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Evaluation of Primary Stability in Mono- and Bicortical Anchored Implants. A Finite Element Analysis

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ABSTRACT:

Objective: To analyze by means of a 3D finite element model the effect of anchoring dental implants in one or two cortical.

Materials and Methods: An in vitro experimental investigation was performed using Finite Elements Analysis. Six conical implants of three different designs and different lengths were designed and placed in a 3D model of the anterior maxilla with type III bone, anchoring a first group of implants only in the occlusal cortical of the bone, while in a second group the apex of the implants was anchored in the cortex of the nasal passages too, so they become monocortical or bicortical anchored. Micromovements of the implants in the bone were generated by simulating a 60-degree inclined force applied at the abutment level with 170 Ncm and 700 Ncm. Amount of micromovements were measured.

Results: Micromovements obtained when the implants were monocortical anchorage and subjected to forces of 170 Ncm, were similar for all the implants (average 27.4um). Whereas with forces of 700 Ncm, the micro-movements increased in all cases. (average 113.49 µm.) Micromovements decreased in all implants when bicortical anchorage was used, both when applying 170Ncm forces (average 8.58 µm) or applying 700Ncm forces (average 34.71µm). In relation to length, short implants showed less micromotion.

Conclusion: According to the results obtained, bicortical anchoring reduces the micromotion of conical implants especially when they are subjected to parafunctional forces and in implants of greater length, ensuring levels of micromotion more compatible with osseointegration, at least in a three-dimensional simulation through FEA.

KEYWORDS: Bicortical anchorage, Finite Element Analysis, Micromotion

INTRODUCTION

Primary stability plays a fundamental role in the success of implants [1]. It is well known that achieving good primary anchorage is necessary to obtain initial implant stability.

Some authors understand primary stability as the absence of perceptible movement of the implant immediately after its installation [2].

Trisi et al.[3] affirmed in 2010 that implant stability depends directly on the mechanical connection between the implant surface and the surrounding bone. Additionally, they explained in 2009 that initial stability, a consequence of the immediate mechanical adaptation between the implant and the bone, depends on the density of the bone tissue, the way of trepanation, and the structure of the implant [4]. In fact, this implant-bone interface can be measured for example through resonance frequency as a reaction to oscillations exerted on the implant-bone contact, where the unit of measurement is recorded as a stability coefficient (Implant Stability Quotient - ISQ) using a commercially available device [5].

The initial stability of the implant is a very important parameter to reduce the formation of fibrous tissue around the implant. The maximum acceptable micromovement described in the literature is between 50 and 150 µm; above these values, the activity of repairing cells may be affected [6,7].

Micromovement is understood as the relative displacement that occurs between the implant and the bone [8]. The term "micromovement" has never been precisely defined, but most researchers have used it to refer to the displacements of the implant at the interface with the bone (sometimes the term "relative movement" or "relative displacement" is used) [9].

These displacements can include sliding or opening of spaces between the implant and the bone. Micro-movements are biologically significant, especially if they begin and continue after implantation. The main effect of micro-movement is to destroy the network of connective tissue, which serves as the initial scaffold for bone development during the early stages of bone maturation[10]. Therefore, micro-movements no greater than 30 µm are positive for proper osseointegration [8], which, as already mentioned; when micro-movements of between 50 to 100 µm occur on the implants, they act negatively on osseointegration, generating in some cases their loss, due to fibrous encapsulation [7,10–13].

Increasing primary stability and reducing micro-movements of implants is crucial for achieving osseointegration [14].

There are four factors that influence primary stability: bone quality, bone quantity, surgical technique, and implant design. [15]

The bone architecture of the upper jaw has traditionally been associated with the presence of less dense bone with areolar spongy bone and only a higher density in the cortical zones, describing the presence of type III and IV bone in this jaw according to Lekholm & Zarb's classification [16]. This is not the case in the lower jaw, where type II or type I bone is more dense [17,18].

Sites for implant placement with low density have been reported as the greatest potential risk factor for implant loss when using standard drilling protocols[19,20] Therefore, to increase initial fixation, some of the alternatives that can be used are the undersized site preparation technique[21], cortical anchorage technique (i.e., reaching the cortical bone of the upper jaw with the implants to increase anchorage)[22–25], and selecting tapered implant designs[26].

Branemark et al.[22] (1984) conducted a clinical study in 101 patients comparing implant osseointegration by anchoring them in the upper jaw within the cortical bone of the sinuses and nasal fossae. The statistical conclusions leaned towards a 96% survival rate for implants anchored in nasal fossae after a follow-up of 5 to 10 years. Ahn et al.[23] (2012) showed that undersize drilling and bicortical anchorage significantly increase the initial stability of implants.

This concept of anchoring in cortices has generated some controversy because some authors refer to the risk of approaching the cortical of the sinus or nasal cavities that could lead to perforation of both membranes with the consequent infection of these cavities [27].

However, there are many research studies that support the implementation of this technique, as already mentioned, especially in less dense maxillae where it is important to reach the areas of greater bone density, such as the cortical of the nasal cavities, the maxillary sinus, or posterior areas of the pterygoid processes to improve stability and stress distribution [22,24,25,28].

