

An Overview of Immediate Root Analogue Zirconia Implants

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Owing to its excellent biomechanical characteristics, biocompatibility, and bright tooth-like color, zirconia has the potential to become a substitute for titanium as dental implant material and to be successfully used as root-analogue implants by reproducing the contours of the extracted tooth. This article presents an overview of the technique of using root analogue zirconia dental implants as an immediate implantation material. These implants are replicas of the extracted tooth and therefore truly anatomically correct and socket friendly.

Key Words: immediate implantation, root analogue implants, custom-made implants, zirconia, zirconia implants

INTRODUCTION

Replacement of lost teeth using oral implants is an accepted treatment modality with well-documented long-term success rates between 90% and 100% at the 10-year follow up.¹ Titanium and titanium alloys are widely used to fabricate dental implants.² Expectations regarding esthetics in dentistry are growing, and research in the field of all-ceramic materials for restoration of natural dentition and dental implants has intensified. To improve the esthetic aspect of dental implants, a ceramic material, zirconia, was introduced.³

Originally, a healing period of 6–9 months was recommended before implant insertion (late implant placement). Later, placement of implants after only 2–3 months was proposed (delayed implant placement), and more recently, immediate implantation after extraction has been performed clinically, but only in highly selected cases. Results with shorter intervals between extraction and implantation are comparable to late implant placement.¹ The major advantages of immediate implant placement

are (1) the decrease in treatment time with fewer surgical interventions leading to an improved quality of life and overall cost reduction and (2) less alveolar bone resorption and soft-tissue regression due to early functional load.¹ However, one problem associated with immediate implant placement using conventional screw- or cylinder-type implants is their incongruence with the extraction socket.² A good fit between the implant and the host bed has been described as an important factor for implant success.⁴ The problem of incongruence can be rectified by using a novel approach wherein custom-made root analogue implants are placed into the extraction socket or by using large-diameter implants, sometimes up to a platform of 6 or 7 mm. By adapting the root to the extraction socket instead of adapting the bone to a preformed standardized implant, bone and soft-tissue trauma are reduced.⁴

Zirconia-based implants were introduced into dental implantology as an alternative to titanium implants. Owing to its ability to be milled into the shape of the natural tooth root and be placed immediately after extraction, its excellent biomechanical characteristics, its biocompatibility, and its bright tooth-like color, zirconia has the potential to become a substitute for titanium as dental implant material.²

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TABLE 1
Assessment of timing of implant placement^{5,6}

	Immediate Placement	Early Placement	Delayed Placement
Timing	Implant placement at the same surgical procedure as tooth extraction	Implant placement 2–6 weeks after tooth extraction	Implant placement 3–6 months after tooth extraction
Advantages	<ol style="list-style-type: none"> 1. Reduced number of surgical procedures 2. Optimizes visualization of the extraction socket 3. Flap elevation may be unnecessary 4. Reduced overall treatment time 5. Optimal availability of existing bone 	<ol style="list-style-type: none"> 1. Allows resolution of any active infection 2. Allows soft-tissue healing to cover socket 3. May allow early healing of the bone (woven bone) 4. Increased soft-tissue area and volume facilitate soft-tissue flap management 	<ol style="list-style-type: none"> 1. Same as for early placement but allows more of fill of the socket by lamellar compact bone to provide initial implant stability in large socket 2. High predictability 3. Mature soft tissues facilitate flap management
Disadvantages	<ol style="list-style-type: none"> 1. Contraindicated if overt bone is present 2. Caution is required if extraction is sufficiently traumatic to complicate the healing process 3. There may be insufficient bone to achieve primary stability of the bone 4. Site morphology may complicate optimal placement and anchorage 5. There is a potential lack of keratinized mucosa for flap adaptation 	<ol style="list-style-type: none"> 1. An additional surgical procedure is required 2. There may be insufficient bone to achieve primary stability of the implant 3. Treatment time is increased 4. Socket walls exhibit varying amounts of resorption 	<ol style="list-style-type: none"> 1. There may be loss of thin labial plate in the resorptive process 2. The treatment schedule is protracted 3. Adjunctive surgical procedures may be required 4. Socket walls exhibit varying amounts of resorption

