canal and the adjacent teeth and gingiva were dried with paper points and air steam for taking one conventional and one digital post impression according to the following description:

Conventional investigation group (C): For each tooth one CPC following a conventional workflow [2] was fabricated. The conventional post impression was obtained using a polyether material (*Impregum, 3 M GmbH, Germany*) with a resin post (*ER CAST-Stift, ISO 90, Komet, Germany*). Subsequently, the impression was used to cast two stone models (Implantat-rock, Picodent, Germany). The first cast of the impression was left unchanged and was used for investigation of the deviation of the digital post impression (see Section 2.4). The second cast of the impression was used for the PC modelling out of wax (*Dentaurum, Germany*) and an equal resin post that was already used for the conventional post impression. The post part was modelled by filling the space between stone model and resin post with wax. Subsequently, the core part was

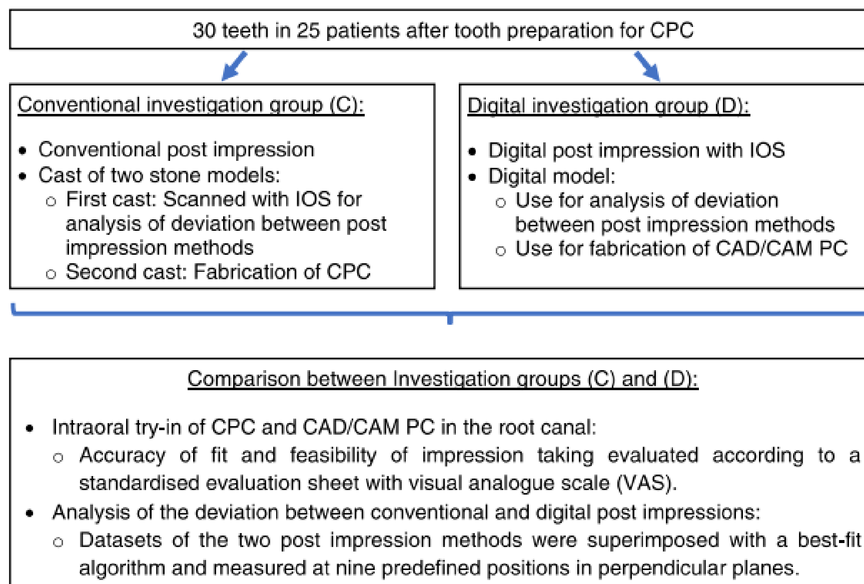

Fig. 1. Schematic diagram of the experimental steps.

modelled with wax and a runner channel was added. The completed wax up was embedded in investment material (Heravest Onyx, Kulzer, Germany) for casting a PC of non-precious alloy (*Wirobond C, Bego, Germany*). The cement gap of CPC was set by the dimension changes of the investment material. Subsequently the runner channel was removed and the CPC was fitted in the stone model, that was used for the PC modelling. Both stone models were scanned with an IOS (*Primescan, Version 5.2.3, Dentsply Sirona, Germany*) and the datasets were superimposed for precluding that there was any significant deviation between the stone models which could influence the results of the study. Moreover, in case of a misfit of the CPC in the first cast stone model the conventional post impression was repeated at a second appointment and a new CPC was fabricated for further investigation. Fabrication of CPC required approximately one week because of the time-consuming analogue workflow and necessary curing times for the stone models and investment material.

Digital investigation group (D): For each tooth one CAD/CAM PC following a fully digital chairside workflow was fabricated. The digital post impression was taken using *Primescan* with an optimal ambient light for scanning of 10.000 lux [23]. Therefore, the oral cavity was illuminated for scanning by switching on the examination light of the dental unit to ensure the best trueness and precision. The completeness of the digital impression of the prepared root canal was checked on the IOS display. If the STL-dataset was incomplete in the apical area of the post space preparation, the lumen was illuminated with a caries detection probe (*KaVo Dialux 2300 L, Germany*) by pushing the probe against the surrounding gingiva or the tooth outside the relevant surface for PC.

Subsequently, the STL-dataset was used to design the CAD/CAM PC in the IOS software. The cement gap parameter was set to 50 µm. CAD/CAM PC was fabricated in less than ten minutes in a milling unit that was developed for chairside restorations (*MCXL, Dentsply Sirona, Germany*) using a fibre-reinforced composite (*Trinia, Bicon Europe Ltd., Germany*) with multidirectional glass fibre mats. Afterwards, the attachment points of the PC to the CAD/CAM block were cut and smoothed. Fig. 2 shows the PC of investigation groups C and D fabricated for one tooth.

2.3. *Intraoral try-in of PC in the root canal*

In a second appointment the PC of both investigation groups were tried-in intraorally in the root canal (Fig. 3). The accuracy of fit and the feasibility of conventional and digital impression taking were evaluated according to a standardised evaluation sheet using a visual analogue scale (VAS) [37]. To achieve reproducibility of the measuring values, only one single investigator performed the evaluation. Moreover, a calibration in preliminary *in vitro* tests was conducted, so that the investigator evaluated CPC and CAD/CAM PC in ten different teeth over a period of two weeks. The variance in the measuring values was <5 mm on a 100 mm VAS after the calibration. On the VAS, the investigator rated the evaluation criteria for accuracy of fit and the feasibility of impression taking on a 100 mm scale without orientation marks, meaning that low values indicated good assessment and high values indicated poor assessment. The evaluation criteria covered all established requirements for accuracy of fit of PC (stable fit without rotatability of the PC, friction of the PC in the root canal against pull-out, modification time to bring the PC in target position) as well as the feasibility of the post impression methods.

2.4. *Analysis of the deviation between conventional and digital post impressions*

For the analysis of the deviation between the two post impression methods, the unchanged stone model made from the first cast of the conventional post impression was scanned using the same IOS that was used for the digital post impression. Subsequently, the corresponding datasets of the conventional and digital post impressions were superimposed using a 3D analysis software (*Version V8 SR1 2020, GOM inspect, GOM GmbH, Germany*) and a best-fit algorithm. The tooth surfaces were marked on both datasets in the software as reference surfaces

Fig. 2. PC of both investigation groups fabricated for one tooth: CPC (left) and CAD/CAM PC (right).

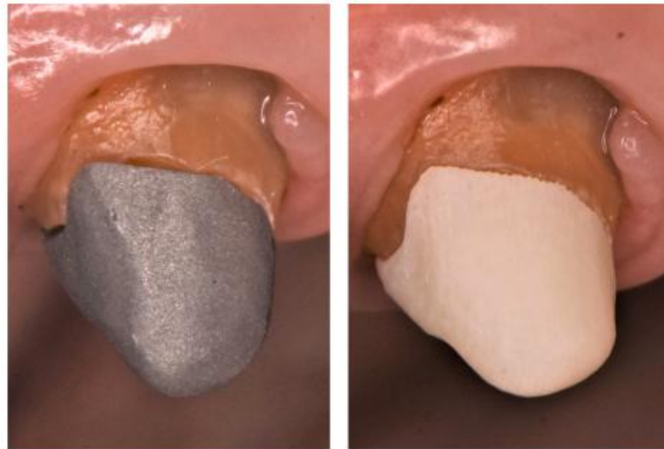

Fig. 3. Intraoral try-in of CPC (left) and CAD/CAM PC (right) in the root canal.

for the superimposition, leaving out the potentially inconsistent gingival areas [38]. The deviation of the datasets was measured at nine predefined points of the root canal using the "measuring flag" function of the analysis software. Therefore, two perpendicular planes were constructed along the lumen of the prepared root canal. One plane was set in mesio-distal direction and one in oral-vestibular direction. On each plane, four measurements were taken: Two at the points of intersection with the root canal entrance and two at the points of intersection with the root canal wall 5 mm apical of the root canal entrance. Measurement point number nine was the deviation between the datasets at the deepest point of the prepared root canal. The dataset of the conventional post impression was set as "CAD" and the dataset of the digital post impression as "NET" in the software meaning that negative values of deviation in the apical area of the post space preparation stand for a deeper impression of the digital post impression. Moreover, the preparation depth was determined in the software by constructing the intersection line between the two planes and measuring the distance from the entrance of the root canal to the deepest point of the preparation. Fig. 4 illustrates a diagram of the superimposition and construction of the measuring positions for the deviation analysis between the two datasets and the preparation depth in the 3D analysis software.

