CLINICAL ORAL IMPLANTS RESEARCH

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Evaluation of the insertion torque, implant stability quotient and drilled hole quality for different drill design: an in vitro Investigation

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Key words: dental implants, resonance frequency analysis, bone density, insertion torque, drill precision

Abstract

Objective: The purpose of the present study was to compare the insertion torque and implant stability quotient between different drill design for implant site preparation.

Materials and Methods: Synthetic blocks of bone (type I density) were used for drilling procedures. Three groups were evaluated: Group G1 - drilling with a single bur for a 4.2 mm conical implant; Group G2 and Group G3 - drilling with three consecutive burs for a 4.1 mm cylindrical implant and for a 4.3 mm conical implant respectively. For each group, 15 drilling procedures were performed without irrigation for 10-mm in-depth. The drilled hole quality (HQ) after the osteotomy for implant site preparation was measured in the five-first holes through a fully automated roundness/cylindricity instrument at three levels (top, middle, and bottom of the site). The insertion torque value (ITV) was achieved with a computed torquimeter and the implant stability quotient (ISQ) values were measured using a resonance frequency apparatus.

Results: The single drill (group 1) achieved a significantly higher ITV and ISQ than the multiple drills for osteotomy (groups 2 and 3). Group 1 and 3 displayed significantly better HQ than group 2.

Conclusions: Within the limitations of the study, the results suggest that the hole quality, in addition to the insertion torque, may significantly affect implant primary stability.

Introduction

Implant stability at the time of surgery is crucial for the long-term success of dental implants. Primary stability is considered of paramount importance to achieve osseointegration (Degidi et al.2013). Primary implant stability can be defined as a function of the local bone quality and quantity, the geometry of the implant, the placement and surgical technique used, and the precise fit in the bone (Bilhan et al. 2010). Thus, the orchestration of the above elements is crucial for the long-term success of the implant (Dilek et al.2008; Stacchi et al.2013) Two main factors that influence primary stability of an implant during placement are the amount of bone-implant contact and the role of compressive stresses at the implant tissue interface.

Such stresses may be beneficial for enhancing the primary stability of an implant, but excessive compression of the blood vessels in the bone tissue surrounding the implant may result in necrosis and local ischemia of the bone at the implant-tissue interface (Nedir et al. 2004; Isoda et al. 2012) In the same respect, secondary stability can also be determined by the bone tissue response to the surgical trauma and the implant surface. In this respect, the quality of the cutter is of fundamental importance, as the intensity of the trauma caused by the osteotomy procedure may determine the bone response. Gehrke 2015) histologically showed better bone response when the final drill used in the osteotomy was new and efficient in cutting (single use).

Shorter healing periods are usually needed for implants with adequate primary stability to achieving osseointegration. On the other hand, implants with poor primary stability need longer healing periods to achieve sufficient gain in secondary stability, to support prosthetic rehabilitation. This suggests the possibility of determining the length of the healing period on an individual basis, making implant treatment safer, more effective, and less time-consuming in some cases (Esposito et al. 1998) Generally, clinicians evaluate primary stability using the percussion test or using their own perception during the insertion process. However, the lack of precision has motivated the development of different methods to objectively evaluate primary stability; in particular, peak insertion torque (IT) and resonance frequency analysis (RFA) are the most used globally. Clinically, RFA values or implant stability quotient (ISQ) values have been correlated with changes in implant stability during osseous healing. Thus, IT and ISQ values are thought to have a positive correlation (Degidi et al. 2009, 2012). However, the formula of higher IT translating into higher primary stability may not always be true because the quantity and quality of bone varies significantly among patients. Therefore, the purpose of the present study was to investigate the IT, RFA and drilling quality (hole precision, that is the linearity and roundness of the borders of the prepared site at any depth, which should be as close as possible to a cylinder or a cone, depending on the profile of the drill used) of three different dental implant design using artificial bone block. The null hypothesis was that using a single drilling step, no difference in drilling quality (hole precision), IT and RFA of the implants occurs, with respect to using conventional multiple-step drilling.