The macro design of the implant plays a very important role in primary stability, as already mentioned. In a comparative study between cylindrical and conical implants, Nappe Abaroa et al. [26] observed significant differences in primary stability between cylindrical and conical implants, with the latter achieving greater primary stability in poor quality bone. Watzak G et al. [29] exposed that these differences in the results obtained for each macro design of the implant may be because conical implants have a greater surface area relative to their length, thus favoring greater bone/implant contact (BIC); therefore, they presented a more stable mechanical anchorage, reflected in greater primary stability than cylindrical ones. Gallardo S et al. [30] showed that conical implants have better insertion torque values and stability than cylindrical implants.

All the above is especially important when performing immediate loading procedures, in which a high degree of initial stability is necessary[15], and where the control of micromovements is one of the keys to determining predictability in immediate loading[7]; especially if performed in the upper jaw where the bone is less dense than in the lower jaw and therefore more unfavorable for immediate loading procedures [31].

Although there are various types of research related to these aspects, Finite Element Analysis is a widely used tool in different studies because it allows the design of all types of models to predict clinical outcomes accurately. It is a numerical method of stress and deformation analysis of structures of any geometry. The structure is divided into what is called "Finite Elements," which are connected by nodes. The type, arrangement, and total number of elements affect the accuracy of the results [32].

In this method, the structure is divided into elements, and an approximation to the solution is constructed on each one using polynomial formulas. It allows the simulation of complex physical systems by constructing approximate numerical solutions that describe the response of any system applied to loads [33].

Van Staden RC [32], De Tolla H et al. [33] have used this method for the study of dental implants. In the past, precise measurements could not be obtained because there were factors that were not exact, such as the characteristics of the bone, the direction and power of the force exerted, and dynamic factors. However, today, with 3D models and the advancement of technology, these errors are controlled, and the analysis of biological structures is much more accurate [34].

Yan X et al. [24] analyzed the association between the apex of implants and the proximity to the cortical bone of the maxillary sinus by measuring stress distribution and showed that anchoring implants in this area is beneficial when performing immediate loading procedures. Sotto et al.[25] evaluated anchoring implants in the cortical bone of the posterior sectors of the upper jaw through FEA and observed that stress distribution decreases considerably. Verri et al. [31] also analyzed stress distribution in the anterior area of the upper jaw by installing bicortical and monocortical implants using FEA.

In the referenced articles, three-dimensional models were designed using software that allowed for the virtual reproduction of the characteristics of different types of bone in the upper jaw. They also analyzed the relationship between the apex of the implants, the cortical bone of the maxillary sinus, and stress distribution. However, it was considered necessary to expand the study on this topic since there are no investigations related to implants of certain brands and designs. Therefore, this experimental work was designed, considering the following hypothesis and objectives cited below.

HYPOTHESIS

Tapered implants anchored in the occlusal and nasal cortical bone (bicortical anchorage) generate fewer micromovements under functional and parafunctional forces compared to implants anchored only in the occlusal cortical bone (monocortical anchorage); this is an advantage when they are immediately loaded.

OBJECTIVES

General Objective

To analyze, through a finite element 3D model, the effect of anchoring tapered implants in the occlusal and nasal cortices, measured in terms of micromovements generated under functional and parafunctional forces.

Specific Objectives

To determine the amount of micromovements of Biomet 3i Full Osseotite Tapered, Straumann BLT, and ML Shi tapered implants that are generated when a functional force of 170Ncm and a parafunctional force of 700Ncm are applied to their restoration when the implant body is anchored only in the occlusal cortical bone (monocortical anchorage).

To determine the amount of micromovements of Biomet 3i Full Osseotite Tapered, Straumann BLT, and ML Shi implants that are generated when a functional force of 170Ncm and a parafunctional force of 700Ncm are applied to their restoration when the implant body is anchored in both the occlusal and apical cortical bones (bicortical anchorage). Compare the micromovements generated in these implants anchored in monocortical or bicortical form under an inclined force of 170Ncm and 700Ncm.

To analyze the influence of implant length on the amount of micromovements generated on Biomet 3i Full Osseotite Tapered, Straumann BLT, and MLS Shi implants when an inclined force of 170Ncm and 700Ncm is applied to their restoration when the implants are anchored only in the occlusal cortical bone.

To analyze the influence of implant length on the amount of micromovements generated on Biomet 3i Full Osseotite Tapered, Straumann BLT, and MLS Shi implants when an inclined force of 170Ncm and 700Ncm is applied to their restoration when the implants are anchored in both the occlusal and apical cortical bones.

To compare the micromovements generated in Biomet 3i Full Osseotite Tapered, Straumann BLT, and ML Shi implants anchored in monocortical or bicortical form under an inclined force of 170Ncm and 700Ncm, in relation to implant length.