2.5. Statistical analysis

The software SPSS Statistics (*Version 26, IBM, USA*) was used for data processing. A pairwise comparison between the two investigation groups regarding the accuracy of fit of PC in the root canal and the feasibility of the post impression methods was evaluated by the Wilcoxon-Test because an independence of the evaluation criteria was not proven. For statistical analysis of the deviation between the datasets of the conventional and digital post impression the measuring points at the entrance of the root canal were assigned to the category "coronal",

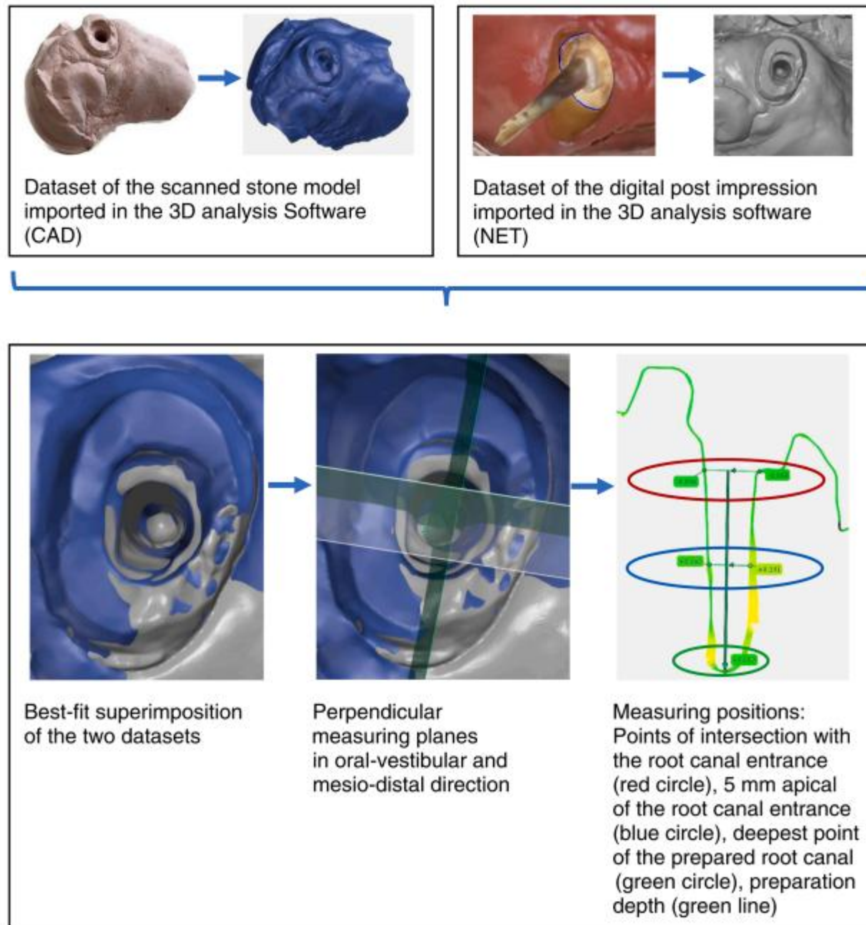

Fig. 4. Superimposition and construction of the measuring positions for the deviation analysis between the datasets and the preparation depth.

the measuring points 5 mm apical of the root canal entrance to the category "middle", and the measuring points at the deepest point of the root canal to the category "apical". A pairwise comparison (median test) of the three categories was performed in order to investigate any significant differences between the independent measurement categories. Due to alpha error accumulation, p-values were corrected according to the Bonferroni method, and the level of significance was set at p-value <0,05.

3. Results

3.1. Accuracy of fit of PC / feasibility of the post impression method

CAD/CAM PC (D) showed significantly better accuracy of fit in the root canal compared to CPC (C) ($p = 0.022$). The mean evaluation value on VAS was 10.17 mm (SD ± 6,9 mm) for group D and 34.64 mm (SD ± 21,45 mm) for group C. Fig. 5 illustrates a box-plot diagram for the accuracy of fit of PC cumulated over the VAS values of the evaluation criteria for accuracy of fit distributed to the digital and conventional investigation groups. The significantly larger variance in the values for CPC showed that accuracy of fit was more predictable for CAD/CAM PC. Table 1 Illustrates the p-values of the pairwise comparisons and the mean VAS values with the standard deviation distributed across the evaluation criteria for accuracy of fit and feasibility of impression taking of the standardised evaluation sheet.

There was a significant difference in the feasibility of the digital post impression concerning the type of tooth indicating that scanning is more feasible in premolars than in anterior teeth ($p = 0.007$) and molars ($p = 0.029$). However, there was no significant difference in the accuracy of fit of CAD/CAM PC regarding the different types of teeth. Furthermore, the preparation depth did not significantly influence the VAS values in either investigation group.

3.2. Deviation between the datasets of post impression methods

The calculated medians of the measurement categories were 18.0 µm for "coronal", 26.0 µm for "middle", and 161.1 µm for "apical". The results of the pairwise comparison between "coronal" and "middle" showed no significant difference. However, a highly significant influence was shown for the pairwise comparisons between "coronal" and "apical" and "middle" and "apical". The p-values of the pairwise comparisons between the measurement categories and the median values with the corresponding standard deviation are illustrated in Table 2.

The deviation increased from "coronal" to "apical" with the highest divergence in the "apical" category. Fig. 6 illustrates a box-plot diagram

Table 1
P-values of the pairwise comparison (Wilcoxon-Test).

Evaluation criteria of the standardised evaluation sheet	Mean value ± Standard Deviation	p-value of Wilcoxon-Test
Stable fit without rotatability of PC	C: 22.6 ± 27.8 mm VAS D: 5.9 ± 5.1 mm VAS	$p = 0.009$ [a]
Friction of PC in the root canal against pull-out	C: 43.1 ± 36.5 mm VAS D: 24.9 ± 12.0 mm VAS	$p = 0.250$
Modification time to bring PC in target position	C: 1.6 ± 3.3 min D: 0.4 ± 1.5 min	$p = 0.015$ [a]
Feasibility of post impression	C: 37.4 ± 28.4 mm VAS D: 6.8 ± 8,2 mm VAS	$p<0.001$ [a]

[a] =Significant influence
C: conventional post impression + CPC
D: digital post impression + CAD/CAM PC.

Table 2
Significant influences of the pairwise comparison (median test).

Deviation between the conventional and digital post impressions		
Categories	Median ± Standard Deviation [µm]	P-value of median test
Coronal (CO)	18.0 ± 7.6	0,158 (MI) <0.001 (AP) [a]
Middle (MI)	26.0 ± 10.9	0,158 (MI) 0.002 (AP) [a]
Apical (AP)	161.1 ± 316.9	<0.001 (CO) [a] 0.002 (MI) [a]

[a] =Significant influence.

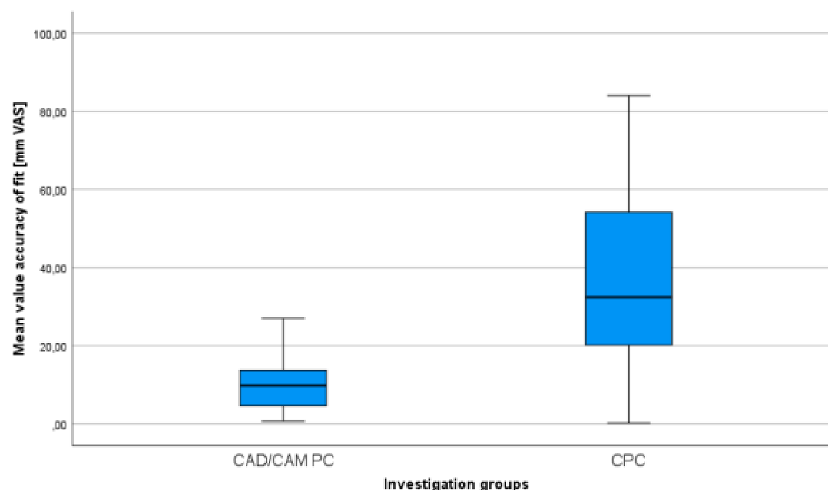

Fig. 5. Box-Plot diagram of values for the accuracy of fit of PC distributed to digital and conventional investigation groups.

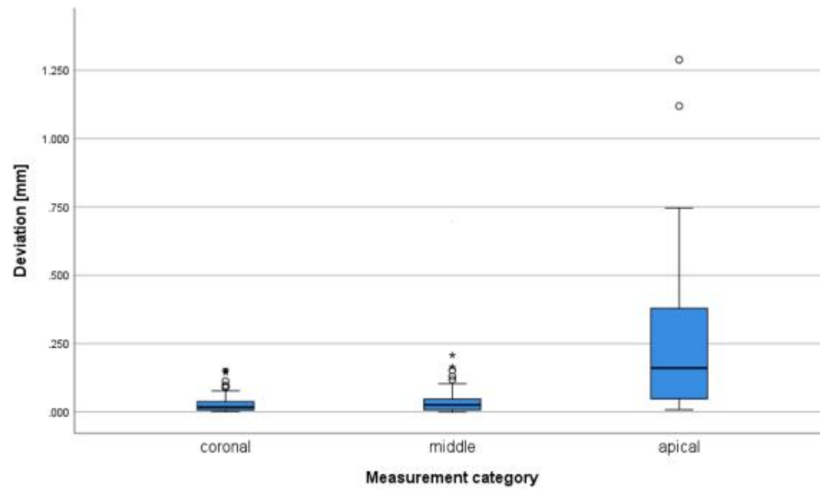

Fig. 6. Box-Plot diagram showing the deviation between the datasets of the conventional and digital post impressions distributed across the three measurement categories ("coronal", "middle" and "apical").

of the deviation between the datasets of conventional and digital post impression distributed to the measurement categories "coronal", "middle" and "apical". There were two statistical outliers over 1 mm in the data of the "apical" category (Fig. 6) which had a negative value, meaning that digital reached deeper than conventional post impression (Fig. 7). However, there was no significant difference in VAC values and deviations in "middle" and "apical" categories regarding those two cases. An X-Ray taken after the CPC cementation showed a gap between the CPC and the deepest point of the post space preparation (Fig. 7), highlighting the insufficient impression depth of the conventional post impressions in those cases.

Furthermore, there was no significant influence on the deviation of

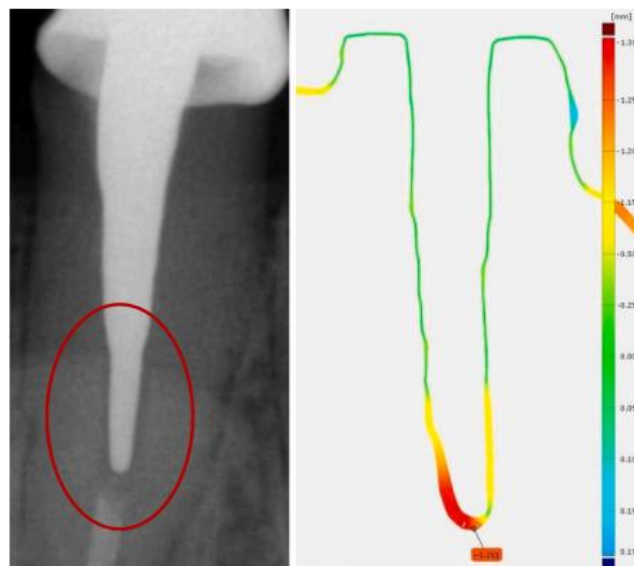

Fig. 7. Left: X-Ray after cementation of CPC showing insufficient accuracy of fit in the apical area (red circle). Right: Analysis of the deviation between post impression methods showing a higher impession depth for the digital post impression (negativ values).

the two post impression methods in anterior teeth, premolars and molars. In the present study the mean preparation depth for PC over all 30 teeth was 9.66 mm (SD ± 2,99 mm) with a maximum of 15.4 mm and a minimum of 6.9 mm. Additionally, the preparation depth did not have a significant influence on the deviation between the datasets of the two post impression methods.