Materials and methods

Bone specimen and groups division

To standardize the bone characteristics, bone blocks of solid rigid polyurethane foam (Nacional Ossos, São Paulo, Brazil), in accordance with the ASTM F1839/08 (Standard Specification for Rigid Polyurethane Foam for Use as a Standard Material for Testing Orthopaedic Devices and Instruments. ASTM International, West Conshohocken, PA, 2012) with a thickness of 40 mm, a width of 10 mm, and a length of 180 mm were used, foam is available in a range of sizes and densities, in this study it was 0.64 grams per cubic centimeter (40 pcf = 40 pounds per cubic foot).

Three groups were considered and are showed in the Fig. 1:

Group 1: One drill 4.2 mm diameter by 10 mm length (1500 rpm) for conical implant, (IdAll Implants Diffusion International (Montreuil, France).

Group 2: Drill sequence for a cylindrical 4.1 mm standard implant diameter by 10 mm length, Straumann (Basel, Switzerland): drill diameters were 2.2 mm (used at 800 rpm), 2.8 mm (600 rpm) and 3.5 mm (500 rpm).

Group 3: Drill sequence for a conical 4.3 mm Nobel Replace® implant diameter by 10 mm length, Nobel Biocare (Sweden): tapered 2 mm (2000 rpm), 3.5 mm (800 rpm) and 4.3 mm (800 rpm).

Fig. 1. Image of the sets (drills and implant) used for each group.

Osteotomy preparation and hole quality analysis

An apparatus was prepared *ad hoc* for this experiment. It was composed of a control panel with a programmable logic controller (PLC) and a step motor with a man-machine interface (MMI). These devices were used to produce continuous drilling movements, which were pre-determined (position, depth, and load) with high precision by the investigator. A device was used to stabilize bone samples while drilling. Fifteen osteotomies of each group were prepared with a gentle surgical technique using a surgical drill at a rotational speed recommended by the manufacturer of each implant system. In the present study, a load of 2 kg was used, according to the procedures of other authors (Lavelle & Wedgwood 1980; Misir et al. 2009)) After the perforations (15 osteotomies), the five-first holes of each group were selected and submitted to a revolutionary concept in automated roundness inspection to measure the hole precision (Talyrond 585, Taylor Hobson, Chicago, IL, USA) (Fig. 2). The five holes were analyzed at three levels, top (p1), middle (p2) and bottom of the hole (p3), showing in the scheme of the Fig. 3. A percentage average of the data was

Fig. 2. Image of the apparatus used to measure the hole precision in the samples.

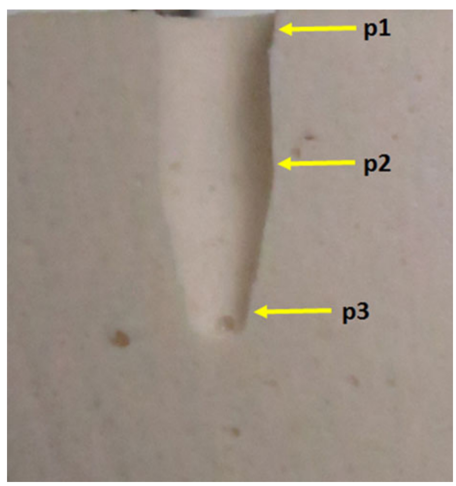

Fig. 3. Different evaluations and measurements with different drills.

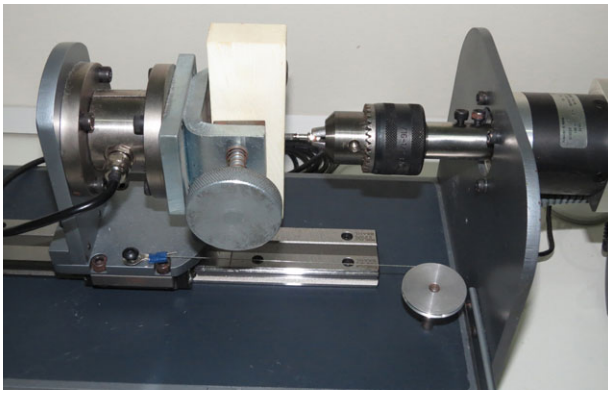

Fig. 4. Image of the computed torquimeter used to measure the insertion torque.