Search Strategy

A PubMed search of the medical literature in English was conducted up to January 2010 using the terms “implants” and “immediate placement,” “delayed placement,” “early placement,” “delayed-immediate,” or “extraction sockets”; “immediate extraction sockets”; “immediate implants”; “root analogue implants”; and “zirconia implants.” Additionally, the bibliographies of seven previous reviews and articles published in *British Dental Journal*, *Clinical Oral Implants Research*, *Dental Update*, *Head and Face Medicine*, *International Journal of Oral and Maxillofacial Implants*, *International Journal of Oral and Maxillofacial Surgery*, *International Journal of Prosthodontics*, *Journal of Esthetic Dentistry*, *Journal of Oral Implantology*, *Journal of Periodontology*, *Journal of Prosthetic Dentistry*, and *New York State Dental Journal*, were manually searched.

Immediate Extraction and Implantation

There are various recommendations regarding timing of implant placement after tooth extraction.

See Table 1^{5,6} for the advantages and disadvantages of each. The implant can be placed

1. Immediately after the extraction during the same surgical procedure.
2. After a delay of a few weeks (late implant placement). This is normally after 2–6 weeks to allow resolution of the infection/inflammation or some soft-tissue coverage.
3. After a delay of 3–6 months (delayed implant placement) to allow bone healing.
4. Months or years after the tooth loss.⁵

In a study by Esposito et al,⁷ a total of 790 implants were originally placed in 300 patients. Of the placed implants, 253 (64 in maxillae) were immediately loaded, 230 (132 in maxillae) were early loaded, and 307 (90 in maxillae) were conventionally loaded. During the follow-up period (1 year of function for all trials, with the exception of 2 trials for which the 6-month data were used), 20 implants failed. Six of the failed implants were immediately loaded, eight were early loaded, and six were conventionally loaded.⁷

In the classification of Wilson and Weber,⁸ the terms “immediate,” “recent,” “delayed,” and “mature” were used to describe the timing of implant placement in relation to soft-tissue predictability and guided bone-regeneration techniques. In the recent classification of Mayfield,⁹ the terms “immediate,” “delayed,” and “late” are used to describe the time intervals of 0 weeks, 6–10 weeks, and 6 months or more after extraction, respectively.¹⁰

The predictability of esthetic success depends on the tissue loss present at the initiation of treatment. The greater the amount of bone and soft-tissue loss, the more difficult it becomes to produce an ideal esthetic result.¹¹

Once the root and clinical crown of a tooth are removed, the propensity of the site is to collapse. This is the result not only of the loss of bone (buccal plate) but also of the soft-tissue contours, which are dependent on the stability of the bone for their support. When bone loss is not prevented, the bony architecture is not present to support and maintain the papillae interdentally.¹² Schropp and coworkers¹³ studied the alveolar ridge augmentations after the extractions of single premolars and molars in 46 patients. Although the vertical changes were negligible, the horizontal resorption amounted to about 30% at 3 months and 50% of the width of the ridge at 12 months after tooth extraction. A median buccolingual ridge reduction of 5.9 mm (25th and 75th percentiles of 4.7 mm and 7.7 mm, respectively) was found. These changes were slightly greater on molar sites than in premolar sites and in the mandible compared with the maxilla. Similar observations were made by Camargo and coworkers.¹⁴ They followed the healing of nonmolar extraction sites for 4–6 months and recorded a horizontal and vertical ridge reduction of 3.1 mm and 2.6 mm, respectively.¹⁵

To avoid many limitations, a number of immediate implant placement protocols have been suggested (see Table 2 for a list of considerations for immediate implantation).¹⁶ However, their predictability and long-term success have yet to be determined. Some of these protocols advocate the use of alloplastic materials to aid in alveolar ridge preservation and gap filling around an implant placed immediately into an extraction socket. The use of a larger-diameter implant, sometimes up to a platform of 6 or 7 mm, has also been advocated. To date, there are no universally accepted clinical,

TABLE 2
Considerations for immediate implantation¹⁶

1. If there is acute infection, use preoperative antibiotic therapy.
2. There should be no purulent exudate at the extraction site.
3. The patient should be warned of possible staged or delayed procedure
4. It is the surgeon's decision to proceed or not at the time of extraction.
5. Use atraumatic surgical removal.
 - a. Section with a high-speed bur.
 - b. Remove the periosteum.
6. Use the lingual/palatal line to prepare and insert the implant
7. The implant should be 2.0 mm longer than the root, and the surgeon should aim to engage 4–5 mm of native bone.
8. The implant must be immobilized at final placement.
9. Maintain adequate soft-tissue closure.

