Chapter

Evolution of Dental Implant Shapes and Today's Custom Root Analogue Implants

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Abstract

Native tooth has a unique design to serve perfect stomatognathic function and esthetics which could never be replaced with another material or apparatus if it is lost. Over the past few decades, screw-type endosseous implants have been considered to be as the gold standard for the rehabilitation of edentulism owing to the similarity with the anatomical root shape and location inside the alveolar bone. They have been widely investigated so as to find out the ideal characteristics. Further researches have focused on the cervical region of the dental implant because the maximum stress is pronounced around the implant neck. The ideal characteristics indicate that a wide implant neck for better stress distribution, and a large surface area with a minimal thread geometry for a better long term crestal bone stability. Along with the growing clinical knowledge and digital technology, an innovative and noteworthy approach for implant dentistry, custom root analogue implant (RAI), has evolved. With the computer aided design and manufacturing (CAD/CAM) methods, original and optimized characteristics could be transferred to the custom dental implants just as performing an original root replacement.

Keywords: dental implant, custom root-shaped implant, anatomically shaped implant, root analogue implant, CAD/CAM, digital dentistry

1. Introduction

Natural teeth have unique design which serve complex stomatognathic functions and fulfill distinctive biomechanical needs. The anatomy of the natural tooth eventuates after a complex biological process which is moderated by epithelial-mesenchymal collaboration [1]. The morphological features in each type of tooth are variable, and several classifications have been proposed to define the diversity of root forms and potential anomalies regarding the number and shape of the roots [2–5]. Basically, the natural root has conical shape with a smaller width towards to the apex and often with longitudinal grooves. The root of the maxillary central incisors is wider mesiodistally in vestibular part, and both maxillary and mandibular canines have wider and longer root forms in order to compensate the lateral and oblique forces whereas maxillary lateral and mandibular incisors present a modest shape. Premolars generally have single root with a slight curve at the apex except from the maxillary first premolar which has probably two roots at vestibular and lingual aspects of the alveolus. In the posterior region that corresponds the great occlusal forces, molars have multi roots. Maxillary first and second molars have three roots, mandibular first and second molars have two roots, and third molars tend to have fused complex roots [2, 3]. Some of the anomalies of the roots excluding the aforementioned common variations are supernumerary roots such as maxillary molars with four roots, distolingual root in mandibular molars, mandibulary canine with two roots [2, 6, 7]. All of the diversity is originated from the distinctive biomechanical requirements and functions. Therefore, understanding the original root anatomy is a precondition for all kind of surgical interventions and functional rehabilitations in dental practice from the preventive and regenerative surgeries to the indispensable tooth extraction [4, 8, 9]. Additionally, tooth loss has not been literally replaced regarding both biomechanically and physiologically yet.

Screw-type endosseous implants have been the most preferable rehabilitation of tooth loss for decades, and have demonstrated highly successful survival rates and clinical outcomes [10]. Numerous experimental studies demonstrated successful osseointegration for immediately placed and loaded dental implants into the fresh extraction socket. It has been suggested that immediate procedures could minimize the alveolar bone and soft tissue resorption, thus, provide better cosmetic results [11]. However, there still have been some obstacles for immediate placement procedures of screw-type dental implants. The foremost deficit is a remained void between the implant and the alveolar socket due to the incongruent geometry of these two. Many grafting or barrier techniques have been studied extensively to overcome this problem [12], yet no approach does literally meet the clinical needs.

While searching new solutions for recovering the fresh socket with immediate screw-type implants, a philosophy of custom root formed implant fabrication had come along. The philosophy of custom made dental implant started in 1960s as an idea of replacing the extracted tooth with eligible dental materials such as composites or polymers [13]. It was realized that if the implant had the same design of the extracted root and was congruent with the socket geometry, no residual voids hereby would remain [14]. Thus, a better recovering and esthetics would be achieved.

Starting with the plastic materials and primitive techniques, the custom root analogue implant production evolved up to the digital rapid prototyping [15] technology. Both milling and additive manufacturing techniques have already been utilized with both titanium and zirconia materials in order to fabricate custom root analogue dental implants [15–17]. Thus, a new perspective to be investigated for the dental practice is upon the stage.

