Biomechanical Behavior of Zirconia Post and Core *In vitro*: a Systematic Review

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Abstract

Restoration of endodontically treated teeth is a common clinical practice which is being improved constantly. One piece zirconia post and cores are being introduced to dental treatments routine and offers aesthetic approach in restoring severely damaged teeth. However the biomechanical properties of such restorations remain unclear. The purpose of this systematic review was to describe biomechanical properties of zirconia post and cores and put them in a perspective with more conventional restorations. An electronic search was conducted in PubMed, Cochrane Library and Clinical Key databases for in vitro studies dating up to October 2019. Clinical studies and case reports were excluded.

Results: a total of 8 articles were included in a systematic review, consisting of 4 in vitro studies and 4 finite element analysis (FEA). Several evaluation parameters were set: zirconia post and core fractural resistance comparison with metal and prefabricated post systems, stress distribution in teeth restored with zirconia post and cores.

Conclusions: zirconia post and core could be a promising restoration for anterior teeth where aesthetic demand is high. It showed similar in vitro biomechanical behavior and fractural resistance to gold alloy restorations, although such findings only show a tendency and further clinical investigation is needed.

Keywords: *zirconia post and core, prosthetic dentistry, biomechanical behavior.*

Introduction

Restoration of endodontically treated teeth is a common clinical practice. Such cases have a prevalent algorithm of firstly restoring tooth with post and core and then, after abutment is created, finishing the work with a crown (1). But as the all-ceramic restorations are highly translucent, esthetic demand for post and core material also arises to reach an overall esthetic final result. Usual cast metal post and cores tend to have negative impact on light transmission (2) making them an undesirable choice for anterior teeth restoration. In pursuance of esthetics, milled zirconia post and cores were introduced. It could be described as a novel alternative to more usual tooth rehabilitation systems, since clinical trials are lacking, even though first insights were made back in 1999 (3). Such restorations are low-time consuming and are made relatively simply using a CAD/CAM system (4,5).

But milled zirconium dioxide post and core is not the only choice for esthetic restoration as there are prefabricated zirconia or glass fiber posts that offer similiar esthetic results. Since there are so many options to choose from, and the only variable that may differ between the groups is biomechanics, it is important to put a zirconia post and cores in a perspective with more common restorations as it would make it easier for clinicians to decide, whether they should consider a different treatment method. The purpose of this study was to review a biomechanical *in vitro* behaviour of custom-made zirconia post and cores and compare them to more conventional restoration types.

1. Methods

A reviewing process was in line with the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analysis) guidelines. An electronic search was conducted in PubMed, Cochrane Library and Clinical Key databases of articles dating up to October 2019 by using a combination of following terms: 'zirconia' AND 'post' AND 'core'. In all data bases search builder was used and key words were set to be searched in all fields of publication in order to extend the results. After initial search article screening and full-text analysis was executed by two independent authors. All disagreements were solved by consulting a third supervising author. Before including, articles were checked with eligibility criteria that were set during the process of study (Table 1). Data extraction was performed independently by dividing articles into groups based on testing method that was used.

Table 1. Eligibility criteria

Inclusion criteria	Exclusion criteria
Studies evaluating one-piece zirconia post and cores	No comparison performed
Studies in English	Primary teeth
In vitro studies	Animal teeth
Finite Element Analysis (FEA) studies	Case report
Objective: fracture load comparison	
Objective: stress distribution	

2. Results

Using established key words electronic search conducted a total of 655 articles. After reviewing articles only by titles 144 were registered for screening, during which 108 articles were excluded. 25 full-text articles were assessed and after exclusion of 17 studies that did not fit the eligibility criteria, 8 articles were included in qualitative synthesis. No studies met the criteria for quantitative analysis. Then articles were divided into two groups according to testing methods: group 1 – *in vitro* studies that used extracted human teeth (n = 4) and group 2 – studies that performed Finite Element Analysis using 3D models of human teeth (n = 4).