radiographic, and histologic variables to determine their biocompatibility and clinical effectiveness for alveolar ridge preservation.¹⁶ During the first 4 months of healing, according to observations and measurements, the buccal-lingual ridge undergoes a reduction of approximately 5 to 7 mm with a 2- to 4.5-mm loss of vertical bone height. Several studies^{17–22} have observed greater apico-coronal changes when comparing multiple adjacent extraction sites to single sites. Replacement therapy, that is, the immediate replacement of the lost root(s) to prevent the loss of alveolar bone in height and width, may be the answer.

The first reported case was described by Schulte²³ in 1976 using a polycrystalline aluminum surface. Since then, numerous clinical case reports have been published and review articles have updated this surgical technique with contemporary findings.^{9,10,24,25} Several articles^{26–32} have defined immediate as occurring on the day on which the tooth was extracted, whereas others use a time-frame of 0 to 15 days or 0 to 7 days.¹² Multiple investigations^{25,33–35} have demonstrated success rates greater than 90% for implants placed into fresh extraction sockets in partially edentulous arches. The success of immediate implants has been well documented histologically.³⁶

Advantages

In nearly all cases, investigators report many advantages for immediate placement. These include

a reduction of surgical procedures, a reduction in treatment time, preservation of alveolar bone, maintenance of ideal soft-tissue contours, better implant placement, simplification of the prosthetic design, and improvement in the patients' psychological outlook for dental treatment.⁶ It has also been suggested that the ideal orientation of the implant, preservation of the bone at the extraction site, and optimal soft-tissue esthetics may be achieved.¹⁰ Another benefit of immediate placement after extraction is that the design and fabrication of the prosthesis are typically improved, resulting in better finished lines and margins, heights of contour, emergence profiles, and interproximal architecture.

Disadvantages

Immediate postextraction implant placement often deals with two major problems: maintaining the initial stability of the implant(s) and preventing soft-tissue ingrowth during the healing period. Both problems may lead to the loss of the implant(s).³⁷ Potential disadvantages of immediate placement include the possibility of infection, thin tissue biotypes with consequent risk of recession, flap dehiscence over the extraction site, and incongruity between the socket wall and the endosseous implant shape. Generally, immediate implants are not inserted into the root sockets of molars because of poor positioning for ideal prosthetics and poor bone quality.⁶ According to Araujo and Lindhe^{38,39} series of studies, immediate implant placement do not prevent the loss of buccal plate.

Root Analogue Implants

In immediate implantation after tooth extraction, however, a socket often presents dimensions that may be considerably greater than the diameter of a conventional implant. Hence, after implant installation a gap may occur in the marginal part of the recipient site. An experiment on total hip arthroplasty in dogs suggested that

1. a close fit between the recipient site and the implant was of critical importance for proper osseointegration, and
2. a gap of 0.5 mm between the bone and the implant compromised the establishment of acceptable bone-to-implant contact (Harris et al. 1983).^{40,41}

Traditional techniques allowing implant placement in extraction sockets use either high-diameter implants in surgically enlarged sockets or grafting⁴² and/or regenerative procedures around primarily stabilized implants⁴³; however, none of these allow immediate loading if the insertion torque and resonance frequency analysis values are less than 35 N/cm and 65 on the an Implant Stability Quotient, respectively. Implant immobilization in the extraction socket is important to preserve the surrounding bone tissue, which is usually affected by the placement of large implants especially designed for this purpose. Strong immobilization is necessary to obtain good osseointegration.⁴⁴

When implants fail to contact surrounding bone during the healing period, soft tissue can grow into the free space, preventing satisfactory osseointegration. In this case, it is advantageous if the implant used for immediate placement has the same design as the extracted tooth root.⁴⁵ In an animal study, it was shown that a circumferential gap of 1–1.25 mm lateral to an implant may heal with new bone and that placement of a membrane did not improve the healing.⁴⁵ In a randomized controlled trial comparing maxillary single implants placed in extraction sockets in patients treated with particulated autogenous bone with patients not subjected to any augmentation procedure, substantial bone gain was obtained in both groups, and no statistically significant differences were found.^{46,47}