4. Discussion

The aim of this *in vivo* study was to investigate the accuracy of fit and the feasibility of the post impressions of CAD/CAM PC fabricated in a fully digital chairside workflow, and to compare the results to CPC fabricated in an established conventional workflow. For the investigation a standardised evaluation sheet with a VAS was used covering all relevant evaluation criteria concerning PC. The use of standardised evaluation sheets for clinical observational studies is an established procedure in dental literature [39,40] in order to achieve clinical practicability and reproducibility of measuring values [37,41,42]. A VAS without orientation marks is able to illustrate small differences in evaluation, because with ordinal scales, the investigator is tempted to sign on the orientation marks leading to repetition of measuring values across different cases [43]. Moreover, the friction of PC against pull-out, the stable fit without rotatability and the feasibility of impression taking are evaluation criteria that obviously cannot be assessed objectively by any kind of practicable instrumental measurement in the patient's mouth. Most studies in dental literature investigating the accuracy of fit of fixed dental prostheses are using the replica technique, in which the cement gap between the restoration and the tooth is represented by a thin layer of impression material that can be measured under a light microscope [44]. However, this technique is not suitable for PC because it is not possible to remove the thin layer of impression material from the post or the root canal without damage, in particular with a high friction of PC against pull-out because of a small gap to the root canal's wall. Other investigation methods, such as the analysis with micro-computer-tomography or the triple-Scan method, are only suitable for *in vitro* setups because of the excessive exposure to radiation and the need for reference structures other than the treated tooth for PC superimposition [19,45]. Furthermore, in order to obtain the best reproducibility of the VAS measurement values, the investigator conducted a self-calibration in preliminary tests. Nevertheless, it has to be mentioned that the use of VAS in this study might be a limitation since the calibration only ensures reproducibility of the measuring values in one single investigator. There is a need for the development of objective assessment methods for the accuracy of fit of PC in future studies. Moreover, it cannot be proven that the VAS values of the evaluation criteria were completely independent. That is why the Wilcoxon test was performed, because this statistical test considers a possible mutual influence between the VAS values and enables a statistical relevant evaluation.

Another limitation of the present study is that the cement gap for CAD/CAM PC was set at 50 μm in the Software, whereas for CPC the cement gap was set by the dimension changes of the investment material. In the conventional workflow it is impossible to define the cement gap by a certain diameter because it is impossible to put an even layer of varnish in the lumen of the post space preparation in the stone model. Therefore, one can assume that the friction and the accuracy of fit of PC is more predictable for the CAD/CAM workflow which is confirmed by the results of the present study because VAS values show a significantly wider variation in group C.

In addition, the deviation between the conventional and digital post impression was assessed. Contrarily to the investigation of accuracy of fit of PC and feasibility of impression taking, the deviation between the datasets of both impression methods was measurable by an objective 3D analysis software. In the present study, the deviation was determined by superimposing the two datasets with a best-fit algorithm. This is an established method in dental literature and has been described by many authors [19,46,47]. Therefore, the software automatically superimposes the datasets over the marked reference structures of the tooth in order to minimise the discrepancy between the point clouds [48]. *O'Toole* et al. investigated different methods of superimposing two datasets using the best-fit algorithm, a three-point superimposition, and a constant coordinate system [49]. The best-fit algorithm led to the fewest discrepancies in a clinically transferable setup, which was confirmed by other authors in dental literature [48,49]. Thus, to evaluate the deviation between the two post impression methods in the present *in vivo* study, the superimposition of the datasets with the best-fit algorithm was the most suitable method. In the present study the 3D superimposition was evaluated on two 2D cutting planes in perpendicular directions in order to standardise the measurement points representing every part of the post space preparation. Moreover, to minimise the influence of the scanner system, the stone models were digitalised using the same IOS that was used for the digital post impressions. *Chen* et al. showed that *Primescan* achieved the highest precision in comparison to another IOS and an extraoral laboratory scanner system [50]. *Ender* et al. confirmed these findings in a comparative study between seven different IOS [51]. *Elter* et al. used *Primescan* in an *in vitro* study for digital post impression because of its superior depth of focus compared to other IOS [22]. Moreover, *Primescan* is part of an established system that was developed for the fabrication of chairside fixed dental protheses and is therefore suitable for a fully digital chairside workflow for the fabrication of CAD/CAM PC. Even though in the present study the PC of investigation group D were milled of a fibre-reinforced composite, the fully digital chairside workflow is applicable to every material that is available for the milling unit. Therefore, CAD/CAM PC have the potential to give the dentist a lot of novel and innovative treatment options for teeth with severe coronal damage [7].

The investigation of the accuracy of fit and feasibility of impression taking according to the VAS on a standardised evaluation sheet showed significantly better results for investigation group D. These results are in line with *Campanella* et al., who investigated the accuracy of fit of CPC fabricated in a conventional workflow and CAD/CAM PC fabricated in a digital workflow [52]. They described that the quality of conventional post impressions are highly dependant on the clinician's skill and are therefore of inconsistent over different dentists. Since the completeness of digital post impressions can be checked on the display of the IOS and can be adjusted if necessary, this can help achieving a higher grade of standardisation of post impression quality because dependence on the clinician's skill decreases. Moreover, the wide variation in the VAS values for CPC show that the conventional workflow is quite inaccurate and error-prone in the present study. One reason for this might be that the conventional workflow consists of many analogue steps (impression, stone model fabrication, wax-modelling, embedding, lost wax technique for cast of PC) which all can be influenced by surrounding factors (e.g.: deformation of the impression material, disinfection of the impression, temperature). Even if every step is standardized to the highest possible degree (automatically mixing procedure of impression material, gypsum and embedding material, constant surrounding factors in the dental laboratory) one cannot avoid an influence of every analogue step on the intraoral accuracy of fit of CPC. The digital workflow skips the analogue model fabrication and modelling of PC by using a software which is independent of these surrounding factors. Therefore, one can conclude that CAD/CAM PC are less error-prone than CPC fabricated in a conventional workflow.

In the present study, there was a significant difference in the feasibility of impression taking between premolars, anterior teeth and molars. One reason for the poorer values of feasibility of impressions taking in molars might be the restrictions of the oral cavity, which makes it more challenging to scan posterior areas with IOS, in particular with *Primescan* because of the comparably large scanning tip. A possible explanation for the poorer feasibility of impression taking in anterior teeth compared to premolars might be that, other than premolars, anterior teeth regularly have a flared or elliptical root canal [31]. This

leads to possible slight undercuts after post space preparation because of the necessity of removing residual endodontic filling material at the root canals wall. These undercuts are challenging to scan because the light can hardly reach every part. Especially in these cases, it was helpful for the investigator to illuminate the lumen with the caries detection probe in order to complete the dataset of the digital post impression. Nevertheless, it must be noted that the use of the caries detection probe in some digital post impressions might have led to a bias in the results because in these cases it was not possible to scan the whole post space preparation without assisting light. It would be of high clinical interest to investigate the influence of assisting light for digital post impressions in future studies. A comparison between the digital post impression with and without caries detection probe was not possible in this study setup since the dataset without assisting light was extended and overwritten while using the caries detection probe. In dental practice this is a great advantage of IOS since a conventional impression is not subsequently completable after curing of the impression material.

Furthermore, the hardware and software of the IOS seems to have a significant influence on digital post impressions. *Pinto* et al. described in 2017 that individual CAD/CAM PC fabricated in a fully digital workflow are not possible since they were not able to scan post space preparations of less than 10 mm; however they used an outdated IOS [24]. *Elter* et al. used the same hardware as the investigator of the present study; however in an *in vitro* setup, and described a mean apical deviation of 357.1 μm for digital compared to conventional post impressions. They concluded that *Primescan* is only suitable for digital post impressions considering strict limitations regarding the preparation depth and diameter [22]. Even in an *in vivo* setup the mean apical deviation in the present study was significantly smaller which is known to be more challenging than *in vitro* because of the saliva and restrictions of the oral cavity [53]. One reason for the improved results of the present study might be the software: *Elter* et al. used the initial version 5.0.0 whereas in the present study the updated version 5.2.3 was used. The influence of the software on the precision of digital impressions has been described in dental literature [25]. This indicates that for digital post impressions, the IOS needs to have a hardware with a high depth of focus and an updated software version in order to achieve good accuracy of fit of CAD/CAM PC. Another reason for the differing results of the present study compared to *Elter* et al., might be the use of an ambient light during digital post impression. In the present study, preparations with a depth of more than 15 mm could be scanned completely, whereas *Elter* et al. described limitations in preparations with a depth of more than 14 mm. In the present study, the dataset of the digital post impression was completed by illumination with a caries detection probe, whereas *Elter* et al. did not consider the ambient light in their study. The significant influence of the ambient light on the precession of digital impression taking was described by *Ochoa-Lopez* et al., whereby the best ambient light differed between the IOS systems [23]. For *Primescan*, they found 10.000 lux to provide optimal conditions, which means that in some cases the lumen had to be illuminated even if the examination light of the dental unit was switched on. Regarding the deviation noted in the categories of "coronal" and "middle", the results of the present study are in line with already published data in dental literature, describing that deviation increases from coronal to apical levels of the post space preparation [19,22]. Besides the possible explanations already mentioned, another reason for the high divergence in the values of measurement category "apical" could be triggered by a known vulnerability of the conventional post impression: Unlike the digital post impression (which can be checked for completeness on the IOS display) with an analogue impression the representation until the deepest point of the post space preparation can hardly be checked. Therefore, it cannot be excluded that the impression material did not reach every part of the lumen, resulting in a CPC with a large cement gap in the apical area. This is hard to detect with conventional impressions. In the present study the authors recognized this in two cases on the X-Ray taken after CPC insertion. In those cases, the digital post impression reached more than 1 mm deeper than the conventional post impression, while the accuracy of fit and the feasibility of impression taking did not show a significant difference. This can be explained as the apical fit of PC in the root canal is not assessable during intraoral try-in. This could be an aim for future investigations since further development of assessment methods for accuracy of fit of PC would be of high clinical relevance. Regardless of the evaluation of accuracy of fit of PC, in the present study every tooth was treated with CPC since after a possible modification both PC were fitable. The reason for this was the lack of a long-term survival analysis of CAD/CAM PC made of *Trinia*, which should be investigated in future clinical studies. Nevertheless, the focus of this study was to compare the two workflows and CAD/CAM PC are not limited to fibre-reinforced composite.