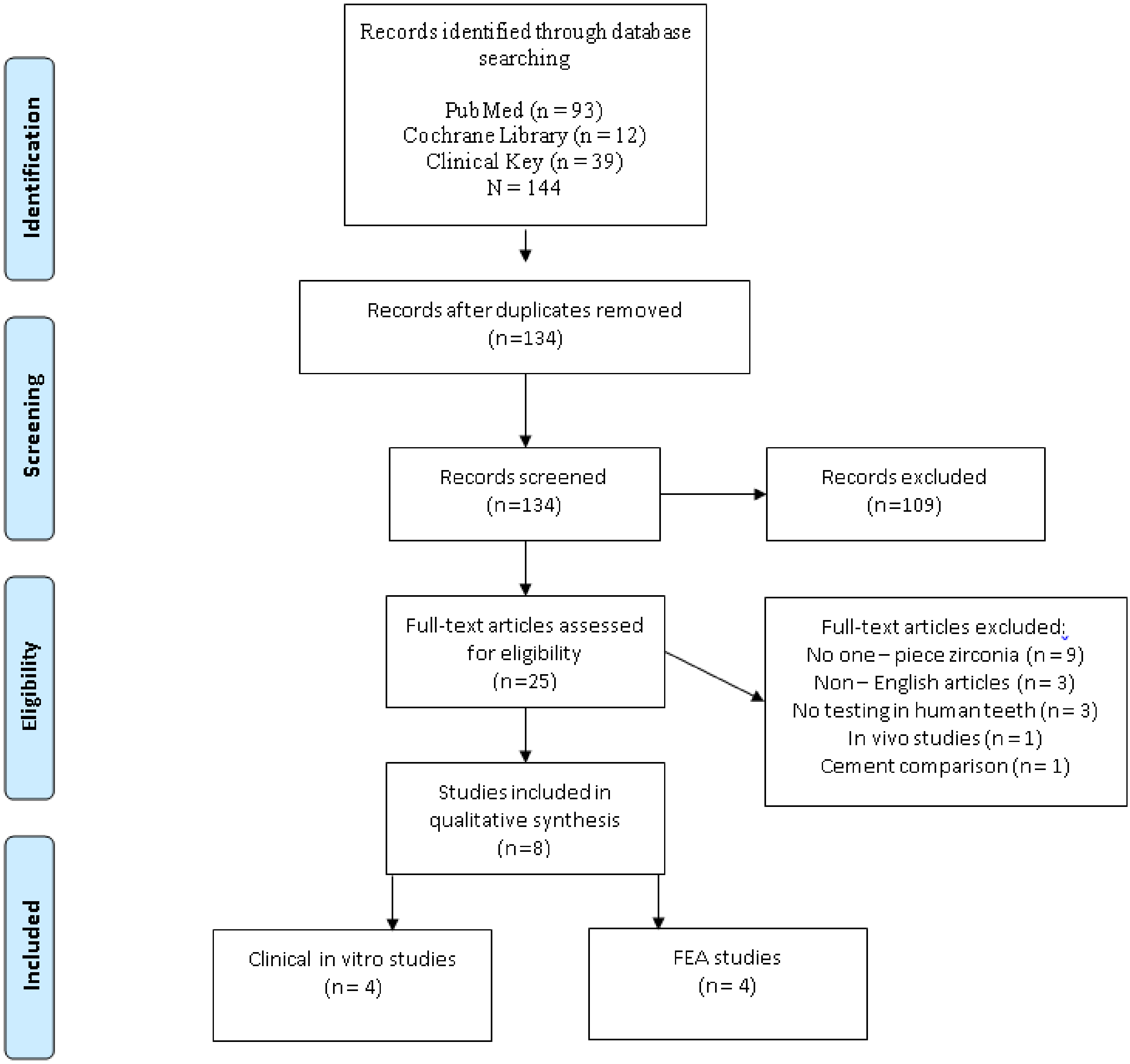

Figure 1. PRISMA flow diagram, showing the inclusion proccess of selected studies.