Table 1. **Data of the implant stability quotient (ISQ) measured in different groups**

	Mean & SD	Median	Range
Group 1	84 ± 2.29	84	81–87
Group 2	75 ± 2.51	75	70–79
Group 3	74 ± 2.41	74	69–78

made in relation of the roundness precision (mean difference of the actual hole profile respect to an ideal circle).

Fixture installation, IT and RF measurements

Ten implants of each group were installed in the last 10 osteotomies not used for the roundness measurement. For the implants installation a Torque Testing Machine - CME (Técnica Industrial Oswaldo Filizola, São Paulo, Brazil), which is fully controlled by software DynaView Torque Standard/Pro M (Fig. 4), with test speed of 5 rpm and angular measuring system with a resolution of 0.002, was used by avoiding possible differences caused by human movement during implant installation. Furthermore, the implants were inserted with a controlled force of 10N, in accordance with standard ASTM F543-2 (2007). The peak IT was measured automatically for all of the implants. Following the final level seating of the implants, all samples underwent resonance frequency analysis (RFA) to measure the implant stability. A Smartpeg™ (Integration Diagnostics AB, Göteborg, Sweden) was screwed into each implant and tightened to approximately 5N. The transducer probe was aimed at the small magnet at the top of the Smartpeg at a distance of 2 or 3 mm and held stable during the pulsing until the instrument beeped and displayed the ISQ value. The implant stability quotient (ISQ) values were measured by Osstell™ Mentor (Integration Diagnostics AB, Göteborg, Sweden). The ISQ values were measured in two different directions, and the 20 values (2 per implant) were used to obtain a mean ISQ value per group (Huang et al. 2002; Turkyilmaz 2006; Kahraman et al. 2009; Roze et al. 2009; Hong et al. 2012).

Statistical analysis

The D'Agostino & Pearson omnibus test was used to test normality of distributions of each group. Statistical analyses were performed using a one-way analysis of variance (ANOVA) to determine the differences between the three groups comparing the three methods (RFA, IT and hole precision) for each of the parameters evaluated. For the comparisons between groups at each observation methods, the Student's unpaired *t*-test was applied. $P < 0.05$ was considered as the significance level. The data were processed in the software Unscrambler®, version 6.11(CAMO A/S, Trondheim, Norway).

Results

Resonance frequency analysis (RFA)

The mean resonance frequency values for the three investigated implant designs, standard deviation (SD) and range are summarized in Table 1**.** Using a one-way ANOVA test comparing the three groups, the test showed high significance ($P = 5.6 \times 10^{-20}$), and it is thus concluded that there is an important effect among the groups, with significance set at $P < 0.05$. The variations in the RFA among the groups, applying the t-test, are shown in the bar graph of Fig. 5 along with the p-values. The single drill (group 1) achieved a significantly higher ISQ than the multiple drills for osteotomy (groups 2 and 3).

Insertion torque value analysis

During the insertion torque testing, all of the implants were stable and anchored in bone. The mean resistance to insertion torque values, standard deviation and range are summarized in Table 2. The groups were compared using a one-way ANOVA test; because F crit (= 3.35) is smaller than F calc (= 22.95), the test is highly significant ($p = 1.5 \times 10^{-6}$), and it is thus concluded that there is an important effect among the groups, with significance set at $P < 0.05$. When the values were compared among the groups using the t-test, statistically significant differences were found as shown in the graph of Fig. 6 with the respective p-values. Again, group 1 showed significantly higher IT values than groups 2 and 3.

