Assessment of Primary Stability of Four Different Implant Designs Inserted into 3D-printed Simulation Models of Lower Jaw

Elitsa Sabeva[1], Stefan Peev[2]

Department of Periodontology and Dental Implantology, FDM, Medical University of Varna

Abstract: ***The aim of this study was to investigate the effect of the implant macro- and micro design on the primary stability. 200 dental implant test specimens were inserted into twenty 3D-printed simulation models of lower jaw,as the maximum insertion torque value, the PTV and the ISQ were measured. Considering the mean values of implants of different diameter, length, design or surface topography we concluded that the cylindrical implants with deeper thread and conical implants, which are tapered in their coronal region demonstrate higher primary stability, compared to the other two implant designs included in the study. The insertion of longer implants with larger diameter and rough surface improved the primary stability in 3D-printed simulation models of lower jaw.***

Keywords: implant primary stability, 3D-printed jaw

1. Introduction

The primary stability is essential for the successful osseo integration process and also is significant in regard to the immediate loading of the dental implants. The aim of this study was to investigate the effect of some factors of the implant macro- and micro design on the primary stability, in order to find out how to improve it under same conditions.

2. Literature Survey

It is believed that factors, which can increase the bone-to-implant contact area as the implant shape, length and diameter may increase also the primary stability, considering that the characteristics of the implant bed also play a key role in shaping the contact between the bone and the implant [1], [2].

Many authors commented the effect of the implant diameter on the primary stability, as the majority considered that the larger diameter leads to higher implant stability [1], [3], [4], [5]. Tsolaki et al. [6] observed better primary stability of the longer implants, but Ostmann et al. [7] reported lower ISQ of them. The most authors found the implant diameter more significant for the implant stability, than the implant length [8], [5], [9]. In regard to the implant design most of the conclusions are similar – tapered implants demonstrate higher primary stability compared to the cylindrical ones [10], [11], [12].

3. Material

200 test specimens of implants were placed into twenty 3D-printed simulation models of lower jaw. This study included four implant designs: cylindrical implants with 0.8 thread pitch (C) implants, cylindrical implants with 1.2 thread pitch and higher thread profile - (CD) implants, implants with tapered shape in their apical region – (TA) implants and implants which are tapered in their coronal region and cylindrical in their apical region – (TC) implants; three diameters 3.3 mm, 4.1 mm, 4.8 mm; three implant lengths – 8mm, 10mm, 12mm and two surface modifications. The implants were distributed as follows: 20 C implants with dimension 3.3 mm/10mm (3.3/10), 20 CD 3.3/10 implants, 20 TA 3.3/10 implants, 20 C implants with dimensions 4.1 mm/10mm (4.1/10), 20 CD 4.1/10 implants, 20 TA 4.1/10 implants, 20 TC 4.1/10 implants, 20 C implants with dimensions 4.1 mm/12 mm (C 4.1/12), 20 TC implants with dimension 4.8 mm/ 10 mm (4.8/10) and 20 CD implants with dimension 4.8 mm/8 mm (4.8/8).

In each group 10 of 20 implants were with smooth surface, colored by anodization and the other 10 are with rough surface, modified by sandblasting with large grit Al_2O_3 followed by acid-etching. So finally the implants were distributed in 20 groups.

During the insertion of the implants in the 3D simulation models were measured: the maximum insertion torque (MIT) using iChiropro (Bien Air Dental SA, Bienne, Switzerland), the damping capacity using Periotest Classic (Medizintechnik Gulden, Germany). The resonance-frequency analysis was performed using Osstell Mentor (Göteborg, Sweden).

In order to print 3D simulation models of lower jaw first we used a conical beam computed tomography of lower jaw to obtain 3D image of it using Planmeca Romexis 3.6.0.R software, whereafter STL files were generated. The file displayed using Autodesk Meshmixer software. Then the software Repetier-Host V 1.0.6 (3Dfactories) prepares the file for printing. We used Visions3DPrinter (3Dfactories). The 3D printer works on a fused deposition modeling principle by laying down molten material in layers, as it hardens immediately after its extrusion from the printers nozzle. The material that we used was PLA PrintPlus 1.75 mm. The Polylactic acid (PLA) is a biodegradable thermoplastic material, which is also classified as a polyester. PLA Print Plus is a PLA filament with diameter of 1.75 mm rolled on a spool. The cross-section of one of the 3D simulation models is shown on fig. 1. It is visible how the bone structure is recreated.