MATERIALS AND METHODS

An in vitro experimental investigation was performed using Finite Elements Analysis. Six conical implants of three different designs (Straumann BLT, Biomet 3i Tapered and ML Shi System) and different lengths (8, 8.5, 11.5 and 12 mm) were designed and placed in a 3D model of the anterior maxilla with type III bone, anchoring a first group of implants only in the occlusal cortical of the bone, while in a second group the apex of the implants were anchored in the cortex of the nasal passages too, so they become monocortical or bicortical anchored. Micromovements of the implants in the bone were generated by simulating a 60-degree inclined force applied at the abutment level with 170 Ncm (functional) and 700 Ncm (parafunctional). The amount of micromovements was measured in three sectors of each implant, apical, middle, and occlusal. The collected data were analyzed by descriptive statistics.

The study was conducted at the Career of Specialization in Oral Implantology at the Faculty of Medicine, Catholic University of Córdoba, Argentina.

Design of 3D model for simulation

A premaxilla 3D model with bone density type III (according to Lekholm & Zarb classification)[16] was designed using SolidWorks® V 2012 software (Dassault Systèmes, Vélizy-Villacoublay, France). To determine the required bone characteristics, the values from two published research studies were considered, referring to bone density [7] and the elastic modulus of medullary and cortical bone of the model. [18]

Finally, to determine type III bone density in terms of Hounsfield units (HU), values of 500 to 800 HU for cancellous bone and >850 HU for cortical bone measured by Cone-Beam Tomography were considered, according to the criteria of Norton & Gamble [35].

The dimensions of the premaxilla were standardized according to the size of each implant, provided that 1 mm of cortical thickness was taken based on computed tomography images of human patients, and that in the case of bicortical implants, the implant was submerged 0.5 mm inside the nasal fossa, and in the case of monocortical implants, it approached 1 mm before the cortical of nasal fossa. The cortical bone thickness was fixed at 1 mm. All implants were placed with their occlusal end flush with the most occlusal edge of the alveolar crest in the vestibular and palatal regions.

Implant selection and placement

The geometry of the three types of conical implants used was: Full Osseotite Tapered by BIOMET 3i ® (Biomet 3i, Palm Beach Gardens, Florida, USA) (4.1 x 8.5 and 4.1 x 11.5), BLT RN by Straumann® (Straumann Holding AG, Basel, Switzerland) (4.1 x 8 and 4.1 x 12), and ML® Dental System Shi (ML Dental Systems, Buenos Aires, Argentina) (3.75 x 8 and 3.75 x 11.5). Therefore, a 3D model of the implants was obtained from the macroscopic design and dimensions of each implant using the same software. A whole Implant/abutment was considered to simplify the analysis. A Gingi-Hue abutment by BIOMET 3i ® (Biomet 3i, Palm Beach Gardens, Florida, USA) with a 4.1 base was defined as standard.

All implants were placed in their respective bone models defining the anchorage as follows: Monocortical anchorage: the implants were placed until the apex was 1 mm before the cortical of nasal fossa (i.e., the apex of the implant remained in cancellous bone) and the implant was placed with its occlusal end flush with the alveolar crest cortical. Bicortical anchorage: the implants were placed until the apex was 0.5 mm inside the cortical of nasal fossa (i.e., the apex of the implant was anchored in the cortical of fossa) and the implant was placed with its occlusal end flush with the alveolar crest cortical.

Force simulation

The simulation was performed with software Solidworks Simulation/SolidWorks® V 2012 (Dassault Systèmes, Vélizy-Villacoublay, France). Non-axial forces of 170 N, which are supported on average by anterior teeth [23–27] during function (chewing), were applied, according to some authors, and 700 N on average, according to other authors, for parafunctional forces (bruxism) [28–30], always at an inclination of 60 degrees, which is the reference angle for anterior teeth according to the literature [31].

Measurement of micromovements

Micromovements generated at the apex, middle third, and base of each implant were measured in each situation[13] (Figure 1).

Micromovement was computed in microns (µm) as the relative displacement generated at a point (node) taken at the distal end of the spiral when the load is applied. This displacement is shown in Figure 1 and goes from the tip of Arrow A to the tip of Arrow B, considering that more than 90 µm is harmful for osseointegration [7,10–13].

Statistical analysis of data

Descriptive statistics were used for data analysis.

RESULTS

Monocortical anchorage

The amount of micromovements generated over Biomet 3i, Straumann BLT and ML Shi conical implants monocortical anchored applying a force of 170Ncm and a force of 700Ncm are expressed in table 1 (Table 1).

The results of the micromovements obtained when the implants were monocortical and subjected to forces of 170 Ncm were similar for all implants, with a range between 23.1 and 32µm (average value 27.4µm.) When the same implants were subjected to forces of 700 Ncm, the micromovements increased in all cases, with a range of 67.36 to 137.3µm (average value 113.49µm.) 8.5mm ML Shi implants showed lower levels of micromovements, followed by Straumann BLT and Biomet 3i implants.

Bicortical anchorage

When implant body is anchored in the occlusal cortical bone and the apex in the apical cortical bone (bicortical anchorage), the amount of micromovements generated over Biomet 3i, Straumann BLT and ML Shi implants when applying a 170 Ncm and 700 Ncm forces are shown in table 2 (Table 2).