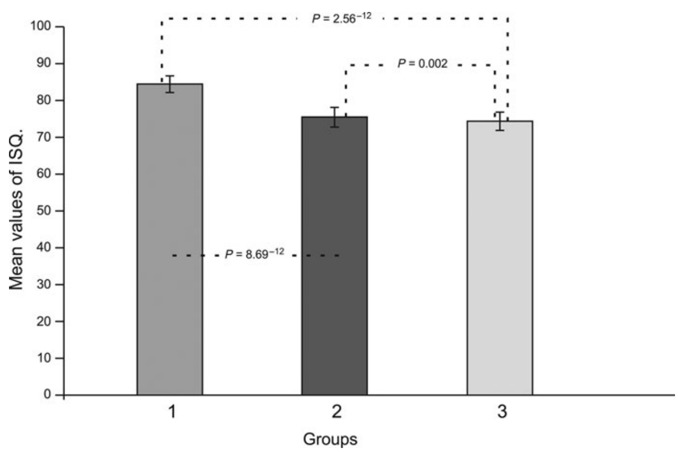

Fig. 5. Bar graph showing the comparisons of the ISQ values and p values between groups.

Table 2. **Data of the implant insertion torque (IT) in Ncm, measured in different groups**

	Mean & SD	Median	Range
Group 1	71.5 ± 4.1	71.8	61–75.8
Group 2	61.6 ± 3.6	61.8	55–68
Group 3	62.0 ± 3.5	61.4	56.1–66.3

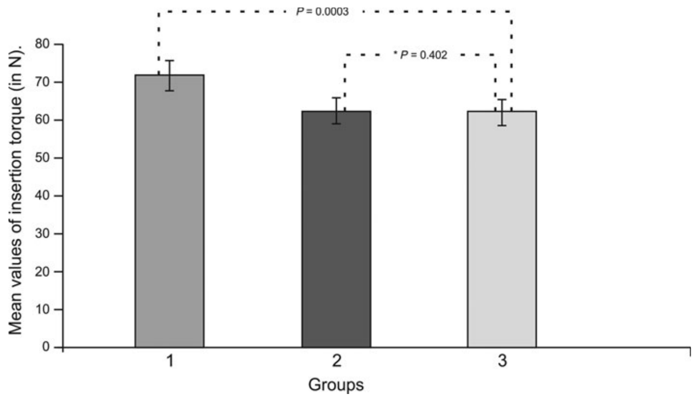

Fig. 6. Bar graph showing the comparisons of the insertion torque values and p values between groups.

Hole precision analysis

These data showed an average accuracy of circularity measured in 3 points for group 1 of 93% (Fig. 7), in the group 2 of 76% (Fig. 8) and for the group 3 of 88% (Figs. 9). Groups 1 and 3 showed significantly better precision as compared to the group 2 ($P < 0.05$).

Discussion

The aim of the present study was to compare different drill systems used for implant site preparation through the insertion torque (IT), primary stability and hole quality of dental implants inserted in artificial cortical bone blocks. The best results for each of these outcomes were achieved by the IDAll implants, for which the implant site preparation was made using a single, high performance drill. This might be a possible explanation for the excellent clinical results recently presented (98% of implant survival) in the evaluation of 350 implants installed with a single drilling step in several clinical procedures (Bettach et al.2015).

In general, the insertion torque determines the primary implant stability, which is considered the most important factor for a successful implant treatment. The distinct ranges of implant primary stability have been distinguished by the resonance frequency method (Martinez et al. 2001; Molly 2006; Sim & Lang 2010; Katsoulis et al. 2012;). Thus, IT was related with the RFA using the Osstell as a method to measure implant stability. The results of the present study interestingly showed that the IT and