2. The evolution and the fabrication procedures of root shaped dental implants

The first attempt of custom root shaped implant was described by Hodosh et al. in 1968 which was called 'Tooth Replica Polymer Implant Concept' [13, 18]. According to this attempt, a plaster mold of the extracted tooth was made right after the extraction. Then, autopolymerizing heat processed polymethacrylate was used alone or with freezed dried cancellous (anorganic) calf bone for creating a 'plastic' or 'plastic-bone mixture' implant material. After the polymer was processed in a flask, and then zephirin chloride washing, the plastic implant was inserted into the alveolar socket. It was the only immediate replacement of lost natural teeth at that time. However, because it resulted in fibrointegration instead of osseointegration, the polymer dental implant was not used for years in clinical practice [19].

In 1992, the root shaped implant idea was revived by using titanium material instead of any polymer by Lundgren and colleagues, and resulted in 88% of bone-to-implant contact [20]. This novelty was inspired by Andersson's method of spark erosion combined with milling machine duplication which was developed for titanium crown fabrication [21]. The milling machine had a tool system that held a stone die of the extracted tooth, and a milling unit integrated with a detection needle and a hydraulic servo-unit which transferred and copied the outer surface of the stone die to a titanium blank.

Following the elementary attempts of creating a dental root analogue, a computer milled anatomical implant system (ReImplant® System, Hagen, Germany) was presented by Kohal et al. [22]. This system was the first computer aided manufacturing of dental implant carrying the original root contours of the extracted tooth. The procedure yet again started after the extraction. The space between the tooth and the socket wall was measured by repositioning the extracted tooth into the socket again for compensating the lost periodontal width. The cervical width was transferred to the computer unit subsequently the data of the laser scanned tooth. Finally, the milling unit with integrated laser camera and computer control station fabricated the root analogue implant out of prefabricated Grade II titanium blank according to the computer data. After polishing the extraosseous cervical part and sandblasting the intraosseous part with Al_2O_3 powder, implant was ultrasonically cleaned with alkaline and autoclaved, and tapped into the respective socket [14, 22]. Similarly, zirconia material was also studied with the computer numerical control (CNC) milling method by Kohal and colleagues first [23].

Another idea for immediate placement of prefabricated anatomically shaped dental implants was suggested by Coatoam [24, 25]. The proper one of the series of anatomically shaped implants in varying lengths (PACE, CAL-Form Inc., Longwood, Fla) was inserted into the healed socket after a waiting period of 6–8 weeks. They asserted that a moldable osteoid which was formed in the early healing socket would readily accept the implant integration and could also facilitate indirect sinus lifting [24, 25]. However, relevant studies have been very limited to state an inference for clinical practice.

In the last decade, growing computer based digital technologies guided the contemporary approaches up to custom root analogue implants, which were called RAI. The clinical procedures were shifted prior to the tooth extraction. Instead of copying or laser-scanning of the extracted tooth, literally computer aided designing (CAD) on the preoperative radiographic data was included to the procedure in addition to the computer aided manufacturing (CAM) methods.

One of the first CAD/CAM combined high-resolution computed tomography based RAI methods was described and commercially available (REPLICATE Immediate Tooth Replacement System, Natural Dental Implants). According to the system, digital imaging and communications in medicine (DICOM) data from a high-resolution cone beam computed tomography (CBCT) or a digital volume tomography (DVT) was obtained. Besides, a digital or two-stage elastomeric impressions with bite registrations were taken preoperatively. Master stone cast models were created and optically scanned. Then, the standardized triangulation language (STL) data of the digitalized master models and the DICOM data of three-dimensional (3D) visualization were offered to compose a 3D envelope that constitutes the digital environment for RAI planning. On 3D envelope, endosseous titanium root-implant portion, zirconia abutment to be glass-soldered onto the titanium root, root analogue implant try-in, provisional crown etc. could be designed [15, 19, 26]. After CAD data was transferred to a five-axis rapid manufacturing machine, the titanium root part out of a medical grade IV solid titanium workpiece and the zirconia parts out of presintered yttria-stabilized tetragonal zirconia material (Y-TZP) were milled, subsequently, the titanium and zirconia parts of implant were glass-soldered to form a one-piece implant. The zirconia parts remained machined surface, and the titanium root was sandblasted and acid-etched. Finally, the implant was delivered in sterile packaging and tapped into the socket [15, 26].

