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BRIEF REPORT

Custom-made, root-analogue direct laser metal forming implant: a case report

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Abstract In the last few years, the application of digital technology in dentistry has become widespread with the introduction of cone beam computed tomography (CBCT) scan technology, and considerable progress has been made in the development of computer-aided design/ computer-aided manufacturing (CAD/CAM) techniques, including direct laser metal forming (DLMF). DLMF is a technology which allows solids with complex geometry to be produced by annealing metal powder microparticles in a focused laser beam, according to a computer-generated three-dimensional (3D) model. For dental implants, the fabrication process involves the laser-induced fusion of titanium microparticles, in order to build, layer by layer, the desired object. At present, the combined use of CBCT 3D data and CAD/CAM technology makes it possible to manufacture custom-made, root-analogue implants (RAI) with sufficient precision. This report demonstrates the successful clinical use of a custom-made, root-analogue DLMF implant. CBCT images of a non-restorable right maxillary first premolar were acquired and transformed into a 3D model. From this model, a custom-made, root-analogue DLMF implant was fabricated. Immediately after tooth extraction, the RAI with a pre-operatively designed abutment was placed in the extraction socket and restored with a single crown. At the 1-year follow-up examination, the RAI showed a good functional and aesthetic integration. The introduction of DLMF technology signals the start of a new revolutionary era for implant dentistry as its immense potential for producing highly complex macro- and microstructures is receiving vast interest in different medical fields.

Keywords Primary stability · Root-analogue implant (RAI) · Computer-aided design/computer-aided manufacturing (CAD/CAM) · Direct laser metal forming (DLMF)

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Introduction

Implant dentistry is constantly evolving towards simplification of clinical procedures and shortened treatment times, with such developments as immediate implant placement. Immediate implants are implants inserted immediately after surgical extraction of the teeth to be replaced [1]. The advantages of immediate implant placement are the decrease in treatment time and the avoidance of a second surgical intervention, leading to overall cost reduction and an improvement in the patients' psychological outlook for dental treatment [1, 2]. To obtain osseointegration, primary stability following implant placement is needed [1, 2]. For this reason, the surgical requirements for immediate implantation include extraction with careful preservation of the alveolar socket walls, and primary implant stability has been achieved by placing implants exceeding the alveolar apex by 3–5 mm, or by inserting implants of greater diameter than the remnant alveolus [1, 2]. The incongruity between the socket wall and the endosseous implant shape remains, however, the major problem associated with immediate implant placement using conventional screw- or cylinder-type implants [1–4]. This problem could be rectified by placing into the extraction sockets a custom-made root-analogue implant (RAI), adapting the root to the extraction socket instead of adapting the bone to a preformed standardized implant [4]. Few studies describing techniques of fabricating and placing custom-made root-analogue implants have been noted in the literature [5–11]. This approach could have several advantages, such as uncomplicated immediate implant placement with decreased bone and soft tissue trauma and increased patient comfort [4]. However, a significant shortcoming with all the previously reported techniques is that the process entails laser scanning or machine copying of an extracted root, with placement of the subsequently fabricated RAI at a second surgery, so that a long waiting time is needed for replacement with these systems [4]. In the last few years, the application of digital technology in dentistry has become increasingly widespread with the introduction of cone beam computed tomography (CBCT) scan technology, and considerable progress has been made in the development of computer-aided design/computer-aided manufacturing (CAD/CAM) techniques, including direct laser metal forming (DLMF) [12–14]. DLMF is a technology in which a high-power laser beam is directed on a metal powder bed and programmed to fuse particles according to a CAD file, thus generating a thin metal layer. Apposition of subsequent layers gives shape to a desired 3D form with minimal post-processing requirements. With DLMF, it is possible to fabricate dental implants of different size and shape directly from CAD models [12–14]. Recently, a novel approach to fabricate a custom-made RAI using a CBCT 3D model and DLMF has been proposed [3]. A CBCT scan of a tooth can be processed and converted into a RAI in order to obtain a precise root replica prior to tooth extraction, thus allowing for immediate implant insertion and avoiding the need for subsequent surgery [3]. The aim of the present study was to demonstrate how new DLMF technologies permit the fabrication of a custom-made root-analogue titanium implant, which can be predictably inserted in a fresh extraction socket, with immediate restoration.