Summarising the results of the present study, the fully digital chairside workflow for fabrication of customised CAD/CAM PC had significant advantages over the conventional workflow for CPC including time saving, accuracy of fit and constantly improved post impression quality. Since with the new workflow customised PC can be fitted in the same session as the post space preparation, the advantages of prefabricated posts regarding treatment simplification and matching elastic modulus to dentine can be combined with the advantages of CPC regarding accuracy of fit and mechanical stability. These advantages led to the implementation of the presented workflow as a standard in our clinic for treatment with PC.

5. Conclusions

Within the limitations of this study, the presented fully digital chairside workflow and the fabricated CAD/CAM PC showed better accuracy of fit and feasibility of impression taking than CPC fabricated in a conventional manner. Therefore, with CAD/CAM, it is possible to restore endodontically treated teeth with customised PC in a single session.

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Ethical approval

In vivo comparison between CAD/CAM PC and CPC (Reg. No. 267/13).

Informed consent

For this type of study, formal consent is not required.

CRediT authorship contribution statement

Jonas Adrian Helmut Vogler: Writing – original draft, Visualization, Methodology. **Louise Billen:** Investigation. **Kay-Arne Walther:** Validation. **Bernd Wöstmann:** Supervision, Project administration, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jdent.2023.104638.

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7.2.8 Anwendung des digitalen Workflows zur Versorgung von frakturierten Teleskoppfeilerzähnen mit glasfaserverstärkten CAD/CAM-Komposit Stiftaufbauten.

J.A.H. Vogler*, K.A. Walther, P. Rehmann, B. Wöstmann, CAD/CAM Post and Core for telescopic crowns after fracture, Int J Comput Dent (2024) (Zur Publikation angenommen am 20.10.2024) (IF 2024: 1,8)

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1 **CAD/CAM Post and Core for telescopic crowns after fracture.**

2 ABSTRACT / KEYWORDS:

3 Aim: Fracture of abutment teeth for telescopic crown retained removeable partial dentures (TCD) is a
4 common cause of failure for this prosthetic restoration. In many cases the telescopic crown (TC) can
5 only be refitted after post and core (PC) treatment, because of insufficient retention surface.
6 Furthermore, if the root canal has an elliptic cross-sectional area or the coronal defect is severe,
7 customised cast post and core (CPC) is still the therapy of choice. Nevertheless, CPC has the
8 disadvantage of an enlarged chair-time because a second appointment for the insertion is mandatory
9 and the mechanical properties of the alloy does not fit to dentin leading to a higher risk for root
10 fracture. In those cases, CAD/CAM PC fabricated in a fully digital chairside workflow can accelerate
11 the treatment and decrease the risk for root fractures by using materials with matching mechanical
12 properties.

13 Materials and methods: This case series presentation includes twelve patients who were treated with
14 TCD and suffered from abutment tooth fracture needing PC treatment to refit TC. The post space
15 preparation as well as the TCD was scanned for fabrication of CAD/CAM PC in less than 10 minutes
16 out of a fibre reinforced CAD/CAM composite.

17 Conclusion: With the presented fully digital chairside workflow, PC fabrication can be accelerated and
18 customised PC are no longer mandatory to a second appointment. The presented fully digital chairside
19 workflow might be an alternative to conventional PC to
20 refit TC after abutment tooth fracture. The CAD/CAM-fabricated PC offers mechanical properties close
21 to dentin and can be fabricated chairside in a short period of time.

22

23 CAD/CAM; Intraoral scanner; Post and core; Telescopic denture; Abutment tooth fracture; Fibre
24 reinforced composite

25

26 INTRODUCTION:

27 Due to extra axial forces when TCD is removed and inserted incorrectly[1] or when the long denture
28 saddle does not fit the edentulous jaw areas[2], risk for abutment tooth fracture increases because of
29 the rigid connection to the denture.[2,3] Thus, fracture of abutment teeth for TCD is frequently described
30 in dental literature as a common cause of failure for these restorations.[2-4] Nevertheless, not in every
31 fracture, extraction of the tooth is mandatory.[5] Since for TCD comparably much tooth structure has to
32 be removed,[6] fracture often occurs within the area of the preparation for TC resulting in an insufficient
33 coronal height to reattach the existing TC without additional effort.[7] In these cases, it is possible to
34 refit the existing TC with PC after endodontic treatment.[8] The precondition for this is that the fracture
35 line is at least 2 mm above the preparation margin of TC because this ferrule is known to be the
36 predominant factor for long-term success of PC treatment.[7]
37 In cases with severe coronal defects after tooth fracture, treatment with customised CPC is still
38 considered to be the "gold standard",[9-11] but an increased risk for root fracture is related to the
39 mismatch of the mechanical properties between alloy and dentin.[10-13] Furthermore, a second
40 appointment is mandatory for insertion of CPC because of the time consuming analogue workflow in
41 the dental laboratory.[1,14] That is why prefabricated posts with composite core build-ups are widely
42 used in dental practices,[15] because this treatment option makes it possible to restore a tooth in a
43 single session.[16] Moreover, by using prefabricated fibre reinforced posts (PFRP) the mechanical
44 properties match to dentin, decreasing the risk for root fracture.[12,17] However, PFRP have a worse
45 accuracy of fit compared to CPC especially in root canals with an elliptic cross-sectional area and are
46 less mechanically stable because of the interface between post and core build-up.[10,18-20] The
47 mechanical stability comes mainly into effect with fractured abutment teeth because of the extra axial
48 forces related to TCD.[1-3] Thus, PFRP are mainly indicated with a greater amount of remaining
49 dentin,[7,21,22] which is unusual after fracture of an abutment tooth of TCD.

50 Therefore, this case series presentation aims to present a fully digital chairside workflow to refit TC
51 after abutment tooth fracture combining the advantages of mechanically stable, well-fitting CPC and
52 single session PFRP treatment by using an intraoral scanner (IOS) and a CAD/CAM material matching
53 to the mechanical properties of dentin.

54 CASE SERIES PRESENTATION:

55 This clinical report describes in total twelve patients who were treated with TCD in the past and were
56 referred to the *[removed for anonymity reasons]* because of suffering from abutment tooth fracture
57 throughout 2023. In one case, the tooth was already root-canal-treated whereas in the remaining
58 eleven cases the tooth showed symptoms of an irreversible pulpitis needing a root canal treatment.
59 All 12 teeth were last posterior anchors of TCD. This case series presentation includes photographies
60 of in total four patients, representing the twelve patients who were treated according to the
61 illustrated workflow. In all cases there was insufficient retention surface to refit TC without any
62 additional effort, but the preparation margin was at least 2 mm below the fracture line, providing
63 sufficient ferrule so that TC could be refitted after PC treatment (Fig. 1). Due to the severe coronal
64 defect the correct position of TC on the abutment tooth was only stable by guidance and support of
65 TCD (Fig. 1). Thus, it would have been necessary for CPC fabrication in the conventional workflow to
66 take the impression of the post space preparation with TCD, so that the patient would have to
67 renounce the denture for the time of CPC fabrication, leading to an uncomfortable functional and
68 aesthetic constraint. Figure 1 illustrates this problem by means of a fractured abutment tooth 34.
69 Recent technical developments of IOS (Primescan, Dentsply Sirona, Germany) make it possible to scan
70 the post space preparation[14,23,24] as well as the TCD extra- and intraorally[25,26], so that a digital model
71 with corresponding STL-datasets can be used for virtual construction of a PC to refit the TC.
72 Subsequently, the same software (CEREC Primescan 5.2.3, Dentsply Sirona, Germany) can be used for
73 CAD/CAM fabrication of the PC in a milling machine that was developed for chairside fabrication of
74 prosthetic restorations (MCXL, Dentsply Sirona, Germany) in less than 10 minutes (Fig. 2). Figure 2

75 shows the workflow by means of a patient who suffered from decementation of a poor-fitting PFRP in
76 combination with a horizontal fracture of the abutment tooth in the area of the preparation for TC.
77 The thick layer of adhesive cement around the post (red arrow) illustrates the bad accuracy of fit in
78 the root canal and the need for reattachment of the TC with a customised PC (Fig. 2). There is a large
79 variety of materials available for chairside and labside CAD/CAM fabrication. In this case series
80 presentation, the PC were milled out of a fibre reinforced CAD/CAM composite (Trinia, Bicon, USA)
81 which has mechanical properties matching to dentin and is therefore suitable for PC fabrication when
82 the orientation of the fibres in relation to the load axis is considered.[14,27,28] This orientation was set in
83 the IOS software by positioning the PC in der CAD/CAM block (Fig. 2).