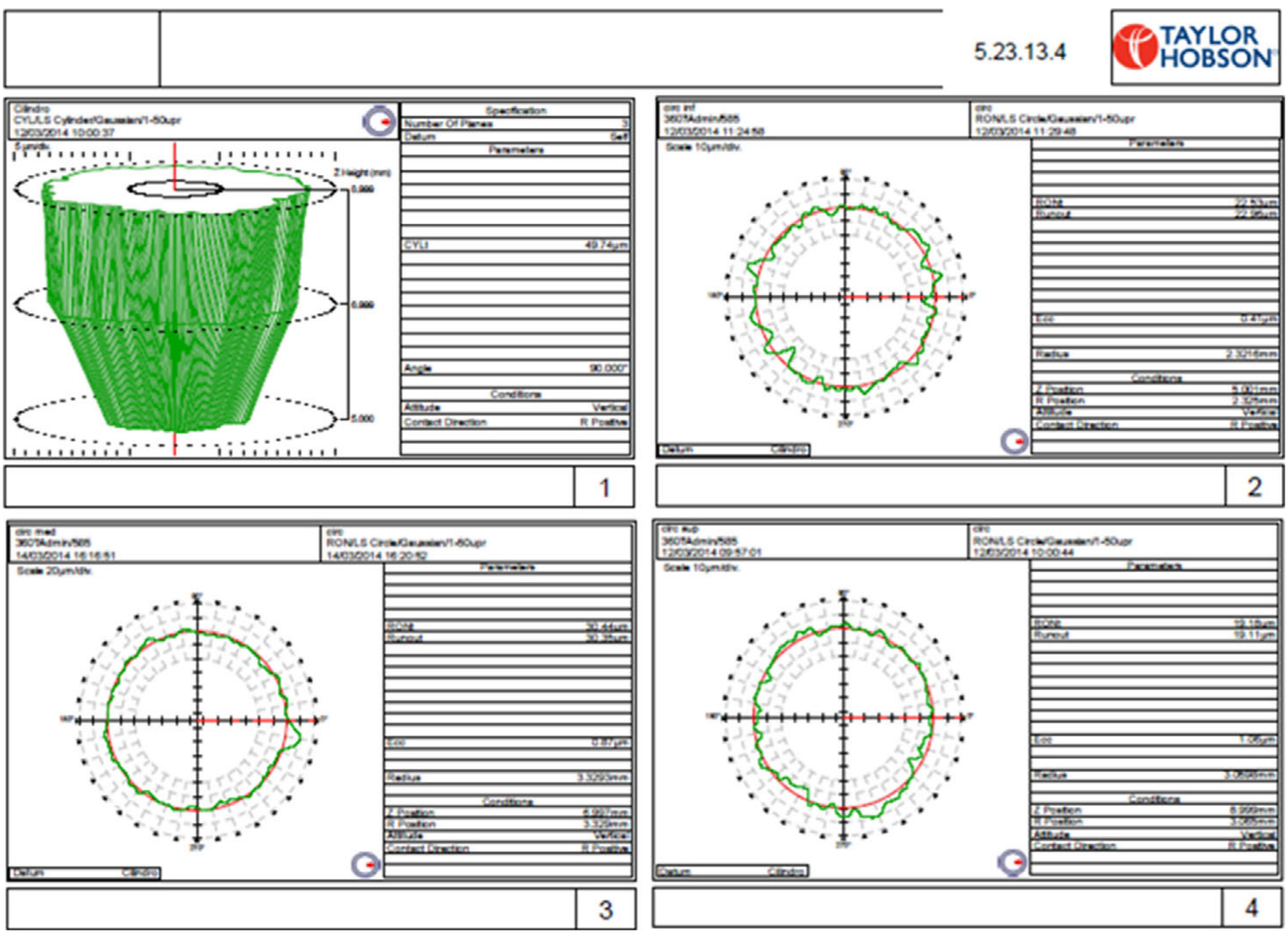

Fig. 7. Graph of the circularity test of the IDI implants (Group 1).