Forces of 700 Ncm generated more micromovements compared to 170 Ncm forces. This means that despite bicortical anchorage, micromovements increased in the presence of parafunctional forces (700 Ncm). However, the range of micromovements was between 20.14 and 51.33µm, (average value 34.5 µm.)

12mm Straumann implants showed the highest micromovements for both functional and parafunctional forces, while 8.5mm ML Shi implants showed the lowest micromovement values.

- **Monocortical anchorage vs bicortical anchorage**

Comparing micromovements generated in Biomet 3i, Straumann BLT, and ML Shi implants anchored in monocortical and bicortical anchorage when an inclined force of 170Ncm was applied, they decreased in all cases (average value of 27.38µm and 8.58µm, respectively). Therefore, bicortical anchorage favored a reduction in micromovements in response to the same applied force compared to monocortical anchorage (Table 3). It was even observed that at the most apical point of force application, the micromovements were lower in all cases.

On the other hand, when comparing the micromovements generated under forces of 700 Ncm in Biomet 3i, Straumann BLT, and ML Shi implants anchored monocortical versus bicortical, they also decreased in all cases (average value of 113.49 and 34.71µm, respectively). Therefore, bicortical anchorage favored decreasing micromovements under the same applied force compared to monocortical anchorage. (Table 4).

Biomet 3i 8.5mm and ML 8.5mm implants showed the lowest values of micromovements when bicortical anchored under a force of 700Ncm.

Furthermore, bicortical anchorage showed micromovements less than 50µm under 700Ncm forces.

When comparing micromovements generated in relation to length of the implants, in implants anchored only in the occlusal cortical bone (MC) and subjected to functional forces of 170 Ncm, the behavior was similar in all three designs for both lengths (Table 5). However, the 8.5mm implants showed less micromovements than the 11.5mm and 12mm implants. When subjected to parafunctional forces of 700 Ncm, the values of micromovements increased in all cases, and differences were observed between the different lengths, with shorter implants having less micromovements than longer ones.

In longer implants, there were no differences between the designs, as they all showed an increase in micromovements between functional and parafunctional forces, while in the shorter implants, the 8.5mm ML implants showed the least increase in micromovements when a parafunctional force was applied.

The influence of implant length on the amount of micromovements generated in Biomet 3i, Straumann BLT, and ML Shi implants when a force of 170Ncm and 700Ncm was applied is shown in table 6 (Table 6)

When applying forces of 170Ncm to bicortical anchored implants, micromovements were lower in 8 and 8.5mm implants, with the 8.5mm ML Shi implant showing the lowest values. Meanwhile, higher micromovements were recorded in 11.5 and 12mm implants, with 12mm Straumann BLT implant showing the highest values. (Table 6)

When applying parafuncional forces of 700Ncm, in all cases micromovements increased, but again the values were lower for short implants than for long implants. The short Biomet 3i implants of 8.5mm recorded fewer micromovements, while the 12mm Straumann BLT implants recorded the highest amount. (Table 6)

Under 170 Ncm forces, micromovements decreased when going from monocortical to bicortical anchorage, especially in short implants. (Table 7) On the other hand, under forces of 700Ncm, results showed that bicortical anchorage favored the reduction of micromovements in all cases, but mainly in longer implants where they decreased from an average of 136.76µm to 44.49µm (Table 8).

Figures 2 to 7 illustrates examples of the results applying a 170 Ncm force over different implants both monocortical and bicortical anchored (Figure 2- 7)

DISCUSSION

A three-dimensional model of the premaxilla with type III bone (according to Lekholm & Zarb Classification)[16] was designed, and for set HU, values from 500 to 800 HU were considered for spongy bone and >850 HU for cortical bone according to Norton & Gamble's [35] criteria. Medullary and cortical elasticity modulus of the model was set according to Ulm et al (1999) [18]. Three different conical implant designs were designed and install to measure the micromovements generated when applying functional and parafunctional forces, whether monocortical or bicortical anchoring. Similar research was conducted by Yan X et al. [24] (2015) who developed a three-dimensional finite element analysis model and analyzed the association between the implant apex and the proximity to the maxillary sinus cortical by measuring stress distribution. Sotto et al. [25](2014) evaluated stress distribution in implants anchored in the cortical of the posterior sectors of the upper maxilla by means of AEF. Verri et al. [31](2015) analyzed stress distribution in the anterior zone of the upper maxilla by means of FEA, installing implants in a bicortical and monocortical way.

In the present study, when monocortical anchorage was used, the micromovements under forces of 170 Ncm were similar for all implants, with an average value of 27.4 µm, that is, practically not greater than 30 µm, a value described by Klein D et al. [8] as positive for osseointegration. However, these micromovements increased under parafunctional forces, with values above 100 µm, except in the case of ML implants that showed micromovements of 67.36 µm. This implies that, under parafunctional simulated forces, micromovements above100 µm were produced, which, as some authors have described, act negatively on osseointegration [7,10–13].