Figure 1: Transversal cross-section of 3D-printed simulation model imitating the typical corticocancellous bone structure.

In each jaw were inserted 10 implants from group, so in 20 jaws were placed 20 different implant groups. In each simulation model the implants were inserted at same positions using individual drill template. Before the osteotomy was done, the 3D printed simulation models were stable fixed using vise. The site preparation protocol was the following:

1) The individual drill template was positioned on the 3D simulation model
2) Pilot osteotomy was performed using 2.2 mm pilot drill to the appropriate depth at a maximum speed of 800 rpm.
3) After the pilot osteotomy was done, the template was removed
4) The osteotomy was enlarged consequently to the desired diameter with a 2.8 mm drill, then with a 3.5 mm drill and with 4.2 mm drill, as for the 3.3 diameter implants site preparation the final drill used was the 2.8 mm drill, for the 4.1 diameter implants – 4.2 mm drill and the last drill used for the site preparation of the 4.8 diameter implants was the 4.2 mm drill.
5) The orifice of the osteotomy was enlarged with a profile drill with a corresponding diameter

The implant site preparation was performed with continuous cooling with sterile saline solution.

The implants were placed using contra angle handpiece CA 20:1 L Micro-series (Bien Air). We controlled and measured the insertion torque during the implant placement using the torque function of the implant unit iChiropro (Bien Air Dental SA, Bienne, Switzerland). Implants were inserted into the osteotomy with speed of 15 rpm. At the end of the insertion the software calculated the maximum insertion torque.

We assessed the damping capacity using Periotest Classic. We used the transfer part of the implants as a suprastucture. We did the measurements, as the handpiece of the device was held perpendicular to the transfer's axis, 0.2-0.7 mm away from its surface and 4mm above the marginal bone area.

Resonance-frequency analysis (RFA) was performed using Osstell Mentor. First on the implant platform we installed the Smartpeg element, as for the purpose of our study we used different types of Smartpeg, according to the different implant platforms .The probe of the Osstell Mentor device was held perpendicular to the axis of the Smartpeg at the level of its magnet. Two measurement in two perpendicular directions were done for each implant and as final value we considered the mean value of the both measurements.

The analysis of all results were done using IBM SPSS Statistics 19 software.

4. Results

On a fig. 2, fig. 3 and fig. 4 are shown the mean MIT values, mean PTV and mean ISQ values distributed by the type/dimensions of the implants included in the study.