2.1. In vitro studies

Table 2. In vitro studies' methodical comparison and results

Author	Tooth type	Number of teeth	Post length (h)	Ferrule	Specimens	Coronal restoration	Load application	Results
Soundar et al. (2014)	Upper central incisor	48	h = 11 d =1.4/1.7	Yes, 2 mm	Post and core system: cast metal (Ni-Cr) (CM), pressable ceramic (PC), prefabricated zirconia (PZ), milled zirconia (MZ)	Yes, cast metal crown	130° to longitudinal axis, 1 mm/min	PC1.4<CM1.7<**MZ1.4**<PZ1.4<PC1.7<**MZ1.7**<CM1.4<PZ1.7 **MZ1.4** had significant difference from CM1.4, CM1.7, PC1.4, PC1.7, PZ1.4, PZ1.7.
Kalyoncuoğlu et al. (2015)	Single rooted premolar	40	h =10 d =1.25±0.5	No	Post and core system: cast metal (Cr-Co) (CM), milled metal (MM), laser sintered metal alloy (LSM), milled zirconia (MZ)	No	130° to longitudinal axis, 1 mm/min	CM<LSM<MM<**MZ** **MZ** had significant difference from all other groups (p<0.05)
Habibzadeh et al. (2017)	Lower first premolar	36	Not specified	Yes, 2 mm	Post and core system: cast metal (Ni-Cr) (CM), milled zirconia (MZ), glass fiber post and composite core (GFP)	Yes, milled zirconia crown	45° to longitudinal axis, 0.5 mm/min	**MZ**<CM<GFP MZ had significant difference from all other groups (p<0.05)
Bittner et al. (2010)	Upper central incisors and canines	85	h =10 d =1.25	Yes, 2 mm	Post and core system: cast gold (CG), milled zirconia (MZ), prefabricated zirconia (PZ), titanium with composite core (TC), combined fiber/zirconia post and composite core (FZ)	Yes, milled zirconia crown	135° to longitudinal axis, 0.5 mm/min	PZ<**MZ**<CG<TC<FZ **MZ** had significant difference from TC and FZ groups. No significant difference from PZ and CG

2.1.1 Milled zirconia vs metal restorations

Results of Soundar et al. (4) showed a significantly ($p<0.05$) lower fracture loads of teeth restored with 1.7 mm or 1.4 mm diameter zirconia post and cores compared with teeth restored with cast metal post of 1.4 mm, accompanying Habibzadeh et al. (6) results which also showed significantly lower fracture resistance of milled zirconia post and cores compared to cast metal restorations. However teeth restored with either 1.7 mm or 1.4 mm diameter zirconia post and cores had a significantly higher fracture resistance compared to teeth restored with 1.7 mm cast metal restoration (4), following Kalyoncuoğlu et al. (5) which also registered a significantly higher fracture resistance among zirconia post and cores when compared with cast, milled or laser sintered metal post-cores. Prefabricated titanium posts were also compared with zirconia, showing a results of significantly higher fracture resistance for a titanium post (7). Only Bittner et al. (7) compared milled zirconia and cast gold post in which teeth restored with zirconia or cast gold post and cores had the same fracture load limits.

2.1.1 Milled zirconia vs prefabricated posts

Soundar et al. (4) compared milled zirconia with prefabricated zirconia, which showed a significantly lower fracture resistance at milled zirconia group when corresponding diameters were compared. Although Bittner et al. (7) showed results of higher fracture resistance for milled zirconia than prefabricated but results had no significant difference ($p>0.05$). Habibzadeh et al. (6) stated that glass fiber posts had a significantly higher load toleration compared to milled zirconia, surpassing it in mean fracture loads more than twice. Bittner et al. (7) used zirconia-reinforced glass fiber posts which also had significantly higher fracture resistance when compared with milled zirconia.

2.2. Finite element analysis (FEA)

Table 3. FEA studies. Methodical comparison and main findings

Author	Tooth type	Restoration type	Variables	Load value (N)	Main findings
Chen D. et al. 2019	Maxillary incisor	Post and core system: One-piece zirconia Coronal restoration - heat-pressed glass ceramic	Ferrule heights (mm) of 0.0, 1.0, 2.0 and 3.0 Post diameters (mm) of 2.5, 2.0 Post heights (mm) of 12.9, 11.9, 10.9	300	- Stress decreases with increasing ferrule height; 3,0 mm ferrule had significantly lower von Mises stress than 0,0 mm. - Increased ferrule heights causes von Mises stress to shift to the root neck. - Lowering post length decreases von Mises stress in dentin, post, and their interface
Chen A. et al. 2015	Maxillary canine	Post and core system: one-piece zirconia, one-piece glass fiber, cast titanium, cast gold.	Dentin wall thickness (mm) of 1.0, 1.5, 2.0, 2.5.	100	- Decreasing alveolar bone height increases von Mises stress in dentin.