Materials and methods

Case description

A 55-year-old healthy male patient with a fractured non-restorable first maxillary right premolar was selected for this study. The patient provided consent for implant therapy. This study was performed according to the principles outlined in the World's Medical Association's Declaration of Helsinki on experimentation involving human subjects, as revised in 2008.

Radiographic scan and image processing

Computer tomographic (CT) datasets of the fractured tooth were acquired using a modern cone beam scanner (Veraviewepocs 3D^{R}, Morita Corporation, Tokyo, Japan). CT datasets were transferred to a specific 3D reconstruction software (Mimics^{R}, Materialise, Leuven, Belgium). With this software, it was possible to construct a 3D projection of the maxilla and the residual root, simulating a "virtual" extraction of the root (Fig. 1a). The virtual root was isolated as a stereolithographic (STL) file and transferred to proprietary, reverse-engineering software (Leader-Novaxa^{R}, Milan, Italy). The root was smoothed in order to obtain a regular surface. The STL file was returned to the 3D reconstruction software again (Mimics^{R}, Materialise, Leuven, Belgium) to test the congruence between the root and the alveolar socket. Then, the file was transferred to Pro/Engineering CAD 3D software (PTC Group^{R}, Needham, MA, USA) where a prosthetic conical abutment was designed, and a reduction of the diameter of the implant neck next to the thin vestibular cortical bone was made (Fig. 1b).

Implant fabrication

DLMF technology (Leader-Novaxa^{R}, Milan, Italy) was used to fabricate the custom-made RAI (Silvetti-Come

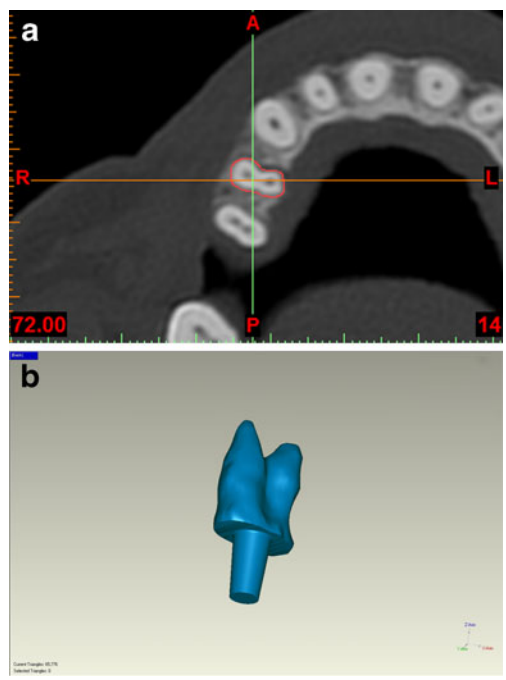

Fig. 1 **a** Computed tomographic (CT) images of the fractured tooth: the residual root is isolated. **b** Stereolitographic (STL) file of the root-analogue implant (RAI) with the prosthetic conical abutment

Technique) with integral abutment, directly from the STL file. The implant was made of Ti–6Al–4V alloy powder, with a particle size of 25–45 μm as the basic material. Processing was carried out in an argon atmosphere using a powerful ytterbium (Yb) fibre laser system (Eos Laser Systems^{R}, Munich, Germany) with the capacity to build a volume up to 250×250×215 mm using a wavelength of 1,054 nm with a continuous power of 200 W, at a scanning rate of 7 m/s. The size of the laser spot was 0.1 mm. To remove residual particles from the manufacturing process, the implant was sonicated for 5 min in distilled water at 25 °C, immersed in NaOH (20 g/L) and hydrogen peroxide (20 g/L) at 80 °C for 30 min and then further sonicated for 5 min in distilled water. Acid etching was carried out by immersion of the sample in a mixture of 50 % oxalic acid and 50 % maleic acid at 80 °C for 45 min, followed by washing for 5 min in distilled water in a sonic bath. Finally, the implant was packaged in custom-made disposable packaging fabricated with the aid of a specific software (Pro/Engineering CAD 3D ^{R}, PTC, Needham, MA, USA).