Another digital root analogue implant approach evolved with the help of 3D additive manufacturing technology which was a procedure to fabricate 3D metallic objects from metal powders on the basis of 3D data. The main powder bed fusion methods have been known as direct metal laser sintering (DMLS) or selective laser sintering (SLS) and selective laser melting (SLM) or direct laser metal forming (DLMF). According to the procedures, metal powder microparticles were formed layer by layer with a focused laser-induced fusion in order to create complex solid objects [27]. RAI fabrication out of Ti-6Al-4V alloy material by a high-end SLM method was first proposed by Moin and colleagues [16]. A high-resolution computed tomography (CT) was performed and the datasets were transferred in the DICOM format. The 3D reconstruction software simulated the virtual extraction of the tooth on 3D projection, and the implant with prosthetic components was designed on a reverse engineering software. Processing was carried out in ytterbium (YB) fiber laser in argon atmosphere, and implants were delivered sterile packaged after ultrasonically cleaned [27].

After titanium, zirconia material was also employed for RAI fabrication with the rapid prototyping technology. Dispersion of a zirconium oxide powder into a liquid solution of polyacrylate was used to form a solidified ceramic object by high-end digital light processing 3D printing method as similar with the powder bed fusion technique [17].

3. The evaluation and clinical predictability of root shaped implants

Considering the early attempts, it could be noticed that root analogue implant fabrication required exhausted and complex clinical and laboratory procedures and had some drawbacks formerly. Hodosh's polymer implant resulted in fibrointegration. The proposal method of Lundgren required a long surgical time which could be regarded as a disadvantage. The computer milled anatomical implant system suggested by Coatoam also required a long time and additional complex procedures. Besides, insufficient primary stability was another matter for these trials because of the periodontal space and the enlargement of the socket during the extraction. ReImplant system tried to compensate this problem by integrating an extra measurement and data transfer onto the laser scanned root. This measurement was obtained on the cervical part of the root, and then applied to the whole root surface. An experimental study in monkeys, regarding the root analogue implants of upper central and lateral incisors showed a mean bone-to-implant contact of 41.2% after 6 months of healing, and the study also reported a common clinical complication, —the fracture of the buccal plate during the implant placement [22]. In accordance with this finding, it could be considered that the extra measurement and the width enlargement of socket could also act as another incongruence for achieving the appropriate passive fit into the fresh socket.

Though, ReImplant and PACE system could serve a similar role for the treatment of convex root form. On the other hand, in cases with unfavorable root shape such as concave contours or complex morphology, original root shaped implant could jeopardize the placement and the hygienic maintenance. However, PACE system could be used to eliminate the disadvantages of unfavorable root form, and it would also take less time to perform in clinical practice because it was totally prefabricated [25].

REPLICATE system was first introduced for single tooth replacement. After revealing the clinical advantages in an animal study [28], a 35-year-old woman was subjected to replacement of a maxillary left central incisor [19]. After the implantation with an approximately 1.4 mm of reduced buccal design, a mixture of platelet-rich plasma (PRP) and osteoconductive bovine bone substitute was inserted in the buccal space for the purpose of stabilizing the buccal tissue architecture. After 6 months of healing with immediate provisional crown, the final zirconia restoration was delivered. At almost 1 year of loading, good esthetics and functional stability of surrounding tissues were reported. Simultaneously, in a dog study, the usage of multi-rooted single tooth implant with a custom shaped lingual splint which is bonded by a self-curing luting cement onto the surrounding teeth was tested. Some of the splints were debonded, but no sign of infection was observed within the 16 months of healing. Bone-to-implant contact and mineral apposition rates yielded no significant change, however, the vertical bone loss was significantly lower (0.35 mm for root analogue implant, 0.79 mm for the control implant) compared to the threaded control implants [15]. In another subsequent human study which reported the clinical and radiographic observations within the 1-year of functional loading, one single premolar out of the five had peri-implant infection with mobility after 4 weeks, and the other two of them were identified in the absence of buccal bone around the implant [26]. The implants of this system were roughened, large-grit sandblasted, and acid-etched (SLA) surface characteristics similar to the conventional threaded implants as an advantage for clinical predictability. On the other hand, considering the poor clinical findings, it should be further investigated to reassure tangible results.