84 With this fully digital chairside workflow, PC fabrication can be accelerated and customised PC are no
85 longer mandatory to a second appointment providing better comfort for the patient and economic
86 advantages for the dentist.[14] Moreover, CAD/CAM PC show even better accuracy of fit in the root
87 canal than CPC fabricated in an analogue workflow.[24] The reason for this is that the digital post
88 impression is less dependent on the clinicians skill because it can be checked instantly on the display
89 for completeness and supplemented if necessary.[29] A conventional post impression is hard to
90 supplement and especially in the apical area it is impossible to check if the impression material
91 reached every part of the post space preparation leading to bad accuracy of fit of PC.[24] Nevertheless,
92 also the digital post impression is not trivial because every IOS is an optical system with different ideal
93 ambient conditions in which the light has to reach every part of the post space preparation in order
94 to gain the best accuracy of fit.[30] *Primescan* achieves the best precision at 10000 lux which is obviously
95 hard to ensure in deep post space preparations.[31] Therefore, deep post space preparations in this case
96 series presentation were illuminated with a caries detection probe when supplementation of the
97 digital post impression was needed. Figure 3 illustrates the difference between the digital post
98 impression with and without illumination of the lumen in a patient with a fractured abutment tooth
99 34.

100 Subsequently after CAD/CAM fabrication the PC is cut off from the block and tried-in intraorally. The
101 fibre reinforced composite does not need for any post-processing after milling except from blasting
102 with aluminium oxide and cleaning with ethanol in an ultrasonic bath immediately before fitting with
103 an adhesive cement system (Panavia V5 + Clearafil Ceramic Primer Plus + Tooth Primer, Kuraray
104 Noritake, Japan) according to the manufacturer's instructions.[14] Figure 4 illustrates the try-in and
105 fitting process by means of a fractured abutment tooth in the lower jaw.
106 There is no necessity for some kind of special follow-up after refitting TC with PC after abutment tooth
107 fracture according to the presented fully digital chairside workflow. Nevertheless, there is evidence in
108 dental literature that survival probability for TCD itself as well as for the abutment teeth increases
109 when patients follow a strict aftercare program, but there is no need for a special focus related to the
110 described workflow.[2,4]
111 DISCUSSION:
112 This case series presentation shows that due to digital advancements, customised PC with better
113 mechanical properties than conventional CPC can be fitted in a single session by using the CAD/CAM
114 technology because time-consuming analogue steps can be renounced.[32]
115 These improvements for PC treatment might come into effect especially in combination with TCD
116 because many authors describe the worst survival probability for PC under TCD compared to all other
117 covering prosthetic restorations.[1,9,33] Furthermore, special care concerning accuracy of fit and
118 mechanical behaviour of the chosen material should be taken when treating abutment teeth for TCD
119 with PC, because a large and inhomogeneous cement gap as well as a rigid post can lead to
120 inconsistent stress distribution into the root dentin, favouring fractures and resulting in a higher risk
121 for tooth loss. [10,32,34-36] This negative effect can even be supported when TCD is removed and inserted
122 incorrectly or when the denture saddle does not fit to the edentulous jaw areas, because the resulting
123 extra axial forces on the tooth are transmitted through the post directly into the root.[1-3] Another cause
124 of failure that is often described in relation to poor-fitting posts is a higher risk for decementation

125 leading to secondary caries thus tooth loss.[10,24] Therefore, one can conclude that PFRP which can be
126 fitted in a single session should only be used to refit TC after fracture if the coronal defect is moderate
127 and the root canal has a round diameter. Nevertheless, this is unusual after abutment tooth fracture.
128 The decementation of PFRP is also illustrated in the case shown in Figure 2. The reason why PC
129 combining the advantages of PFRP and CPC can only recently be fabricated is that suitable materials
130 for customised PC with matching mechanical properties to dentin are limited to the comparably new
131 CAD/CAM workflow.[10,37,38] *Al-Qarni* published a review over CAD/CAM PC and agreed that the clinical
132 data about this promising new technology is scarce.[10] One limitation that many authors described in
133 the past was that in their investigations the digital post impression with IOS was only possible with
134 short and conical post preparation depths.[23] Nevertheless, many IOS that were used in these older
135 studies are no longer up to date and therefore incomparable to modern systems.[39,40] Due to the
136 further development of IOS in both Soft- and Hardware, newer studies described that even deep post
137 space preparations can be scanned properly.[24,37] However, it can be assumed that not every system is
138 suitable for digital post impression since they differ concerning their ideal ambient conditions and
139 especially their depth of focus.[23,31,39] That is why the dentist should be well informed about the IOS in
140 use since by knowing how to optimize the scanning conditions for the specific system one can avoid
141 failures and improve the quality of the digital impression.[24,31] Furthermore, *Primescan* is particularly
142 suitable for fabrication of CAD/CAM PC to refit TC because it is part of a well-established system for
143 chairside fabrication of prosthetic restorations.[14] Therefore, the combination of an IOS with a Software
144 including virtual construction ability (CAD) as well as milling control (CAM) and a compatible chairside
145 Milling Unit (MCXL) accelerates the fabrication of PC and enables the single session treatment
146 presented in this case series presentation.
147 Nevertheless, there are still some limitations to the presented workflow which need to be considered
148 by clinicians. Since the CAD/CAM PC were milled as a monobloc restoration consisting of a post and a
149 core part, this workflow is only applicable with an absence of undercuts. These undercuts can either
150 result from axial deviation between the coronal defect and the post space preparation or if in

151 multirooted teeth more than one post space preparation is needed in order to provide sufficient
152 adhesive surface for PC treatment. In these cases, PFRP are advantageous because post and core part
153 are not connected until fitting in the tooth and therefore undercuts can be filled with composite
154 before light curing. However, Trinia has a 43% higher fracture load than PFRP and a mechanical
155 behaviour similar to that of dentine which makes this material in particular suitable for fabrication of
156 PC when extra axial forces can be expected.[28,41] Nevertheless, it has to be mentioned that yet the only
157 survival data for PC made of Trinia are based on in vitro chewing simulation imitating an intraoral wear
158 of five years.[14] Therefore, more clinical and in-vitro studies are needed to evaluate the long term
159 survival of PC fabricated in the presented workflow. Moreover, an improvement of PC treatment with
160 TCD is of high clinical relevance since many authors found the worst survival probability with TCD
161 compared to all other covering prosthetic restorations.[1,22,33]
162 Possible alternatives to the treatment of refitting TC with PC are extracting the tooth and placing an
163 implant or fitting of a special prefabricated post with a ball attachment connection in order to reattach
164 TCD on a fractured abutment tooth renouncing the existing TC, described by *Rottner et al.*[5] The
165 disadvantage of placing an implant is the necessity of a surgical treatment related to higher burden
166 and costs for the patient. The advantages are good survival rates of an implant treatment and a high
167 load capacity.[42] A disadvantage related to the technique described by *Rottner et al.* is that the ball
168 attachment is related to a strictly rigid connection to TCD, transmitting occlusal forces only onto the
169 tooth. Though, TCD can be modified in order to transmit occlusal forces onto both the soft tissue and
170 the tooth, which can be advantageous for tooth preservation in particular in patients with few
171 remaining teeth.[4] The advantage is that the treatments is described as being fast and comparably
172 cheap.[5]

173 CONCLUSION:

174 The presented fully digital chairside workflow can improve the quality of the treatment of PC to refit
175 TC after abutment tooth fracture. In particular, through this workflow well-fitting customised PC with

176 mechanical properties similar to dentin can be fabricated chairside in a short period of time.
177 Therefore, fabrication of customised PC is no longer mandatory to a second appointment because of
178 the renouncement on time-consuming analogue work steps.

179

180 **CAD/CAM Stiftaufbauten bei frakturierten Teleskoppfeilern.**

181 ZUSAMMENFASSUNG / INDIZES:

182 Ziel: Die Pfeilerzahnfraktur von Teleskopprothesen (TP) ist eine häufige Misserfolgsursache bei dieser
183 prothetischen Versorgungsoption. In vielen Fällen kann die Teleskopkrone (TK) nur nach
184 Rekonstruktion mittels Stiftaufbau (SA) wiedereingesetzt werden, da die Restretentionsfläche nicht
185 ausreicht. Wenn der Wurzelkanal dabei einen elliptischen Querschnitt aufweist, oder der koronale
186 Defekt ausgeprägt ist, stellt ein individuell gegossener Stift-Stumpfaufbau (GSA) nach wie vor die
187 Therapie der Wahl dar. GSA haben jedoch die Nachteile einer verlängerten Behandlungszeit, da ein
188 zweiter Termin für das Einsetzen erforderlich ist und die mechanischen Eigenschaften der Legierung
189 nicht an das Dentin angepasst sind, was zu einem höheren Risiko von Wurzelfrakturen führen kann.
190 In diesen Fällen kann ein CAD/CAM SA, der in einem volldigitalen chairside Workflow hergestellt wird,
191 die Behandlung beschleunigen und das Risiko von Wurzelfrakturen verringern, indem Materialien mit
192 dentinähnlichen mechanischen Eigenschaften verwendet werden.
193 Material und Methoden: In dieser Fallserie werden zwölf Patienten mit einer
194 Teleskoppfeilerzahnfrakturen vorgestellt, bei denen ein Stiftaufbau zur Wiederbefestigung der TK
195 erforderlich war. Die Stiftbettpräparation sowie die TP wurden gescannt und in weniger als 10
196 Minuten ein CAD/CAM SA aus einem faserverstärkten CAD/CAM-Komposit hergestellt.