Surgical and prosthetic procedure

Local anaesthesia was obtained by infiltrating articaine 4 % containing 1:100,000 adrenaline (Ubistesin^{R}, 3M Espe, St. Paul, MN, USA). The surgical access was obtained in a conservative manner by means of an intrasulcular incision, and the first maxillary right premolar was carefully extracted avoiding any damage to the socket and soft tissue. The loss of one of the cortical walls could compromise the correspondence between the custom-made implant and the socket, reducing primary stability, thus jeopardizing the final result of the treatment. The extraction socket was carefully debrided by means of curettage. After that, the root-analogue implant was placed in the socket under finger pressure and subsequent gentle tapping with a hammer and a mallet. Primary stability was achieved as checked by palpation and percussion, due to the perfect correspondence between the RAI and the post-extraction socket (Figs. 2 and 3a, b). At the end of the surgical procedure, interrupted sutures were positioned (Supramid^{R}, Novaxa Spa, Milan, Italy), and a provisional single crown was cemented (Temp-Bond^{R}, Kerr, Orange, CA, USA) on the abutment of the custom-made RAI. The provisional restoration was taken out of any functional occlusal contacts both in centric occlusion and during excursive mandibular movements, and the patient was instructed to chew predominantly on the contralateral side and avoid hard food. The patient received dexketoprofen, 25 mg two times a day (Enantyum^{R}, Menarini, Bologna, Italy) as post-operative analgesic. Antibiotic therapy with amoxicillin+clavulanic acid (Augmentin^{R}, Glaxo-SmithKline Beecham, Brentford, UK), 1 g two times a day was also administered and maintained for 6 days. Detailed instructions about oral hygiene were given, with mouthrinses with 0.12 % chlorhexidine (Chlorexidine^{R}, OralB, Boston, MA, USA) administered for 7 days. The patient was seen on a weekly basis during the first 4 weeks. At the first control visit, 7 days after the surgery, a clinically healthy marginal area was present, and no post-operative pain or swelling was reported. There was no bleeding or wound infection. Sutures were removed. After 2 weeks, the peri-implant tissues showed a good marginal adaptation. After 3 weeks, the peri-implant tissues were stable and in optimal conditions. The provisional restoration was maintained in situ for 3 months, after which the definitive restoration, a cemented, metal–ceramic single crown, was placed.

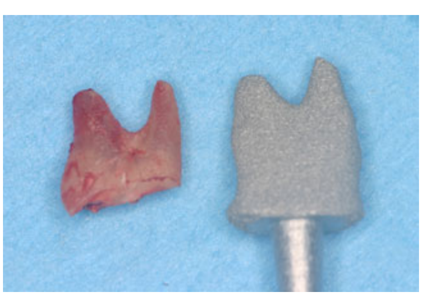

Fig. 2 **a** The extracted fractured tooth and the RAI before insertion in the fresh alveolar socket

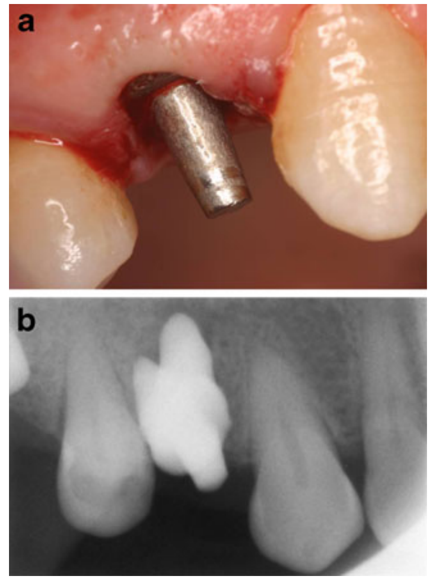

Fig. 3 **a** The custom-made RAI immediately after insertion in the fresh alveolar socket. **b** Post-operative x-ray. Note the perfect correspondence between the RAI and the post-extraction socket

Results

One year after placement, the RAI was still in function (Fig. 4a). The implant was stable, with no signs of infection