ML Shi implants of 8.5mm showed lower levels of micromovements, followed by Straumann BLT and Biomet 3i Tapered. These differences in micromovements could be related to the design of each implant since, although all are conical, the ML SHI implants have a more aggressive thread design with greater thickness at the edge. Similar results were shown by M. Herrero-Climent et al. [36] (2020) when they compared several implant designs, and those that had this thread design showed higher stability coefficient values (ISQ). Also, in a comparative research, Heng-Li Huang et al. [37] (2007) concluded that the square design of the threads generates less stress in the surrounding bone than the triangular one.

On the other hand, in implants with bicortical anchorage, when parafunctional forces of 700 Ncm were applied, the amount of micromovements increased compared to micromovements with functional forces of 170 Ncm but did not practically exceed 50 µm. This means that bicortical anchorage favored reducing micromovements to more acceptable values that would favor osseointegration.

Straumann BLT implants of 12mm showed the highest micromovements for functional and parafunctional forces, while Biomet 3i Tapered and ML Shi, both of 8.5mm, showed the lowest values of micromovements. As already mentioned, the macro-geometry of the implants influences stress distribution in the bone as shown by Hyo-Sook Ryu [38]especially at the cervical portion of the bone, where stepped-design implants generate less stress on the surrounding bone; this would explain the differences in the micromovements generated in the studied tapered implants.

Micromovements generated with bicortical anchorage of 170Ncm, decreased in all cases in relation to monocortical anchorage. Therefore, bicortical anchorage favored the reduction of micromovements under the same applied force. Additionally, it was observed that the micromovements were lower at the most apical point of force application in all cases.

The micromovements generated using forces of 700 Ncm on bicortical anchored implants also decreased in all cases. It is important to highlight that obtaining bicortical anchorage allows for a decrease in micromovements to values that act positively on osseointegration. On the other hand, if only monocortical anchorage is obtained, the results of this study showed micromovements ranging from 67.36 to 137.3 µm, with an average value of 113.49 µm, values that could be detrimental to osseointegration [7,10–13]. Similar results were suggested by Yan X et al.[24] (2015), who showed in a finite element study that bicortical anchorage of Nobel Biocare implants in the maxillary sinus cortical bone subjected to inclined forces of 129Ncm, increased initial stability, especially in immediate loading procedures. They also showed that the thickness of the crestal and sinus cortical bone influences micromovements and stress distribution; however, the crestal cortical bone would be more important than the sinus floor cortical bone. Sotto et al[25] (2014) evaluated the stress distribution in Cone Morse Titamax EX; Neodent, Curitiba, Brazil (4.0 × 11-mm) implants anchored in the cortical of the posterior sectors of the maxilla by means of FEA. They showed that the model where the implants were placed subcrestally with anchorage in the apical cortical bone exhibited less micromovement compared to the crestal monocortical anchorage model (anchored in the crestal cortical bone) when eccentric loads of 200Ncm were applied. They concluded that subcrestal implant placement decreases tension in the crestal cortical bone around dental implants, regardless of apical anchorage; however, apical cortical anchorage can be effective in limiting implant displacement. Therefore, just as in the present study, bicortical anchorage is effective in reducing micromovements, especially in response to eccentric forces. Verri FR et al.[31] concluded that the bicortical technique showed less tendency to movement in 4x11mm implants and their components, when subjected to forces of 178Ncm. The cortical bone in the apical region showed an increase in stress concentration for bicortical techniques.

When comparing the micromovements generated in relation to implant length anchored only in the occlusal cortical bone and subjected to functional forces of 170 Ncm, the behavior was similar in the three designs for both lengths, showing values close to 30µm. However, the 8.5mm implants showed less micromovement than the 11.5mm and 12mm implants. When subjected to parafunctional forces of 700Ncm, there was a correlation between the increase in applied loads and micromovements, with values above 90µm, indicating that the combination of monocortical anchorage with overload could have an unfavorable effect on osseointegration, regardless of implant length. It should be noted that the 8.5mm ML implants showed the lowest micromovements.

On the other hand, when bicortical anchoring was used for both functional and parafunctional forces, the micromovements were lower in the 8mm and 8.5mm implants, with the 8.5mm ML Shi implant showing the lowest values for functional forces, and the 8.5mm Biomet 3i implant exhibiting the lowest values for parafunctional forces. Meanwhile, higher micromovements were registered in the 11.5mm and 12mm implants, with the 12mm Straumann BLT implant showing the highest values. However, it is important to highlight that all micromovements remained below 50µm.

Furthermore, under a force of 170 Ncm, micromovements decreased when transitioning from monocortical to bicortical anchoring, and in short implants, they were even lower than in longer implants, with both cases having values below 30µm.

On the other hand, when subjected to parafunctional forces of 700 Ncm, the results showed that bicortical anchoring favored the reduction of micromovements in all cases, but especially in longer implants, where the average micromovements decreased from 136.76µm to 44.49µm. This clearly indicates that longer implants experience higher micromovements. This latter observation could be attributed to the fact that longer implants experience more bending and higher stress, as demonstrated in the studies by Memayi et al. [39] and Pierrisnard et al. [40]. Similar results were also found by Toniollo et al. [41] and Jomjunyong et al. [42] when investigating the effect of splinting on short and longer implants.