197 Fazit: Mit dem vorgestellten volldigitalen chairside Workflow kann die SA Behandlung beschleunigt
198 werden, da individuelle SA nicht mehr zwingend einen zweiten Termin zum Einsetzen benötigen.
199 Daher kann dieser Workflow eine Alternative für die Versorgung von frakturierten Teleskoppfeilern
200 mit konventionellen GSA sein. Die CAD/CAM SA zeigen hierbei ein mechanisches Verhalten ähnlich
201 dem des Dentins und können chairside in kurzer Zeit hergestellt werden.

202 EINLEITUNG:

203 Aufgrund nichtaxialer Kräfte beim Herausnehmen und falschen Einsetzen von TP[1] oder wenn der lange
204 Prothesensattel Inkongruenzen zum Prothesenlager aufweist[2], steigt das Risiko einer
205 Pfeilerzahnfraktur aufgrund der starren Verbindung zwischen TP und Pfeilerzahn. [2,3] Aus diesem Grund
206 wird die Fraktur von Teleskoppfeilerzähnen in der Literatur als häufige Misserfolgsursache bei diesen
207 Restaurationen beschrieben.[2-4] Jedoch geht nicht jede Fraktur zwingend mit der Extraktion des Zahnes
208 einher.[5] Weil für TP vergleichsweise viel Zahnhartsubstanz entfernt werden muss,[6] kommt es häufig
209 zu Frakturen im Bereich der TK-Präparation, sodass die Stumpfhöhe nicht mehr ausreicht, um die
210 vorhandene TK ohne zusätzliche Maßnahmen wieder zu befestigen.[7] In diesen Fällen ist es möglich,
211 die vorhandene TK nach der endodontischen Behandlung mittels eines SA wieder zu befestigen.[8]
212 Voraussetzung hierfür ist, dass die Frakturlinie mindestens 2 mm oberhalb der Präparationsgrenze der
213 TK liegt, da dieser Ferule-Effekt den Langzeiterfolg von SA maßgeblich beeinflusst.[7]
214 Bei ausgeprägten koronalen Defekten nach einer Zahnfraktur gilt die Behandlung mit individuellen
215 GSA nach wie vor als "Goldstandard",[9-11] allerdings besteht hierbei ein erhöhtes Risiko für
216 Wurzelfrakturen, da die mechanischen Eigenschaften der Legierung und des Dentins nicht
217 übereinstimmen.[10-13] Außerdem ist für das Einsetzen von GSA, aufgrund des zeitaufwändigen
218 analogen Arbeitsablaufs im Dentallabor, immer ein zweiter Termin erforderlich.[1,14] Aus diesem Grund
219 werden in Zahnarztpraxen häufig konfektionierte Stifte mit Kompositstumpfaufbauten verwendet,[15]
220 da diese Behandlungsoption die Wiederherstellung eines Zahns in einer einzigen Sitzung ermöglicht.
221 [16] Darüber hinaus sind die mechanischen Eigenschaften von konfektionierten, glasfaserverstärkten
222 Stiften (KGS) mit denen des Dentins vergleichbar, was das Risiko von Wurzelfrakturen verringert.[12,17]
223 Andererseits weisen KGS im Vergleich zu GSA insbesondere bei Wurzelkanälen mit elliptischem
224 Querschnitt eine schlechtere Passgenauigkeit auf und sind aufgrund der Phasengrenze zwischen Stift
225 und Stumpfaufbau mechanisch weniger stabil.[10,18-20] Diese mechanische Instabilität kommt vor allem
226 bei frakturierten Teleskoppfeilerzähnen aufgrund der auftretenden nichtaxialen Kräfte zum Tragen.[1-
227 3] KGS sind daher hauptsächlich bei größeren Restdentinmengen indiziert,[7,21,22] was nach einer
228 Teleskoppfeilerfraktur selten vorliegt.

229 Diese Fallserie stellt einen volldigitalen chairside Workflow zur Widerbestfestigung von TK nach einer
230 Pfeilerzahnfraktur vor, der die Vorteile von mechanisch stabilen, passgenauen GSA mit denen einer
231 KGS-Behandlung in einer Sitzung kombiniert. Mit Hilfe eines intraoralen Scanners (IOS) und eines
232 CAD/CAM-Materials, das auf die mechanischen Eigenschaften von Dentin abgestimmt ist, ist es
233 möglich individuelle SA in einer Sitzung anzufertigen und einzugliedern.

234 FALLSERIENVORSTELLUNG:

235 In diesem klinischen Fallbericht werden insgesamt zwölf Patienten beschrieben, die in der
236 Vergangenheit mit TP behandelt und wegen einer Pfeilerzahnfraktur im Laufe des Jahres 2023 an die
237 Abteilung *[aus Anonymitätsgründen entfernt]* überwiesen wurden. In einem Fall, war der Zahn bereits
238 wurzelkanalbehandelt, wohingegen in den anderen elf Fällen der Zahn Symptome einer irreversiblen
239 Pulputis zeigte, welche eine Wurzelkanalbehandlung nötig machten. Alle 12 Zähne waren posterior
240 endständige Pfeilerzähne einer TP. Dieser Fallserienbericht umfasst Fotografien von insgesamt vier
241 Patienten, die die zwölf Patienten repräsentieren, welche nach dem dargestellten Workflow
242 behandelt wurden. In allen Fällen reichte die Reststumpfhöhe nicht aus, um die TK ohne zusätzliche
243 Maßnahmen wiederzubefestigen, aber die Präparationsgrenze lag mindestens 2 mm unterhalb der
244 Frakturlinie, sodass die TK mittels SA wiedereingesetzt werden konnte (Abb. 1). Aufgrund des
245 ausgeprägten koronalen Defektes war die korrekte Position der TK auf dem Pfeilerzahn nur durch die
246 Führung und Stabilisierung der TP eindeutig (Abb. 1). Aus diesem Grund wäre es für die GSA
247 Herstellung im konventionellen Workflow notwendig gewesen, die Abformung der
248 Stiftbettpräparation mit der TP vorzunehmen, sodass der Patient für die Zeit der GSA Herstellung auf
249 die Prothese hätte verzichten müssen. Dies wäre unweigerlich mit erheblichen funktionellen und
250 ästhetischen Einschränkungen verbunden gewesen. Abbildung 1 veranschaulicht dieses Problem am
251 Beispiel eines frakturierten Pfeilerzahns 34. Neueste, technische Entwicklungen auf dem Gebiet der
252 IOS (Primescan, Dentsply Sirona, Deutschland) ermöglichen es, die Stiftbettpräparation[14,23,24] sowie
253 die TP[25,26] extra- und intraoral zu scannen, sodass ein digitales Modell aus STL-Datensätzen für die

254 virtuelle Konstruktion eines SA zur Wiederbefestigung der TK errechnet werden kann. Anschließend
255 kann dieselbe Software (CEREC Primescan 5.2.3, Dentsply Sirona, Deutschland) für die CAD/CAM-
256 Fertigung des SA auf einer für die chairside Fertigung von prothetischen Restaurationen entwickelten
257 Schleifmaschine (MCXL, Dentsply Sirona, Deutschland) in weniger als 10 Minuten verwendet werden
258 (Abb. 2). Abbildung 2 zeigt den Workflow anhand eines Patienten mit einem dezementierten,
259 passungenauer KGS in Kombination mit einer horizontalen Pfeilerzahnfraktur im Bereich der TK-
260 Präparation. Die dicke Adhäsivzementschicht an dem KGS (roter Pfeil) verdeutlicht die schlechte
261 Passgenauigkeit im Wurzelkanal und die Notwendigkeit der Wiederbefestigung der TK mit einem
262 individuellen SA (Abb. 2). Sowohl für die chairside, als auch für labside CAD/CAM-Fertigung steht eine
263 große Auswahl an Materialien am Markt zur Verfügung. In diesem Fallserienbericht wurden die SA aus
264 einem glasfaserverstärkten CAD/CAM-Komposit (Trina, Bicon, USA) gefräst, welches über
265 dentinähnliche mechanische Eigenschaften verfügt und daher für die SA Herstellung besonders
266 geeignet ist. Voraussetzung hierfür ist, dass die Ausrichtung der Fasern in Bezug auf die
267 Belastungsachse berücksichtigt wird.[14,27,28] Diese Ausrichtung wurde in der IOS-Software durch
268 Positionierung des SA im CAD/CAM-Block eingestellt (Abb. 2).
269 Mit diesem volldigitalen chairside Workflow kann die SA Herstellung beschleunigt und individuelle SA
270 müssen nicht mehr zwingend erst in einem zweiten Termin eingegliedert werden, was einen höheren
271 Komfort für den Patienten und wirtschaftliche Vorteile für den Zahnarzt mit sich bringt.[14] Darüber
272 hinaus weisen CAD/CAM SA eine noch bessere Passgenauigkeit im Wurzelkanal auf, als GSA, die in
273 einem analogen Workflow hergestellt wurden.[24] Der Grund dafür ist, dass die digitale Stiftabformung
274 unabhängiger von der Erfahrung und dem Können des Zahnarztes ist, da sie sofort auf dem Bildschirm
275 auf Vollständigkeit überprüft und gegebenenfalls ergänzt werden kann.[29] Eine konventionelle
276 Stiftabformung ist dagegen schwer zu ergänzen und insbesondere im apikalen Bereich ist es unmöglich
277 zu überprüfen, ob das Abformmaterial jeden Teil der Stiftbettpräparation erreicht hat, was zu einer
278 schlechten Passgenauigkeit des GSA führen würde.[24] Dennoch ist auch die digitale Stiftabformung
279 nicht trivial, denn jeder IOS ist ein optisches System mit herstellerabhängigen idealen