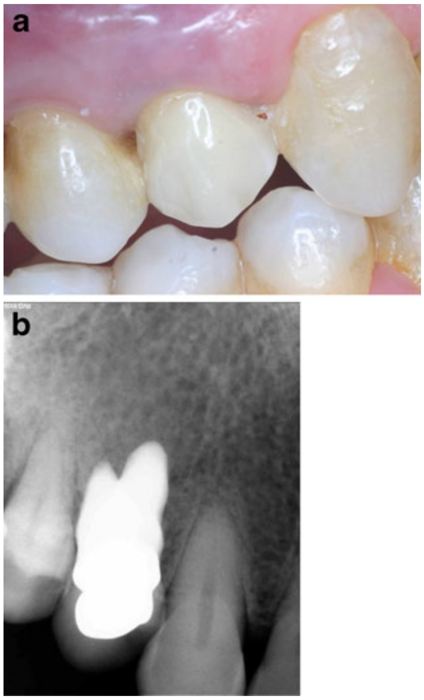

Fig. 4 **a** The definitive restoration in situ 1 year after implant placement. **b** x-ray at 1-year follow-up with the RAI and crown in situ

such as pain or suppuration. The good conditions of the peri-implant tissues were confirmed by the radiographic examination, with unchanged peri-implant marginal bone level and no peri-implant radiolucency (Fig. 4b). The radiographic profile of the implant–crown complex was very similar to that of a natural tooth, with the two distinct roots of the first premolar in evidence. No prosthetic complications occurred. The prosthetic restoration showed optimal functional and aesthetic integration.

Discussion

The concept of replacing teeth with custom-made RAIs was trialled as early as 1969 by Hodosh et al. [5]. However, the polymethacrylate tooth analogue was encapsulated by soft tissue rather than osseointegrated [5]. Animal studies with root-identical titanium implants yielded extremely favourable results with clear evidence of osseointegration [6]. Kohal et al. further refined the approach of root-analogue titanium implants by widening the coronal aspects of the implant to compensate for the lost of periodontium and to obtain a good congruence between implant and extraction socket [7]. In several instances, however, the implant insertion led to fractures of the thin buccal wall of the alveolar bone [7]. A subsequent clinical study revealed excellent primary stability, but with a high, disappointing failure rate of 48 % at 9 months' follow-up [8]. A possible explanation for this is that a perfect fit of the implant leads initially to excellent primary stability; however, it might be responsible for the intermediate time aesthetic failure, due to subsequent uniform pressure-induced resorption simultaneously involving the entire alveolar surface [8]. In fact, cortical bone covering the root is very thin with no or few blood vessels and prone to fracture [4, 9, 10]. Due to this high failure rate, the use of these root-analogue titanium implants was not recommended in the clinic [8]. More recently, zirconia-based implants were introduced as an alternative to titanium implants. In a clinical report by Pirker et al., the immediate placement of a root-analogue non-submerged zirconia implant with macro-retention in the interdental space and a diameter reduction of 0.1 to 0.3 mm next to the buccal cortical bone yielded excellent functional and aesthetic results with no clinically noticeable bone resorption or soft tissue recession at 2-year follow-up [9]. These results were confirmed in more recent clinical studies demonstrating that the presence of macro-retentions limited to the interdental space can improve primary implant stability and finally osseointegration, and the reduction of the diameter of the implant next to the thin cortical bone is important to avoid fracture and pressure-induced bone loss [10, 11]. Nowadays, modern CBCT acquisition and 3D image conversion, combined with the DLMF process, allows the fabrication of custom-made, root-analogue titanium implants, perfect copies of the radicular units we need to replace. These new implants are congruent with the root socket, and they are an alternative to the traditional threaded, straight or tapered implant systems intended to replace a missing tooth. In our present study, a custom-made, root-analogue DLMF titanium implant with a pre-operatively designed abutment was placed into an extraction socket. The root-analogue implant was fabricated in an argon atmosphere using a powerful Yb fibre laser system, with the capacity to build a volume up to $250 \times 250 \times 215$ mm using a wavelength of 1,054 nm with a continuous power of 200 W, at a scanning rate of 7 m/s. The size of the laser spot was 0.1 mm. A perfect congruence between implant and extraction socket was obtained, with a diameter reduction of 0.1 to 0.3 mm next to the buccal cortical bone. At the 1-year follow-up examination, the RAI showed an almost perfect functional and aesthetic integration. The fabrication of a custom-made RAI with the DLMF technique presents some distinct advantages. The DLMF technique allows the fabrication of functionally graded titanium implants, with a relatively high porosity at the surface and a high density in the core [12–14]. This kind of modulation may allow better load adaptation, avoiding stress-shielding and pressure-induced bone loss [12–14]. With DLMF, a porous surface is obtained, capable of accelerating the healing processes and promoting osseointegration [12–14]. In fact, with DLMF it is possible to control the porosity of each layer and consequently of the 3D model by changing the processing parameters, such as laser power and peak power (for CW and pulsed lasers, respectively), laser spot diameter, layer thickness, hatching pitch (or scan spacing), scan speed and scanning strategy, or by modifying the size of the original titanium particles. Moreover, since the information on the abutment design is digital, the definitive prosthetic temporary crown can be made with CAD/CAM technology. Further studies are needed with a larger sample of patients to evaluate the benefits of this technique. The introduction of DLMF technology, however, signals the start of a new revolutionary era for implant dentistry as its immense potential for producing highly complex macro- and microstructures is widely recognized and is receiving vast interest and attention from many researchers in different medical fields.