Rapid manufacturing techniques also seem promising for fabricating modern root analogue implants. The accuracy of root analogue implant fabricated by powder bed fusion methods revealed acceptable discrepancy. The volumetric measurement of the 3D surface model of the tooth was 0.27% of greater than the optical scanned original root while the RAI was 6.33% of smaller than optical scanned original root [16] and was 0.6–5.9% of smaller than the socket [29]. The local disparity of RAI was more pronounced at the incisal area and the root apex, with a maximum of 0.15 and 1.86 mm, respectively [29]. In a prospective clinical study, 1-year survival revealed 100% of stable with a confirmed good condition of the peri-implant tissue, and no prosthetic complications was observed [30]. In addition to the favorable results, it was suggested that a perfect fit of RAI on the buccal cortical bone could be accused for esthetic failure and also pressure-induced bone loss or fracture of the buccal plate. Therefore, reducing the diameter about 0.1–0.3 mm was offered as a useful strategy [27].

Pirker and Kocher reported the clinical results of computer milled zirconia RAI. Zirconia was used because of its well-known improved biomechanics and esthetic results. The diameter of the implant next to the thin cortical bone was reduced for avoiding fracture and pressure-induced bone loss. The implant with a surface of only sandblasting failed within 2 months, but the other implant surface strategy which added macroretentions on entire root surface showed 92% survival after 2-year follow-up [31]. Nevertheless, CNC milling zirconia was reported to have some disadvantages such as being time-consuming, substantial waste of raw material, and limited accuracy [17, 32] whereas the 3D printed zirconia RAI was a faster procedure as against, and demonstrated a disparity less than 1 mm [17].

4. Advantages of the root shaped implants for immediate placement and future considerations

Owing to the 3D additive manufacturing technology, remarkable characteristics such as functionally graded titanium material, and 3D interconnected controlled porous structure could be delivered to the custom root shaped dental implants [33–35]. Thus, minimizing the stress-shielding effects, providing a long-term stable fixation, and improving bone ingrowth could be possible [36]. Additionally, lower risk of implant surface contamination is another advantage of laser metal sintering method since minimal postprocessing treatment is required [35].

Regarding these knowledge and available clinical results, it could be suggested that combining the root analogue implant strategy with digital technology provide a number of advantages over the previous procedures such as faster preoperative preparation, relatively easier surgical procedures, simpler fabrication of esthetic restoration, and improved biomechanics. Also it would be a cheaper alternative for immediate implant and prosthetic requirements in compromised clinical conditions.

As another matter of fact, comprehensive experimental and clinical studies indicate the importance of the cervical region of the dental implant because the maximum stress is pronounced around the implant neck [37]. The ideal characteristics of dental implant is suggested that a wider neck for a better stress distribution [38], and a large surface area as well as possible with a minimal thread geometry for a better long term crestal bone stability [39]. Therefore, the original root shaped dental implant would be a plausible strategy to achieve better crestal bone stability and supporting esthetics. In addition to that, optimized surface roughness and chemical factors should be taken into account for a good long term biological health. In the literature, the micro-nano hybrid surface topography of titanium alloy was mentioned beneficial on biological responses of osteoblasts [40]. Alkaline phosphatase activity of the cells was greater onto nanotextured rough surfaces, and calcium deposition was higher on microtextured rough surfaces rather than nanotextured surfaces [41]. With the guidance of this knowledge, custom root analogue implants could be better designed with optimized macro and micro surface features in the future.

5. Conclusion

As a brief, considering the prevalent knowledge of clinical dental implant practice, screw-type dental implant has been the most plausible and predictable approach for replacing edentulous alveolar sites. However, it seems not so convenient and could not meet the clinical needs for immediately restoring the fresh extraction socket. Custom root shaped implant strategies emerged as the only realistic implementation and the prospective preference of immediate implant placement for both single- and multi-rooted teeth.

Contemporary computer aided digital technologies assist to overcome the hazardous anatomical drawbacks of jaws, and also to eliminate the excessive surgical augmenting procedures and compromise healing. On the contrary, the CAD/CAM root analogue implant strategies would simplify the immediate tooth replacement and improve the reliability.

Lastly, it should be noted that there are scarce number of objective clinical data regarding 3D planned and manufactured root analogue dental implant methods, and further clinical studies are required to conclude significant results.

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