The concept of replacing teeth with custom-made root-analogue implants was reported as early as 1969; however, the autopolymerized and heat-processed polymethacrylate used to fabricate the tooth analogue was encapsulated by soft tissue rather than osseointegrated.⁴⁵ Lundgren and colleagues reintroduced the idea of root-analogue implants in 1922.⁴⁵

Instead of using polymers, titanium was used in an experimental model of immediate implant placement, leading to bony integration in 88%.^{4,48} A good fit between the implant and the host bed has been described as an important factor for implant success.^{4,49}

In a rabbit study, Schenk and Willenegger⁵⁰ suggested that comprehensive bone bridging, that is, the rapid formation of woven bone that occurs to close a defect, is dependent on the size of the void. Thus, if the size of a defect is greater than 2.5 mm, bridging may become incomplete. The validity of

this conclusion was demonstrated by Carlsson et al.⁵¹ They used a rabbit model and placed implants in recipient sites that provided gaps of varying size (group A Ω 0 mm; group B Ω 0.35 mm; group C Ω 0.85 mm) between the implant and the host bone. In biopsies obtained after 6 and 12 weeks of healing, it was observed that residual gaps (between 0.22 and 0.54 mm in width) occurred in group B and group C.⁴¹ A long-term study by Denissen and Kalk⁵² showed that immediately placed submerged hydroxyapatite implants contributed to the maintenance of alveolar ridge volume; in addition, in a clinical report, Wheeler and colleagues⁵³ demonstrated preservation of hard and soft tissue with enhancement of the esthetic result after immediate placement of tapered root-analog implants combined with custom healing abutments.⁴⁷ Kohal and colleagues⁵⁴ further refined the approach of root-analogue titanium implants by widening the coronal aspect of the implant to compensate for the lost periodontium and to obtain a good congruence between implant and extraction socket. In several instances, the implant insertion led to fractures of the thin buccal wall of the alveolar bone. In a clinical study, Pirker and Kocher^{1,4} described an excellent primary stability of root-analogue titanium implants that were sustained up to 1 month but had a highly disappointing failure rate of 48% at the 9-month follow-up. A perfect fit of the implant without any retentions leads to an excellent primary stability; however, at the same time, it might be responsible for failure in the intermediate term because of the subsequent uniform pressure-induced resorption concerning the entire alveolar surface simultaneously. A cross-section of the jaws shows that there is only sufficient room for enlargements and retentions in the interdental space, whereas the thin buccal and lingual layers do not allow for any enlargement of implants in this area.⁴⁵

In a recently developed root analogue implant system, computer-aided design/computer-aided manufacturing was used for the fabrication of the root analogue, which allowed for the immediate replacement of the teeth that had to be extracted.^{49,54} Alternatively, copy milling of the extracted teeth can also be done. Several authors have reported the advantages of the root analogue implant. Lundgren concluded that this system osseointegrated with a high degree of predictability

and the quality of bone-to-implant contact was high enough to function well.⁴⁷ However, a long surgical time was needed for immediate replacement with this system. Three-dimensional imaging has been developed to gather a vast number of complex slice images.⁵⁵ Instead of the traditional implantation procedure, a computerized tomography (CT) scan of the tooth could be processed and converted into a root analogue implant.⁵⁶ This technological advancement was termed "rapid prototyping." With rapid prototyping techniques, the surgical time can be reduced and the implant operation can be simplified. There have been various subdivisions in rapid prototyping techniques. Two methods, fused deposition modeling and stereolithography, are the most frequently used techniques. It is less clear; however, whether this is an accurate and reliable technique.⁵⁵

In the fused deposition modeling technique, rapid prototyping operates on the principle of depositing material in layers or slices to build up a tooth model. The use of CT scans allowed parts of the tooth to be serially recorded slice by slice. Similarly, an object could be reproduced slice by slice using three-dimensional computed stereolithography data in conjunction with a rapid prototyping machine. Stereolithography is a method of rapid prototyping that uses data obtained from CT scans stored in three-dimensional form.