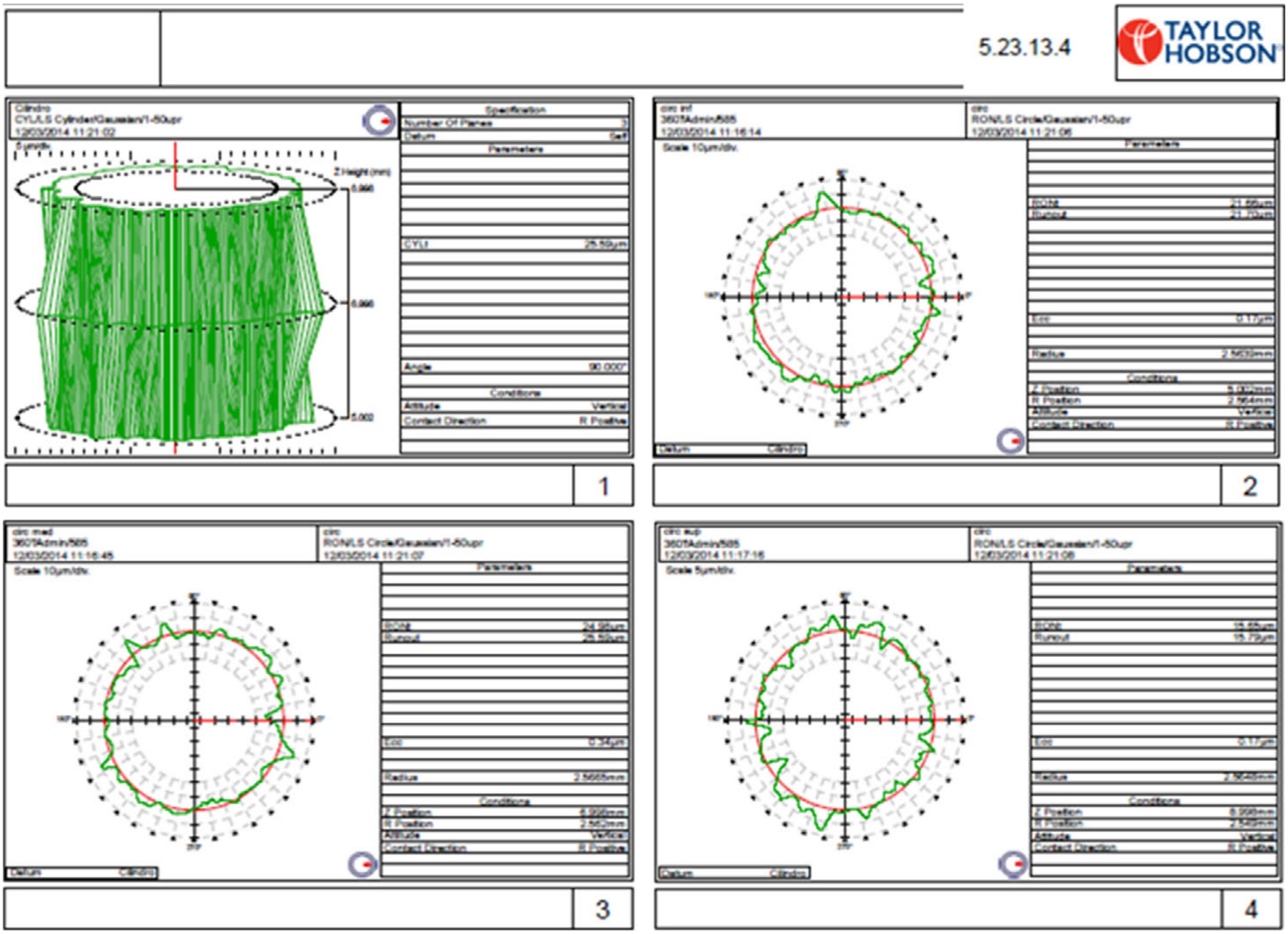

Fig. 8. Graph of the circularity test of the Straumann implants (Group 2).

initial stability increased according to the hole quality, suggesting a positive correlation between these parameters, that could be further investigated in subsequent investigations. It may be speculated that the more precise the cylindrical/conical hole produced by the drill, the better the fit with the implant and, consequently, the higher the possibility of achieving an optimal implant primary stability, with favorable consequences on osseointegration and load-bearing capacity. Conversely, an implant with a poor fit to the drilled site may achieve poor stability and have an increased risk of excessive micromovements at the bone-implant interface, with deleterious effects on osseointegration.