Nevertheless, bicortical anchoring reduced micromovements in all cases.

CONCLUSION

According to the results obtained, bicortical anchoring reduces the micromotion of conical implants especially when they are subjected to parafunctional forces and in implants of greater length, ensuring levels of micromotion more compatible with osseointegration, at least in a three-dimensional simulation through FEA.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest with the manufacturers and brands of the materials used in the study.

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Table 1. Micromovements under functional and parafunctional forces in monocortical anchored implants.

	Functional force 170 cm				Parafuntional force 700 Ncm			
Monocortical Implant Anchorage	**MC 1**	**MC 2**	**MC3**	**Average Value**	**MC 1**	**MC 2**	**MC3**	**Average Value**
Straumann BLT 8mm	14.8	23.9	32.9	23.86	62.8	101	138	100.61
Straumann BLT 12mm	16	30	47	31	76	133	192	134.6
Biomet 3i tapered 8.5 mm	11	23.7	35.3	23.3	63.1	106	145	104.7
Biomet 3i tapered 11.5 mm	18.3	31.9	49.2	31.03	74.4	132	203	136.4
ML Shi 8.5 mm	15.6	21.9	31.8	23.1	46.9	65.2	90	67.36
ML Shi 11.5 mm	19.6	31.6	44.8	32	86.9	126	199	137.3

Table 2. Micromovements under functional and parafunctional forces in bicortical anchored implants

	Functional force 170Ncm				Parafuntional force 700Ncm			
Bicortical Implant Anchorage	**BC1**	**BC2**	**BC3**	**Average Value**	**BC1**	**BC2**	**BC3**	**Average Value**
Straumann BLT 8mm	1.09	7.5	14.2	7.86	4.59	32.2	59.6	32.13
Straumann BLT 12mm	1.5	11	25	12.5	5	46	103	51.33
Biomet 3i tapered 8.5 mm	0.12	3.52	11.1	4.91	2.32	14.1	44	20.14
Biomet 3i tapered 11.5 mm	1.13	9.7	22.5	11.11	3.67	33.6	77.5	38.25
ML Shi 8.5 mm	0.26	3.68	9.03	4.32	3.26	19.2	45.2	22.55
ML Shi 11.5 mm	1.9	10.2	20.5	10.86	6.4	41.9	83.4	43.9

Table 3. Comparison of micromovements in monocortical vs bicortical anchored implants under functional forces (170Ncm)

Functional force 170 Ncm								
	MONOCORTICAL Anchorage				BICORTICAL anchorage			
Implant	**MC 1**	**MC 2**	**MC3**	**Average Value**	**BC1**	**BC2**	**BC3**	**Average value**
Straumann BLT 8mm	14.8	23.9	32.9	23.86	1.09	7.5	14.2	7.86
Straumann BLT 12mm	16	30	47	31	1.5	11	25	12.5
Biomet 3i tapered 8.5 mm	11	23.7	35.3	23.3	0.12	3.52	11.1	4.91

Biomet 3i tapered 11.5 mm	18.3	31.9	49.2	31.03	1.13	9.7	22.5	11.11
ML Shi 8.5 mm	15.6	22.1	31.8	23.1	0.26	3.68	9.03	4.32
ML Shi 11.5 mm	19.6	31.6	44.8	32	1.9	10.2	20.5	10.86

Table 4. Comparison of micromovements in monocortical vs bicortical anchored implants under parafunctional forces (700 Ncm)

	Para-functional force 700 Ncm							
	MONOCORTICAL Anchorage				**BICORTICAL Anchorage**			
Implant	**MC 1**	**MC 2**	**MC3**	**Average Value**	**BC1**	**BC2**	**BC3**	**Average Value**
Straumann BLT 8mm	62.8	101	138	100.61	4.59	32.2	59.8	32.13
Straumann BLT 12mm	33	62	90	134.6	5	46	103	51.33
Biomet 3i tapered 8.5 mm	63.1	106	145	104.7	2.32	14.1	44	20.14
Biomet 3i tapered 11.5 mm	74.4	132	203	136.4	3.67	33.6	77.5	38.25
ML Shi 8.5 mm	46.9	65.2	90	67.36	3.26	19.2	45.2	22.55
ML Shi 11.5 mm	86.9	126	199	137.3	6.4	41.9	83.4	43.9

Table 5. Influence of the length of monocortical anchored implants on micromovements generated after applying forces of 170 and 700 Ncm

	Functional Force 170 cm					**Parafunctional force 700 Ncm**				
MONOCORTICAL Implant Anchorage	**MC 1**	**MC2**	**MC3**	**Average Value**	**Average Value over length**	**MC 1**	**MC2**	**MC3**	**Average Value**	**Average Value over length**
Straumann BLT 8mm	14.8	23.9	32.9	23.86	23.42	62.8	101	138	100.61	90,89
Biomet 3i tapered 8.5 mm	11	23.7	35.3	23.3		63.1	106	145	104.7	
ML Shi 8.5 mm	15.6	21.9	31.8	23.1		46.9	65.2	90	67.36	
Straumann BLT 12mm	16	30	47	31	31.34	76	133	192	136.6	136,76
Biomet 3i tapered 11.5 mm	18.3	31.9	49.2	31.03		74.4	132	203	136.4	
ML Shi 11.5 mm	19.6	31.6	44.8	32		86.9	126	199	137.3	

Table 6. Influence of the length of bicortical anchored implants on micromovements generated after applying forces of 170 and 700 Ncm.