280 Umgebungsbedingungen, wobei immer gewährleitet werden muss, dass das Licht jeden Teil der
281 Stiftbettpräparation erreicht.[30] Primescan erreicht die beste Präzision bei 10000 Lux, was bei tiefen
282 Stiftaufbereitungen offensichtlich schwer zu gewährleisten ist.[31] Daher wurden tiefe
283 Stiftbettpräparationen in diesem Fallserienbericht mit einer Karieserkennungssonde erleuchtet, wenn
284 eine Ergänzung der digitalen Stiftabformung im apikalen Bereich erforderlich war. Abbildung 3 zeigt
285 den Unterschied zwischen der digitalen Stiftabformung mit und ohne Erleuchten des Lumens bei
286 einem Patienten mit einem frakturierten Pfeilerzahn 34.
287 Unmittelbar nach der CAD/CAM-Fertigung des SA wurde dieser aus dem Block herausgetrennt und
288 intraoral anprobiert. Der glasfaserverstärkte Komposit musste nach dem Fräsen nicht weiter
289 nachbearbeitet werden. Nach Abstrahlen mit Aluminiumoxid und der Reinigung mit Ethanol in einem
290 Ultraschallbad wurde der SA mit einem Adhäsivzement (Panavia V5 + Clearafil Ceramic Primer Plus +
291 Tooth Primer, Kuraray Noritake, Japan) gemäß den Herstellerangaben eingesetzt.[14] Abbildung 4
292 veranschaulicht den Einprobe- und Einsetzprozess anhand eines frakturierten Pfeilerzahns im
293 Unterkiefer.

294 Grundsätzlich besteht keine Notwendigkeit für eine spezielle Nachsorge nach dem Wiedereinsetzen
295 einer TK mittels eines SA gemäß dem vorgestellten volldigitalen chairside Workflow. Dennoch gibt es
296 in der Literatur Hinweise darauf, dass die Überlebenswahrscheinlichkeit für TP und deren Pfeiler
297 steigt, wenn die Patienten eine strikte Nachsorge einhalten.[2,4] Es besteht jedoch keine Notwendigkeit
298 für eine explizite Änderung dieser Nachsorge im Zusammenhang mit dem beschriebenen Workflow.

299 DISKUSSION:

300 Dieser Fallserienbericht zeigt, dass aufgrund des digitalen Fortschritts und mit Hilfe der CAD/CAM-
301 Technologie individuelle SA mit besseren mechanischen Eigenschaften als konventionelle GSA in einer
302 einzigen Sitzung eingesetzt werden können, da auf zeitaufwändige analoge Schritte verzichtet werden
303 kann.[14] Diese Verbesserungen für die Behandlung mit SA könnten vor allem in Kombination mit TP
304 zum Tragen kommen, da viele Autoren die schlechteste Überlebenswahrscheinlichkeit für SA unter TK

305 im Vergleich zu allen anderen prothetischen Versorgungen beschreiben.[1,9,33] Darüber hinaus sollte bei
306 der Versorgung von Teleskoppfeilerzähnen mit SA ein besonderes Augenmerk auf die Passgenauigkeit
307 und das mechanische Verhalten des gewählten Materials gelegt werden. Ein großer und inhomogener
308 Zementspalt sowie ein rigider Stift kann zu einer inhomogenen Spannungsverteilung im Wurzeldentin
309 führen, was Frakturen begünstigt und ein höheres Risiko für Zahnverlust mit sich bringt.[10,32,34-36] Dieser
310 negative Effekt kann sogar noch verstärkt werden, wenn die TP falsch entnommen oder eingesetzt
311 wird, beziehungsweise wenn der Prothesensattel Inkongruenzen zum Prothesenlager aufweist, da die
312 daraus resultierenden nichtaxialen Kräfte auf den Zahn über den Stift direkt in die Wurzel übertragen
313 werden.[1-3] Eine weitere Misserfolgsursache, die häufig im Zusammenhang mit passungenauen SA
314 beschrieben wird, ist ein höheres Dezementierungsrisiko, das zu Sekundärkaries und damit zu
315 Zahnverlust führen kann.[10,24] Daraus lässt sich schließen, dass KGS, die zwar in einer einzigen Sitzung
316 eingesetzt werden können, nur dann für die Wiederbefestigung von TK nach Pfeilerzahnfrakturen
317 verwendet werden sollten, wenn der koronale Defekt moderat ist und der Wurzelkanal einen runden
318 Querschnitt aufweist. Dies ist jedoch nach Pfeilerzahnfrakturen nicht immer der Fall. Die
319 Dezementierung von passungenauen KGS wird auch in dem in Abbildung 2 dargestellten Fall deutlich.
320 Der Grund warum SA, die die Vorteile von KGS und GSA vereinen, erst seit Kurzem hergestellt werden
321 können, liegt darin, dass geeignete Materialien für individuelle SA mit dentinähnlichen mechanischen
322 Eigenschaften sich nur in dem vergleichsweise neuen CAD/CAM-Workflow verarbeiten lassen.[10,37,38]
323 Al-Qarni publizierte in diesem Zusammenhang eine Übersichtsarbeit über CAD/CAM SA und
324 beschrieb, dass die klinische Datenlage für diese vielversprechende neue Technologie noch begrenzt
325 ist.[10] Eine Einschränkung, die viele Autoren in der Vergangenheit beschrieben haben, war, dass in ihren
326 Untersuchungen die digitale Stiftabformung mit IOS nur bei kurzen und konischen Aufbereitungstiefen
327 möglich war.[23] Viele IOS, die in diesen älteren Studien verwendet wurden, sind jedoch nicht mehr auf
328 dem neuesten Stand der Technik und daher nicht mit modernen Systemen vergleichbar.[39,40] Durch die
329 Weiterentwicklung der IOS sowohl im Soft- als auch im Hardwarebereich beschreiben neuere Studien,
330 dass auch tiefere Stiftbettpräparationen gescannt werden können.[24,37] Es ist jedoch davon

331 auszugehen, dass nicht jedes System für die digitale Stiftabformung geeignet ist, da sich diese
332 hinsichtlich ihrer idealen Umgebungsbedingungen und vor allem ihrer Tiefenschärfe
333 unterscheiden.[23,31,39] Aus diesem Grund sollte der Zahnarzt gut über das verwendete IOS informiert
334 sein, denn wenn er weiß, wie er die Scanbedingungen für das jeweilige System optimieren kann, lassen
335 sich Fehler vermeiden und die Qualität der digitalen Abformung verbessern.[24,31] Darüber hinaus eignet
336 sich Primescan besonders gut für die hier vorgestellte Herstellung von CAD/CAM SA zur
337 Wiederbefestigung von TK, da es Teil eines ausgereiften Systems für die chairside Fertigung von
338 prothetischen Restaurationen ist.[14] Erst die Kombination eines IOS mit einer Software für die virtuelle
339 Konstruktion (CAD) sowie die Frässteuerung (CAM) und zusätzlich eine kompatible chairside
340 Fräseinheit (MCXL), ermöglicht die in diesem Fallserienbericht vorgestellte Behandlung mit
341 individuellen SA in einer Sitzung.
342 Nichtsdestotrotz, gibt es auch bei dem hier vorgestellten Workflow einige Limitationen, welche der
343 Behandler beachten muss. Aufgrund der einteiligen Herstellung der CAD/CAM SA, bestehend aus
344 einem Stift- und einem Stumpfanteil, eignet sich der Workflow nur, wenn keine Unterschnitte
345 vorhanden sind. Diese Unterschnitte können einerseits aus einer Achsenabweichung zwischen der
346 koronalen Kavität und der Stiftbettpräparation entstehen, oder bei mehrwurzligen Zähnen auftreten,
347 wenn zur Gewährleistung einer ausreichenden Adhäsionsfläche mehr als ein Kanal stiftaufbereitet
348 werden muss. In diesen Fällen sind KGS vorteilhaft, da der Stift- und der Stumpfanteil erst beim
349 Einsetzen in den Zahn verbunden werden und daher Unterschnitte vor der Lichthärtung mit Komposit
350 aufgefüllt werden können. Andererseits hat Trinia eine 43% höhere Frakturresistenz, als KGS und
351 darüber hinaus mechanische Eigenschaften, die denen des Dentins entsprechen, weshalb das Material
352 besonders geeignet ist, wenn mit nichtaxialen Kräften gerechnet werden muss.[28,41] Jedoch muss an
353 dieser Stelle darauf hingewiesen werden, dass bisher nur Überlebenszeitendaten zu SA aus Trinia
354 vorliegen, die auf einer in vitro Kausimulation über eine simulierte Tragedauer von 5 Jahre basieren.[14]
355 Aus diesem Grund sind mehr klinische und Laborstudien notwendig, um den Langzeiterfolg von SA,
356 die nach dem hier vorgestellten Workflow hergestellt wurden, zu untersuchen. Des Weiteren ist eine