		Coronal restoration – not specified	Alveolar bone loss of 1/3, ½ and 2/3 bone level		- Von Mises stress in dentin for zirconia specimens was lower than with other materials at constant bone levels and dentin wall thickness. - No significantly different stress distribution between different dentin wall thickness although more favorable results were in thicker dentin wall specimens.
Nokar S. et al. 2018	Maxillary central incisor	1 group – Ni-Cr / gold post and core, restored with metal-ceramic (MC) crown 2 group – stainless steel, titanium, carbon fiber, glass fiber, quartz fiber posts and composite cores restored with MC's 3 group – zirconia post and core, zirconia post, carbon fiber post, glass fiber post, quartz fiber post with composite cores, restored with all-ceramic crowns	None	100	- Zirconia post and core specimens showed higher stress at gingival border. - Zirconia post and cores showed lowest Von Mises stress between the middle and cervical thirds of the root; results were similar to Ni-Cr specimens. - Zirconia post and cores may be alternative to metallic posts.
Marghalani T. et al. 2012	Maxillary canine	Post and core system: one – piece zirconia, cast gold Coronal restoration – all-ceramic crown	None	100	- No significant differences between stress in teeth restored with wither post and core material. - Zirconia post and core von Mises stress was 4.81 % lower than in gold post andcore. - Zirconia post and core could be aesthetic alternative for cast metal restorations.

Zirconia post and core showed a significantly lower von Mises stresses in dentin compared with glass fiber posts at all tested bone levels (1/3, ½, 2/3, no bone loss) (8), following another study which concluded that one piece zirconia post and cores have more favorable stress distribution than pre-fabricated glass fiber posts (9) (Table 3). Besides that zirconia post and core shows very similar performance when compared to cast gold, Ti or Ni-Cr post and cores, leaving no significant differences between mentioned materials

(8,10), although metal restorations resulted in less stress concentration at either gingival border or between the middle and cervical thirds of the root (9).

Zirconia post and cores showed an inverse stress distribution with different dentin thickness (1.0 mm, 1.5 mm, 2.0 mm, 2.5 mm residual root dentin walls were compared), as more stress concentrate in dentin than post when dentin wall is left thinner contrary to thicker dentin walls, which lead to stress accumulation on the post itself (8). Although it has to be mentioned, that one-piece zirconia specimens are tend to absorb most of the generated stress as they are stiffer due to higher elastic modulus than dentin, hence less stress accumulate in dentin itself (8). Additionally another study came to similar results as decreasing the length and diameter of zirconia post and cores showed less von Mises stress accumulation in dentin, post and their interface, leaving with a conclusion that smaller post dimensions should be considered for more favorable clinical results (11). Furthermore, FEA results showed, that stress zones appear to be in a root at a level of residual bone, in which tension gradually increases when bone level is decreasing (8).

Different ferrule heights for zirconia post and cores showed an influence on stress distribution, as maximum von Mises stresses in radicular dentin, post and post-dentin interface gradually decreases when ferrule is left higher, leaving a significant difference between 0 mm and 3 mm ferrules (11). Also stress location shifting is monitored, as changing ferrule heights from 0 mm to 1, 2 and 3 mm results in stress ascension from mid – root towards the cervical part of the root. (11).

3. Discussion

Zirconium dioxide is a considerable material for dental restorations as it has a similiar Young‘s modulus to stainless steel and a comparable flexural strenght to titanium or cast gold (12). What makes a difference is a high elastic modulus in zirconia, considerably surpassing a dentin, leaving with an implication that more stress is transferred to dentin, which could result in fractures of dental tissue (12,13).

All reviewed studies differed in methodical execution of testing, therefore, in results too. Although some matching results are observed. But when it comes to biomechanics, one should consider that human masticatory system is a complex combination of structures that function together (14). Therefore, *in vitro* studies which only rely on one-way load application can only show a tendency of various restorations performance in vivo, but not a general conclusion.