The initial stability is known to be highly dependent on the local bone density. The IT also increases according to the thickness of the cortical bone, and a slight increase was observed for initial stability. This suggests that the volume of high dense cortical bone affects the initial stability and it corroborates a recent study in which the same artificial bone model was used (Cleek et al. 2007; Motoyoshi et al. 2007; Salmória et al. 2008). Then, to there were variations in the type of bone (quality) during measurements, we used a completely cortical bone block.

The osteotomy using different methods (piezoelectric vs. conventional drilling) has demonstrated different clinical results (Da Silva Neto et al. 2014) i.e., the stability of implants placed using the piezoelectric method was greater than that of implants placed using the conventional technique. These data may indicate that the surgical technique has an important function in the implant stability (Bilhan et al. 2010). Drill design should allow for the less traumatic surgery as possible, and this consideration should determine drill characteristics as flute geometry and design, sharpness of the cutting tool, diameter, as well as drilling protocol features such as drilling speed, axial force (pressure applied to the drill), bur angulation, irrigation, torque and thrust forces, use of multiple burs with incremental diameter vs. one-step drilling (Oh et al. 2011; Augustin et al. 2012) Also bone characteristics like cortical bone thickness and bone density, as well as the time needed for implant site preparation may affect heat generation during drilling (Tehemar 1999; Chacon et al. 2006; Gronkiewicz et al. 2009).

In previous study in which the temperature generation using single IDI drills was compared to the multiple drills of other two systems, the results showed no significant difference in the heat produced in the bone surrounding the implant site, measured with a thermocouple (Gehrke et al. 2015). While there might have been a slight overestimation of the temperature in the groups using multiple drills, due to a reduced recovery between consecutive drilling steps, this