Zirconia as a Root Analogue Custom Implant Material

The family of ceramic materials includes bioinert nonresorbable metal oxides such as alumina (Al₂O₃) or zirconia (ZrO₂), which can be used as dental implants.⁵⁴ In the 1980s, an implant made of aluminum oxide (Al₂O₃), the Tübinger immediate implant, was used but later withdrawn from the market because of its high clinical fracture rate.⁵⁸ Partially stabilized zirconia, which is comparable to the highest values for oxide ceramics, has been introduced as a new ceramic implant material.⁵⁹ Yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) exhibits a very high flexural strength (900 to 1200 MPa), a favorable fracture toughness (KIC7 to 1 MPa^m^{-1/2}), and a suitable Young's modulus (210 GPa).⁵⁸

Zirconia is a strong biomaterial and is a unique dental ceramic because of its ability to undergo transformation toughening. The mechanical prop-

erties with high-fracture resistance and the elastic modulus of zirconia might also contribute to bone healing and provide mechanical stability. Moreover, this material is highly radiopaque.⁵⁹ Biocompatibility has been evaluated using *in vitro* tests performed on different materials (eg, powders or compacts, different impurity levels) with different cell lines in different biologic conditions (eg, fibroblasts, phytohemagglutinin-stimulated lymphocytes) and with similar positive results. Furthermore, *in vitro* carcinogenicity and mutagenicity tests showed negative results.⁵⁸ In a comprehensive review on zirconia ceramic, Picconi and Maccauro⁶¹ stated that there is general agreement on the absence of local or systemic toxic effects after the implantation of zirconia ceramics into muscles or bones of different animals or after powder injection in mice. Because radioactive exposure is not caused by the zirconia itself but by impurities, the purification process of precursors of Y-TZP must be controlled carefully.⁵⁸ The quality of the bone-implant contact was comparable to that of alumina implants and was influenced by implantation site and implant surface modifications. In the animal studies reviewed for this article, osseointegration was evaluated at 4 weeks to 24 months after insertion in different animal models and sites and under different loading conditions. The mean bone implant contact ratio was above 60% in almost all experimental groups, indicating successful osseointegration. In those investigations that used titanium implants as a control, zirconia implants were comparable to or even better than titanium implants.² Davies⁶² emphasized the importance of implant surface design and microtopography to achieve what he called "de novo bone formation" on the implant surface itself, in addition to the ingrowth of bone from adjacent bone surfaces. Roughened surfaces were also shown to support osteoconduction leading to bone formation on the implant surface.⁶² Furthermore, Sennerby et al⁶³ found that Y-TZP implants with a moderately roughened surface showed a fourfold to fivefold increase in resistance to torque forces compared with machined Y-TZP implants after 6 weeks of healing. Kohal et al⁶⁴ reported a higher percentage of osseointegration for nonloaded zirconia implants; they also found a direct bone-to-implant contact of approximately 82% for the nonloaded implants and 70% for the loaded zirconia implant group 3

months after implantation. Thus, partially stabilized zirconia is considered an attractive endosseous dental implant material.⁵⁹

However, the technique of immediate implantation of root analogue zirconia is restricted to cases of extraction of periodontally sound tooth with a sufficiently deep socket, an atraumatic extraction, sufficient bone support, and absence of periapical pathologies. Pirker and Kocher¹ selected root-identical implants with significant modifications by (1) using zirconia for its excellent biocompatibility and improved esthetic results; (2) adding micro-retentions to the entire root surface and macro-retentions strictly limited to the interdental space to get beyond primary stability and improve osseointegration; (3) reducing the diameter of the implant next to the thin cortical bone to avoid fracture and pressure induced bone loss; and (4) choosing a single-stage implantation resulting in immediate, albeit limited, functional load via the crown stump for prevention of bone resorption. The maxillary right premolar was carefully extracted, avoiding any damage to the socket and soft tissue.

The extraction socket and area of the apical periodontitis were cleaned by means of curettage, and an iodoform-soaked cotton gauze was placed in the socket. The root was laser scanned and macro-retentions were designed. In addition, a crown stump was designed for later connection to the crown. The implant was then milled from a zirconium dioxide block, and the surface was roughened by sandblast and sintered for 8 hours to achieve the desired mechanical properties. The implant was then cleaned in an ultrasonic bath containing 96% ethanol for 10 minutes, packaged, and sterilized in a steam sterilizer. On day 4, the iodoform cotton gauze was removed, and the alveolar socket was again curetted and flushed with sterile physiologic saline solution. The custom-made individualized root analogue implant was then placed into the socket under finger pressure and subsequent gentle tapping with a hammer and a mallet to achieve the primary stability.