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References

1. Koh RU, Rudek I, Wang HL (2010) Immediate implant placement: positives and negatives. Implant Dent 19:98–108
2. Kazor CE, Al Shamari K, Sarment DP, Misch CE, Wang HL (2004) Implant plastic surgery: a review and rationale. J Oral Implantol 30:240–254
3. Moin DA, Hassan B, Mercelis P, Wismeijer D (2011) Designing a novel dental root analogue implant using cone beam computed tomography and CAD/CAM technology. Clin Oral Implants Res nov 14. doi:10.1111/j.1600-0501.2011.02359.x
4. KMR, Sharma D, DRP (2011) An overview of immediate root analogue zirconia implants. J Oral Implantol. doi:10.1563/AAID-D-10-00208
5. Hodosh M, Povar M, Shklar G (1969) The dental polymer implant concept. J Prosthet Dent 22:371–380
6. Lundgren D, Rylander H, Andersson M, Johansson C, Albrektsson T (1992) Healing-in of root analogue titanium implants placed in extraction sockets. An experimental study in the beagle dog. Clin Oral Implants Res 3:136–144
7. Kohal RJ, Hurzeler MB, Mota LF, Klaus G, Cafessee RG, Strub JR (1997) Custom-made root analogue implants placed into extraction sockets. An experimental study in monkeys. Clin Oral Implants Res 8:386–392
8. Kohal RJ, Klaus G, Strubl JR (2002) Clinical investigation of a new dental immediate implant system. The reimplant-system. Deutsch Zahn Z 57:495–497
9. Pirker W, Kocher A (2008) Immediate, non-submerged, root-analogue zirconia implant in single tooth replacement. Int J Oral Maxillofac Surg 37:293–295
10. Pirker W, Kocher A (2009) Immediate, non-submerged, root-analogue zirconia implants placed into single-rooted extraction sockets: 2-year follow-up of a clinical study. Int J Oral Maxillofac Surg 38:1127–1132
11. Pirker W, Wiedemann D, Lidauer A, Kocher A (2011) Immediate, single stage, truly anatomic zirconia implant in lower molar replacement: a case report with 2.5 years follow-up. Int J Oral Maxillofac Surg 40:212–216
12. Mangano C, Mangano F, Shibli JA, Luongo G, De Franco M, Briguglio F, Figliuzzi M, Eccellente T, Rapani C, Piombino M, Macchi A (2012) Prospective clinical evaluation of 201 direct laser metal forming implants: results from a 1-year multicenter study on 62 patients. Lasers Med Sci 27:181–189
13. Mangano C, Piattelli A, Iezzi G, Mangano F, Raspanti M, Shibli JA, Cassoni A (2011) Scanning electron microscopy (SEM) and x-ray dispersive spectrometry evaluation of direct laser metal sintering surface and human bone interface: a case series. Lasers Med Sci 26:133–138
14. Mangano C, Mangano F, Shibli JA, Ricci M, Perrotti V, d'Avila S, Piattelli A (2012) Immediate loading of mandibular overdentures supported by unsplinted direct laser metal forming (DLMF) implants. Results from a 1-year prospective study. J Periodontol 83:70–78