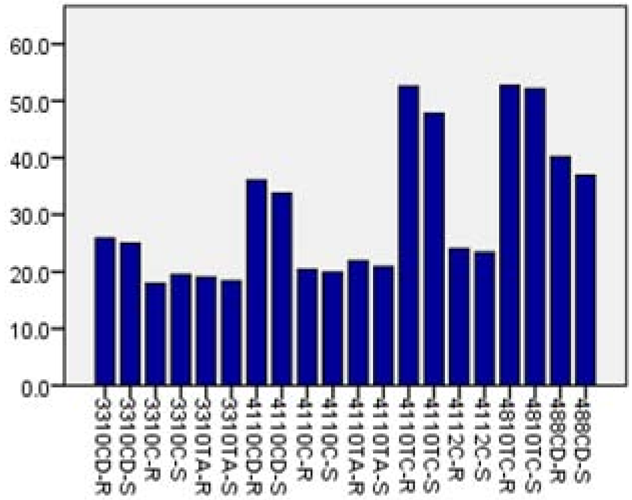

Figure 2: Mean MIT values, distributed by implants

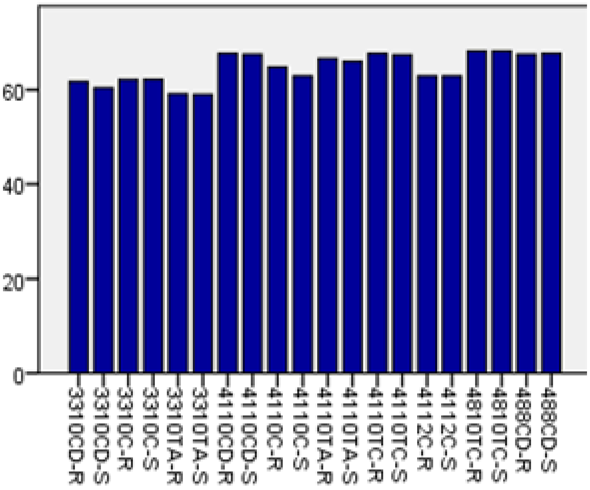

Figure 3: Mean ISQ distributed by implants

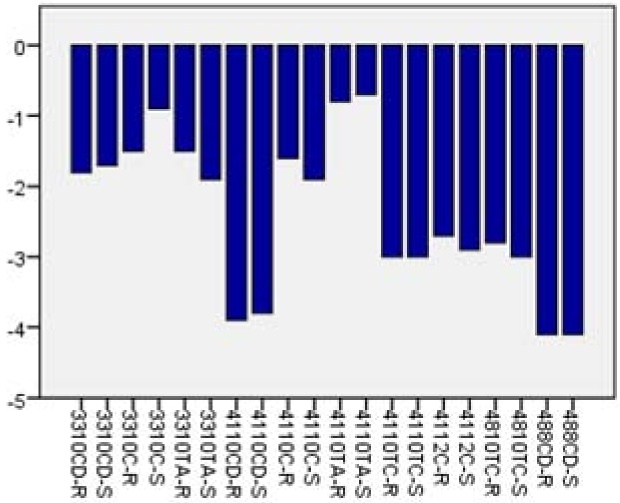

Figure 4: Mean PTV distributed by implants

To find out how does the implant diameter influence the primary stability we compared the mean MIT values, mean PTV and mean ISQ of implants with different diameters, same length, same design and same surface topography.
When we compared the mean values of 3.3 mm/10 mm and of 4.1 mm/10 mm cylindrical implants of both designs we established the following relation: the insertion of larger diameter implants leads to higher primary stability, according to the results of the damping capacity measurements, MIT and resonance-frequency analysis. This also applies to the both types tapered implants. According to the marginal tapered implants we compared implants of 4.1 mm and 4.8 mm diameter.

The influence of the implant length on the primary stability was observed by comparing mean values (MIT, PTV, ISQ) of implants with different length (10mm and 12 mm) and same diameter (4.1 mm), design and surface topography. We found out that the cylindrical implants with length of 12 mm are more stable than the 10 mm implants, according to the mean MIT values and mean PTV, but not according to the mean ISQ, which was higher for the shorter implants.

The effect of the implant design was analyzed by comparing the mean values from all measurements of implants with different design and same other parameters (diameter – 4.1 mm and length – 10mm). The cylindrical implants with higher thread profile and the coronally conical implants demonstrated highest primary stability, followed by apically tapered implants and the other type cylindrical implants. We observed small difference between the mean values of CD and TC implants, and also between TA and C implants.

When we compared the results of 3.3 mm/10 mm C, CD and TA implants we observed similar relation.

To investigate the impact of the surface topography on the primary stability we analyzed the mean values of on implants with same design and same other parameters, but with different surface modification and we established that the surface roughness leads to better primary stability, according to the MIT, PTV and ISQ, although the difference is not very demonstrative in all of the cases.

5. Discussion

It seems that some mechanical properties of the-3D printed PLA material are comparable to those of the jaw bone considering the similar MIT, PTV and ISQ.

The probable reason for the better primary stability of the 1.2 thread pitch cylindrical implants is the higher thread profile. Other authors also reported higher stability of an implants with deeper thread [13]. We think that the primary stability of the implants, which are conical in their upper third is due to the coronal tapered shape which increases the implant diameter in its marginal region.

Our results about the impact of the implant diameter match those, reported by the majority [1], [3], [4], [5]. Other authors didn't observe any relation between the implant diameter and the implant stability [14]. We observed lower ISQ of longer implants, which is similar to the results of Ostmann [7] . After all, considering the mean PTV and MIT we established that the insertion of implants with longer length could lead to a better primary stability, Tsolaki et al. [6] reported similar conclusion. Most of the authors reported better primary stability of the tapered implants compared to the cylindrical implants [10], [11], [12]. That doesn't match our observation in cases, where we used cylindrical implants with higher thread profile, in all other cases our results are similar to those of other investigators. According to our and other studies the implant diameter affects the primary stability more than the implants length [8], [5], [9]. Mazzo et al. [15] concluded that the acid-etched implants demonstrate better stability. We also established that the rougher surface could lead to a higher primary stability.

6. Conclusion

The primary stability of cylindrical implants inserted in 3D-printed simulation models of lower jaw could be improved by choosing implants with higher thread profile. Implants, which are tapered in their coronal area, demonstrate higher primary stability compared to implants, which are conical in their apical region. Larger diameter, longer length and rough surface are factors, which influence positively implant primary stability in 3D-printed simulation models.