	Functional Force 170 cm					**Para- functional force 700 Ncm**				
BICORTICAL Implant Anchorage	**BC1**	**BC2**	**BC3**	**Average Value**	**Average Value over length**	**BC1**	**BC2**	**BC3**	**Average Value**	**Average Value over length**
Straumann BLT 8mm	1.09	7.5	14.2	7.86	5,69	4.59	32.2	59.8	32.13	24,94
Biomet 3i tapered 8.5 mm	0.12	3.52	11.1	4.91		2.32	14.1	44	20.14	
ML Shi 8.5 mm	0.26	3.68	9.03	4.32		3.26	19.2	45.2	22.55	
Straumann BLT 12mm	1.5	11	25	12.5	11,49	5	46	103	51.33	44,49
Biomet 3i tapered 11.5 mm	1.13	9.7	22.5	11.11		3.67	33.6	77.5	38.25	
ML Shi 11.5 mm	1.9	10.2	20.5	10.86		6.4	41.9	83.4	43.9	

Table 7. Influence of the length of monocortical vs bicortical anchored implants on micromovements generated after applying forces of 170Ncm.

	Functional Force 170 cm									
	MONOCORTICAL Anchorage					**BICORTICAL Anchorage**				
Implant	**MC 1**	**MC 2**	**MC3**	**Average Value**	**Average Value over length**	**BC1**	**BC2**	**BC3**	**Average Value**	**Average Value over length**
Straumann BLT 8mm	14.8	23.9	32.9	23.86	23.42	1.09	7.5	14.2	7.86	5,69
Biomet 3i tapered8.5 mm	11	23.7	35.3	23.3		0.12	3.52	11.1	4.91	
ML Shi 8.5 mm	15.6	21.9	31.8	23.1		0.26	3.68	9.03	4.32	
Straumann BLT 12mm	16	30	47	31	31.34	1.5	11	25	12.5	11,49
Biomet 3i tapered 11.5 mm	18.3	31.9	49.2	31.03		1.13	9.7	22.5	11.11	
ML Shi 11.5 mm	19.6	31.6	44.8	32		1.9	10.2	20.5	10.86	

Table 8. Influence of the length of monocortical vs bicortical anchored implants on micromovements generated after applying forces of 700Ncm.

	Parafunctional force 700 Ncm									
	MONOCORTICAL anchorage					**BICORTICAL anchorage**				
Implant	**MC 1**	**MC 2**	**MC3**	**Average Value**	**Average Value over length**	**BC1**	**BC2**	**BC3**	**Average Value**	**Average Value over length**
Straumann BLT 8mm	62.8	101	138	100.61	90,89	4.59	32.2	59.8	32.13	24,94
Biomet 3i tapered 8.5 mm	63.1	106	145	104.7		2.32	14.1	44	20.14	
ML Shi 8.5 mm	46.9	65.2	90	67.36		3.26	19.2	45.2	22.55	
Straumann BLT 12mm	76	133	192	136.6	136,76	5	46	103	51.33	44,49
Biomet 3i tapered 11.5 mm	74.4	132	203	136.4		3.67	33.6	77.5	38.25	
ML Shi 11.5 mm	86.9	126	199	137.3		6.4	41.9	83.4	43.9	