Firstly, custom made dowels consisted a major part of all subjects. Only one *in vitro* study, that used natural teeth, showed a superior fracure resistance of milled zirconia when compared to metal restorations (5). Furthermore, it was highly heterogenous from all other studies as it was the only one which did not performed a coronal restoration and a ferrule effect for its‘ specimens (5), leaving with an assumption that major influencing variables of biomechanics such as ferrule effect were left behind (15).

But what favors the milled zirconia restorations are FEA studies. All studies has shown more favorable stress distribution in custom made zirconia restoration when compared to prefabricated dowels (8,9). Also, no significantly different von Mises stresses were observed in either milled zirconia or cast metal specimens (8,10). Ultimately, FEA studies could be considered as a relatively closer to *in vivo* biomechanics as periodontal ligament, cortical and cancellous bone was took into account. Moreover, comparison of cast gold and milled zirconia has given similar results in both in vitro and FEA, suggesting that both treatment methods could have same clinical performance (7,8,10).

When comparing with prefabricated dowels, milled zirconia showed lower fracture resistance in many *in vitro* studies (4,6,7).

Tooth-colored post and core is considerable restoration when aesthetic demand is high, for example when restoring defected anterior teeth. Although fractural loads of teeth restored with milled zirconia where lower in many studies, this might not be relevant as fractural loads highly surpass average biting loads in adults, which, according to one study, is 284,9 N on average (16), proposing that registered fracture resistance is enough for human bite (Table 4).

Table 4. Fractural load of teeth restored with zirconia post and core.

Author	Fracture load (N)
Bittner et al. (2010)	442.71
Soundar et al. (2014)	312.00 (415.00)
Habibzadeh et al. (2017)	435.34
Kalyoncuoğlu et al. (2015)	315.4

One of the main criteria, influencing endodontically treated teeth fractural resistance is residual root dentin wall thickness. Clinicians are strongly advised to maximize the preservation of natural healthy dentin in order achieve more successful results (17) – this can be reached by decreasing post diameter. Increasing the residual wall thickness not only leads to more favorable stress distribution (less Von Mises stresses in root) (8,11), but also significantly increases bearable occlusal load (17) and may increase the possibility of root fracture (18). However it still not fully clarified what dentin thickness – post diameter ratio should be considered as the most beneficial, since particular dimensions may not be suitable for every clinical case, as teeth measurements vary for each patient.

Ferrule has been a hot topic for a long time and it should be considered when preparing a space for zirconia post and core. Many studies accompany the results of our selected studies. Two *in vitro* studies revealed that presence of the ferrule promotes more satisfactory stress distribution in a root, also increasing maximum fracture load (19,20) and decreases stress at the interface of restoration and dentin (11). Ultimately, Yang et al. (21) have shown that absence of the ferrule might compromise the clinical success of the restoration. Mamoun et al. (22) explains, that post helps to retain the core as it extends the restorations' bond strength by increasing surface area, but the main biomechanical variable that determines the clinical outcome is the ferrule, leaving with an implication, that a teeth-restoration complex, where only post retains the core, is a generally bio-mechanically unstable.

When talking about zirconia post and core performance in vivo, only one prospective clinical trial was made, where 72 defective teeth in 47 patients were restored with one piece zirconia post and core. After an average follow up of 65.0±4.8 months no incidence of teeth nor restoration failure was registered, implying that CAD/CAM zirconia post and cores could be a good choice for restoration of defective teeth (23).

4. Conclusions

Based on the findings of systematic review, the following conclusions were formed:

1. Teeth restored with zirconia post and cores tend to have lower fractural resistance compared to teeth restored with cast metal post and cores.
2. Zirconia post and core showed more favorable stress distribution in radicular dentin during occlusal loading than prefabricated posts.
3. Milled zirconia post and cores could be a clinical alternative to similiar gold restorations.
4. As fractural loading surpasses average human biting load, zirconia post and cores could be considered as esthetic restoration for anterior teeth.
5. Excessive preparation of root dentin should be avoided when preparing space for a post in order to achieve higher fractural resistance.
6. In order to achieve bio-mechanically stable teeth-restoration complex, ferrule should be prepared when restoring teeth with zirconia post and core.

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