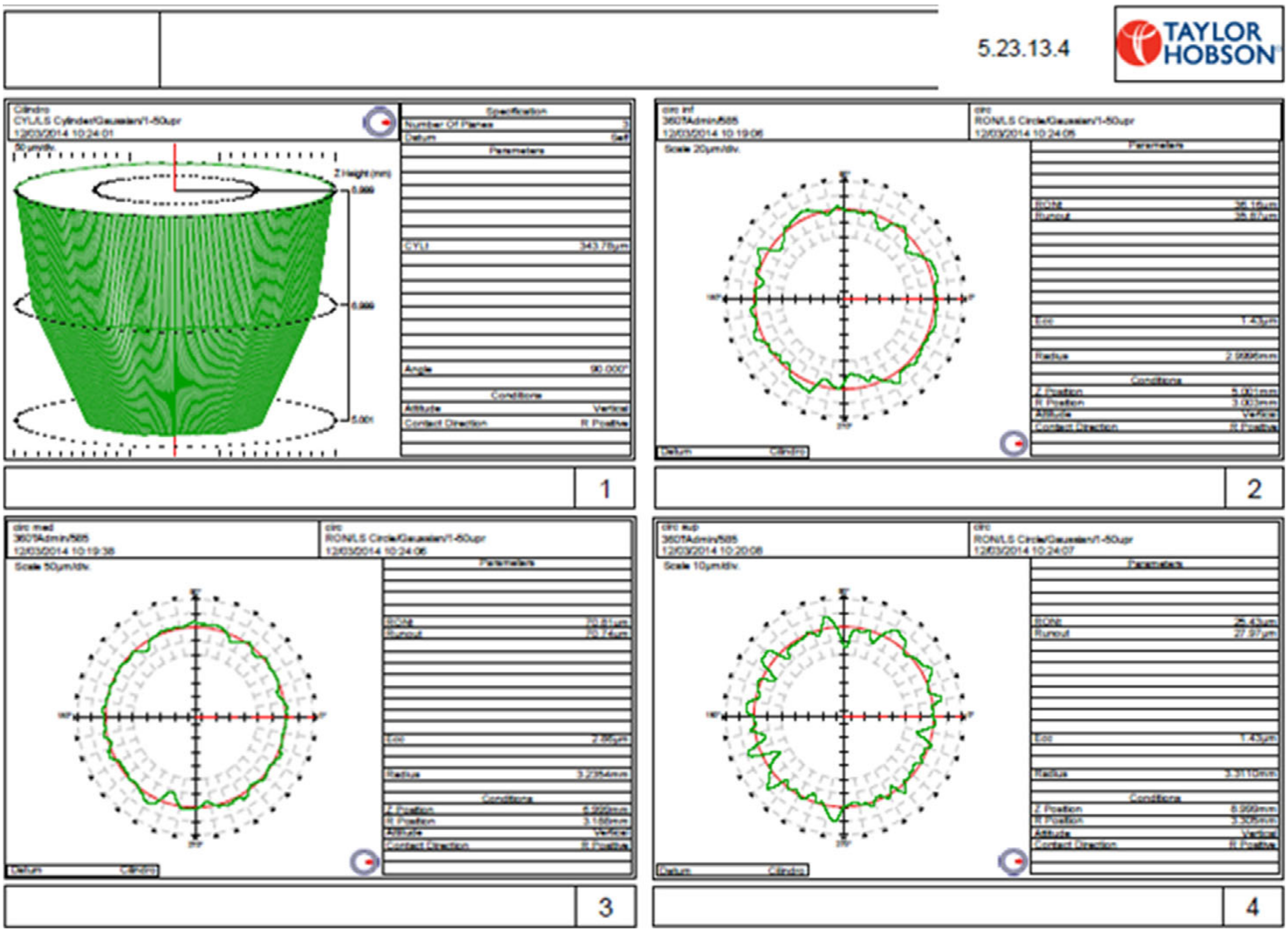

Fig. 9. Graph of the circularity test of the Nobel Replace® implants (Group 3).

allowed for a standardization of the protocol. The possibility of shortening the overall drilling procedure may prove beneficial to tissues reducing the local damage as well as the patients' discomfort. In fact, prolonged tissue exposure may be detrimental to the postoperative course due to the increased release of pro-inflammatory cytokines and consequent amplified inflammatory response (Penarrocha et al. 2006).

The blocks of synthetic bone used in the present study have been specifically designed to reproduce the physical properties of the cortical bone in terms of hardness, density, elasticity (Young module), in accordance with the ASTM F1839/08. The physical features of these synthetic bone blocks are homogeneous throughout their volume, so as to obtain a good standardization of the procedures and avoid introducing possible sources of bias in the measurements. The use of synthetic bone blocks, as well as other standardized procedures, has been recommended by a recent systematic review aiming at evaluating, through an analysis of published papers on this topic, the main factors affecting the temperature increase and drill wear during implant site preparation (Möhlhenrich et al. 2015). On the other hand, due to natural inhomogeneities in the human jawbones, there might be differences between such synthetic model and the in vivo situation. Finally, only blocks of bone type 1 were used, which is not so common in clinical situations. This was done because it is in this type of bone where the cutting precision is more important and also where the insertion torque and ISQ values are more uniform between groups.

Biologic and anatomical consequences such as the osteotomy quality of cortical bone seem to be significant factors affecting primary stability, and estimation of bone density and the optimal selection of drill system are important.

Conclusion

The present study, within the limitations, showed that a single bur system achieves greater precision in the osteotomy than a conventional drilling sequence while preparing implant site and may be considered as safe as the latter. Furthermore, it may increase the torque of insertion and consequently the initial stability of the implants. More studies, both *in vitro* possibly on human bone samples, and in vivo, will help to achieve a better understanding the importance of hole quality during the preparation of implant sites.

Conflict of Interest

The authors declare that they have no conflicts of interest.

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