At the control visit 10 days later, a clinically healthy marginal area was present, and no postoperative pain or swelling was reported. There was no bleeding or wound infection. After 4 months a composite crown was cemented.

At the 2-year follow-up, the patient presented with a stable implant, unchanged peri-implant

marginal bone level as monitored by radiographs and soft-tissue parameters, and no bleeding on probing. Hence, excellent esthetic results were achieved with no signs of periodontitis or bone resorption. The single-stage implant approach with a crown stump led to an early functional load allowing for osseointegration while preventing bone resorption.¹

In a follow-up study,⁴ the same authors concluded that by introducing significant modifications, such as macro-retentions and implant diameter reduction next to the cortical bone, primary stability and excellent osseointegration of immediate root analogue zirconia implants can be achieved while preventing unesthetic bone resorption. The macro-retentions have to be limited to the interdental space to avoid fracture of the thin buccal cortex. This novel approach could form an alternative method for replacing teeth immediately after extraction. The preliminary results of human trials with multi-rooted teeth indicate that this method might be applied to all teeth.⁴

In a case report by Pirker and Kocher,⁶⁵ a right maxillary molar with extensive root caries and chronic apical periodontitis was removed after an unsuccessful root canal treatment. Author: In the Zirconia as a Root Analogue Custom Implant Material section, paragraph 8, sentence 1, please add the correct Pirker and Kocher citation. Copy editor Five days after extraction, the iodoform cotton gauze was removed, the alveolar socket was again curetted and flushed with sterile saline solution, and a one-piece (implant + abutment) zirconia implant with a surface roughened by sandblast was placed into the extraction socket and subsequently gently tapped into place. Primary stability was achieved as checked by palpation and percussion. The soft tissue healed unremarkably around the implant within 3 days. No bleeding was observed on probing or wound infection over the entire follow-up period. The definitive restoration with a composite crown was performed 3 months after extraction. At the 2-year follow-up, the patient presented with a stable implant, an unchanged peri-implant marginal bone level, no signs of marginal or apical implantitis as monitored by radiographs and soft-tissue parameters, and no bleeding on probing. The patient was satisfied with the excellent functional and esthetic result.¹⁵

The technology described herein combines a

truly anatomical implant design with the use of a new biomaterial and surface technology, including both micro-retentions and macro-retentions.⁶⁵

CONCLUSION

Presently, pure titanium is the material of choice for dental implants. This material has been used for about 30 years as an implant substrate and has shown high rates of success. However, there is the disadvantage that black metallic components may show through the mucosa or become visible in cases of soft-tissue recession, and an increasing number of patients are asking for metal-free treatment options. One possible solution would be to make implants from tooth-colored materials, such as ceramics. Favorable mechanical, biological, and esthetic properties; the potential for osseointegration; and the ability to customize it and place it immediately after extraction make zirconia a ceramic material of choice for dental implants in recent times. The problem associated with immediate implant placement using these conventional implants is the incongruence with the extraction socket. Today, the combination of anatomically oriented implant designs, new biomaterials such as zirconia ceramics, and surface technologies has resulted in dental implants that are specially designed to replace each individual tooth. Significant modifications, such as macro-retentions, seem to indicate that primary stability and excellent osseointegration of such implants can be achieved, while preventing unesthetic bone resorption leading to unesthetic results. Zirconia implants are mainly manufactured as one-piece Y-TZP implants. To establish an excellent esthetic result, especially in the anterior region, these implants must be placed at a perfect angulation and apicocoronal position. The information on two-part Y-TZP implants is limited to one in vitro study in which the implants restored with two different all-ceramic crowns did not sufficiently withstand static and cyclic loading and were thus not recommended for clinical use. This novel approach of placing custom root analogue zirconia implants immediately after extraction is minimally invasive, respects the underlying anatomy, saves time and costs, and results in improved esthetic results, leading to increased patient acceptance. This successful approach war-

rants further clinical research in well-controlled trials.

ABBREVIATIONS

CT: computerized tomography

Y-TZP: yttria-stabilized tetragonal zirconia polycrystal

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