357 Verbesserung der Behandlungsmethoden von SA unter TP von hohem klinischen Nutzen, da viele
358 Autoren hierfür die schlechtesten Überlebenswahrscheinlichkeiten im Vergleich zu allen anderen
359 prothetischen Versorgungsoptionen beschreiben.[1,22,33]
360 Mögliche Behandlungsalternativen zur Wiederbefestigung einer Teleskopkrone nach
361 Pfeilerzahnfraktur mittels SA sind die Extraktion des Zahnes und Insertion eines Implantates, sowie
362 das Einsetzen eines speziellen, konfektionierten Stiftes mit einem Kugelattachment. Dieser wurde von
363 *Rottner et al.* beschrieben und befestigt die TP auf dem frakturierten Pfeilerzahn, ohne die
364 vorhandene TK wiederzuverwenden.[5] Die Nachteile einer Implantation sind die Notwendigkeit eines
365 chirurgischen Eingriffs, welcher unweigerlich mit einer höheren Belastung des Patienten sowie
366 höheren Kosten verbunden ist. Vorteilhaft sind die guten Überlebensraten von
367 Implantatversorgungen in Verbindung mit deren hoher mechanischer Belastbarkeit.[42] Ein Nachteil,
368 der mit der Behandlungsoption nach *Rottner et al.* verbunden ist, ist dass das Kugelattachment eine
369 starre Verbindung zwischen dem Pfeilerzahn und der TP herstellt, wobei die Kaukraft nur auf den
370 Pfeilerzahn weitergeleitet wird. TP mit TK können allerdings so modifiziert werden, dass die Kaukräfte
371 sowohl auf die Gingiva, als auch auf den Zahn verteilt werden. Dies kann sich vor allem bei wenigen
372 Restzähnen positiv auf den Zahnerhalt auswirken.[4] Der Vorteil der Behandlungsoption nach *Rottner*
373 *et al.* ist andererseits, dass die Behandlungsoption als vergleichsweise schnell und günstig
374 beschrieben wird .[5]

375 SCHLUSSFOLGERUNG:

376 Der vorgestellte volldigitale chairside Workflow kann die Qualität der Versorgung mit SA für die
377 Wiederbefestigung der TK nach einer Pfeilerzahnfraktur verbessern. Insbesondere kann durch diesen
378 Workflow in weniger als 10 Minuten ein passgenauer individueller SA mit dentinähnlichen
379 mechanischen Eigenschaften chairside hergestellt werden. Somit ist für die Behandlung mit
380 individuellen SA nicht mehr zwingend ein zweiter Termin erforderlich, da auf die zeitaufwändigen,
381 analogen Arbeitsschritte verzichtet werden kann.

382

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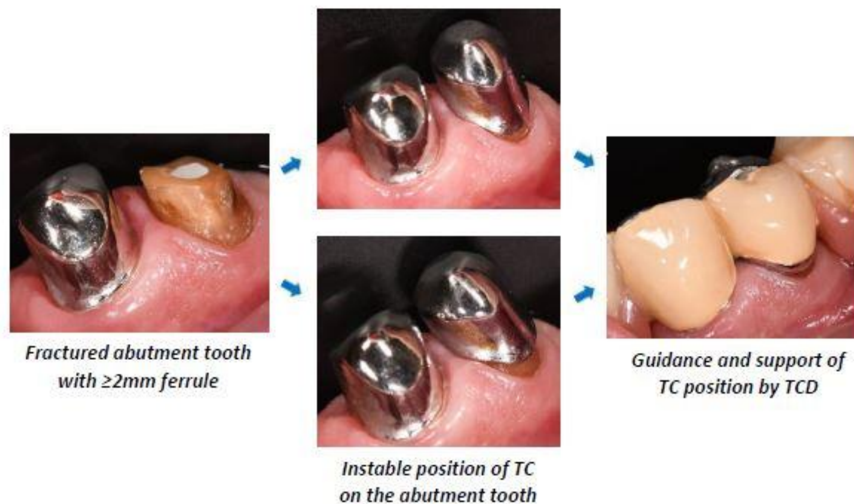
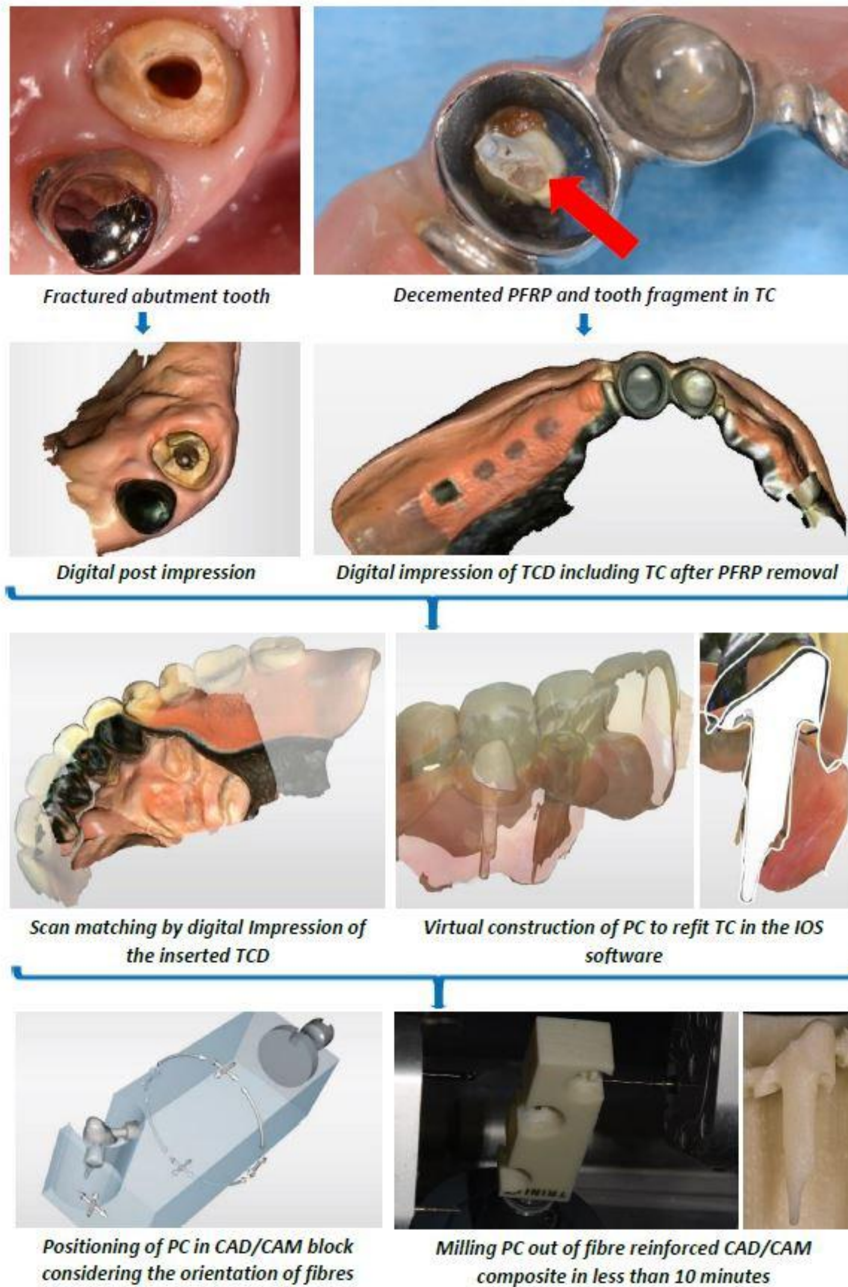
491 FIGURE LEGENDS:



492

493 *Figure 1: Fractured abutment tooth with sufficient ferule but instable TC position without guidance and support of TCD.*

494 *Abbildung 1: Frakturierter Pfeilerzahn mit ausreichend Ferule, aber instabiler TK-Position ohne Führung und Stabilisierung*
495 *durch die TP.*



496

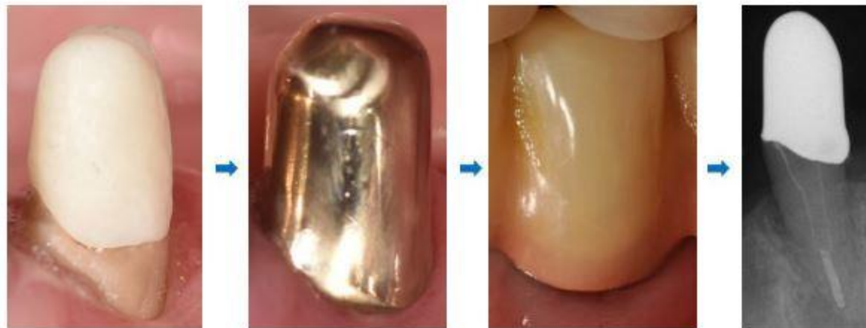
497 *Figure 2: Fully digital workflow for CAD/CAM fabrication of customised PC to refit TC after abutment tooth fracture.*

498 *Abbildung 2: Volldigitaler Workflow für die CAD/CAM-Fertigung eines individuellen SA zur Wiederbefestigung der TK nach*
499 *einer Pfeilerzahnfraktur.*

500

501 *Figure 3: Supplementation of the digital post impression (red circle) by illumination of the lumen with a caries detection probe*
502 *outside the regio of interest for scanning.*

503 *Abbildung 3: Ergänzung der digitalen Stiftabformung (roter Kreis) durch Erleuchten des Lumens mittels Kariesdetektionssonde*
504 *außerhalb der scanrelevanten Strukturen .*



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506 *Figure 4: Try-in and fitting process of PC to refit TC after abutment tooth fracture. The X-Ray after PC insertion (right) shows*
507 *excellent accuracy of fit by a thin layer of radiopaque adhesive cement.*

508 *Abbildung 4: Einprobe und Einsetzen des SA zur Wiederbefestigung der TK nach einer Pfeilerzahnfraktur. Das Röntgenbild*
509 *nach der SA-Insertion (rechts) zeigt eine hervorragende Passgenauigkeit durch eine dünne Schicht radioopaken*
510 *Adhäsivzementes.*

511

512 DISCLAIMER:

513 The authors declare that they have no competing financial interests or personal relationships that
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519 All authors listed have significantly contributed to the investigation, development and writing of this
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521

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529 Alle aufgeführten Autoren haben wesentlich zur Untersuchung, Entwicklung und Verfassen dieses
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Gießen, den 16.11.2024

Dr. med. dent. Jonas Adrian Helmut Vogler