References

[1] Lachmann S, Laval JY, Axmann D, Weber H, Influence of implant geometry on primary insertion stability and simulated peri-implant bone loss: an in vitro study using resonance frequency analysis and damping capacity assessment, Int J Oral Maxillofac Implants. 2011 Mar-Apr;26(2):347-55.
[2] Barikani H, Rashtak S, Akbari S, Fard MK, Rokn A. The effect of shape, length and diameter of implants on primary stability based on resonance frequency analysis. Dental Research Journal. 2014;11(1):87-91.
[3] Gómez-Polo M, Ortega R, Gómez-Polo C, Martín C, Celemín A, Del Río J. Does Length, Diameter, or Bone Quality Affect Primary and Secondary Stability in Self-Tapping Dental Implants? J Oral Maxillofac Surg. 2016

Mar 22. pii: S0278-2391(16)00345-1. doi: 10.1016/j.joms.2016.03.011.

[4] Horwitz J, Zuabi O, Peled M, Resonance frequency analysis in immediate loading of dental implants, Refuat Hapeh Vehashinayim. 2003 Jul;20(3):80-8, 104

[5] Möhlhenrich SC, Heussen N, Elvers D, Steiner T, Hölzle F, Modabber A. Compensating for poor primary implant stability in different bone densities by varying implant geometry: a laboratory study. Int J Oral Maxillofac Surg. 2015 Dec;44(12):1514-20. doi: 10.1016/j.ijom.2015.08.985. Epub 2015 Sep 9. PubMed PMID: 26362488.

[6] Tsolaki IN, Najafi B, Tonsekar PP, Drew HJ, Sullivan AJ, Petrov SD. Comparison of osteotome and conventional drilling techniques for primary implant stability: an in vitro study. J Oral Implantol. 2016 Mar 3.

[7] Ostman PO, Hellman M, Wendelhag I, Sennerby L. Resonance frequency analysis measurements of implants at placement surgery. Int J Prosthodont. 2006 Jan-Feb;19(1) 77-83; discussion 84.

[8] Maiorana C, Farronato D, Pieroni S, Cicciu M, Andreoni D, Santoro F. A Four-Year Survival Rate Multicenter Prospective Clinical Study on 377 Implants: Correlations Between Implant Insertion Torque, Diameter, and Bone Quality. J Oral Implantol. 2015 Jun;41(3):e60-5. doi: 10.1563/AAID-JOI-D-13-00206.

[9] Rokn A, Ghahroudi AR, Mesgarzadeh A, Miremadi A, Yaghoobi S. Evaluation of stability changes in tapered and parallel wall implants: A human clinical trial. J Dent (Tehran) 2011;8:186–200.

[10] Toyoshima T, Tanaka H, Ayukawa Y, Howashi M, Masuzaki T, Kiyosue T, Koyano K, Nakamura S., Primary Stability of a Hybrid Implant Compared with Tapered and Cylindrical Implants in an Ex Vivo Model, Clin Implant Dent Relat Res. 2014 Feb 9. doi: 10.1111/cid.12205.

[11] Menicucci G, Pachie E, Lorenzetti M, Migliaretti G, Carossa S, Comparison of primary stability of straight-walled and tapered implants using an insertion torque device, Int J Prosthodont. 2012 Sep-Oct;25(5):465-71.

[12] Sennerby L, Pagliani L, Petersson A, Verrocchi D, Volpe S, Andersson P. Two different implant designs and impact of related drilling protocols on primary stability in different bone densities: an in vitro comparison study. Int J Oral Maxillofac Implants. 2015 May-Jun;30(3):564-8.

[13] Lee S-Y, Kim S-J, An H-W, et al. The effect of the thread depth on the mechanical properties of the dental implant. The Journal of Advanced Prosthodontics. 2015;7(2):115-121.

[14] Merheb J, Temmerman A, Rasmusson L, Kübler A, Thor A, Quirynen M. Influence of Skeletal and Local Bone Density on Dental Implant Stability in Patients with Osteoporosis. Clin Implant Dent Relat Res. 2016 Apr;18(2):253-60.

[15] Mazzo CR, Reis AC, Shimano AC, Valente ML. In vitro analysis of the influence of surface treatment of dental implants on primary stability. Braz Oral Res. 2012 Jul-Aug;26(4):313-7.