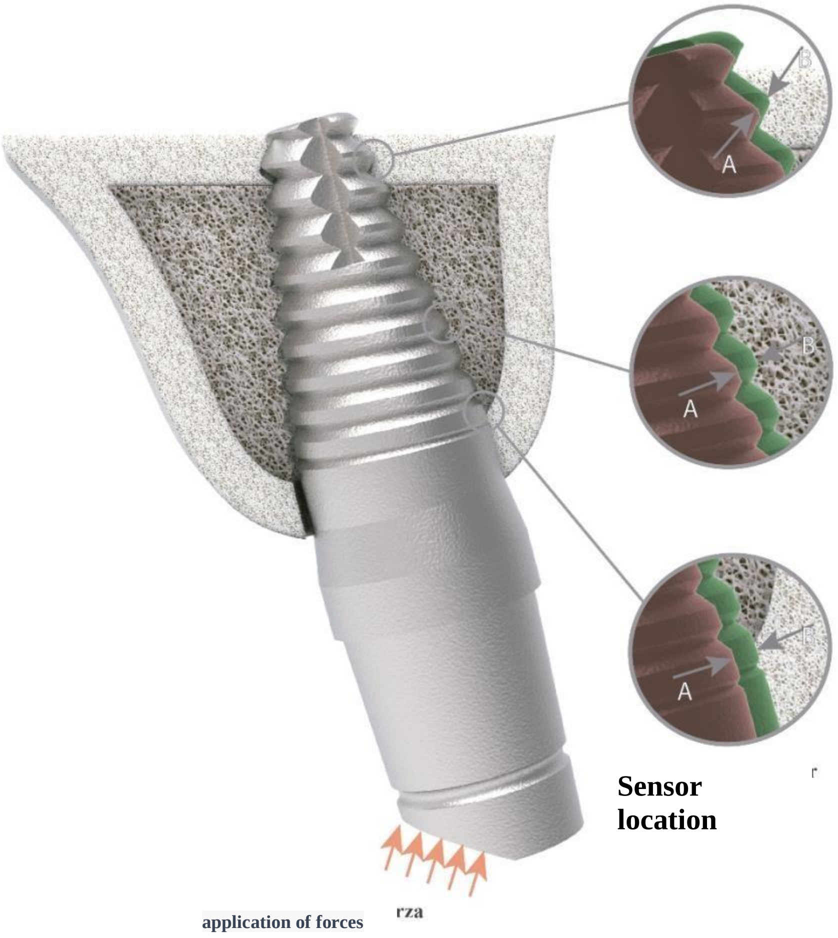

Figure 1. Measurement points for the micromovements generated, at the apex, middle zone, and occlusal of each implant in each condition.

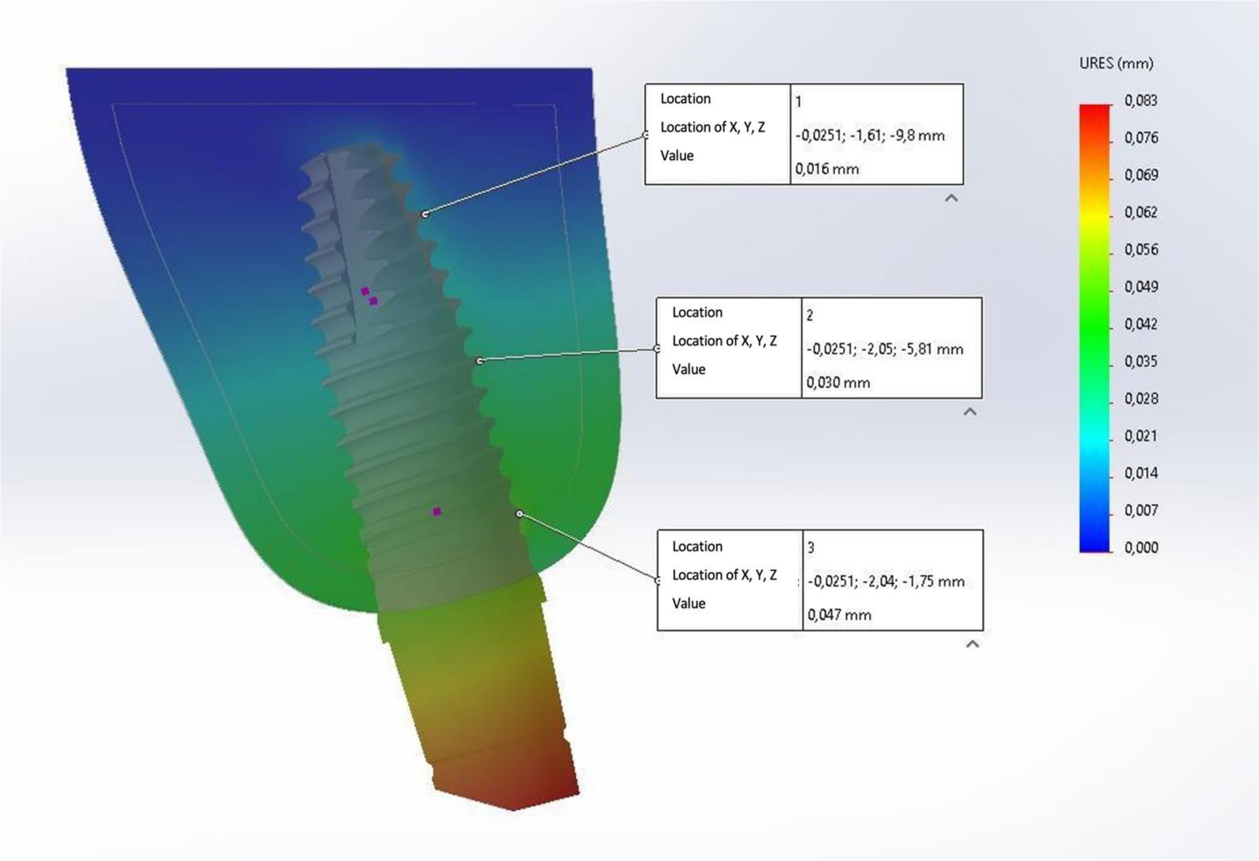

Figure 2: Example of functional force applied over an Straumann BLT implant 4.1 x 12 placed monocortically.

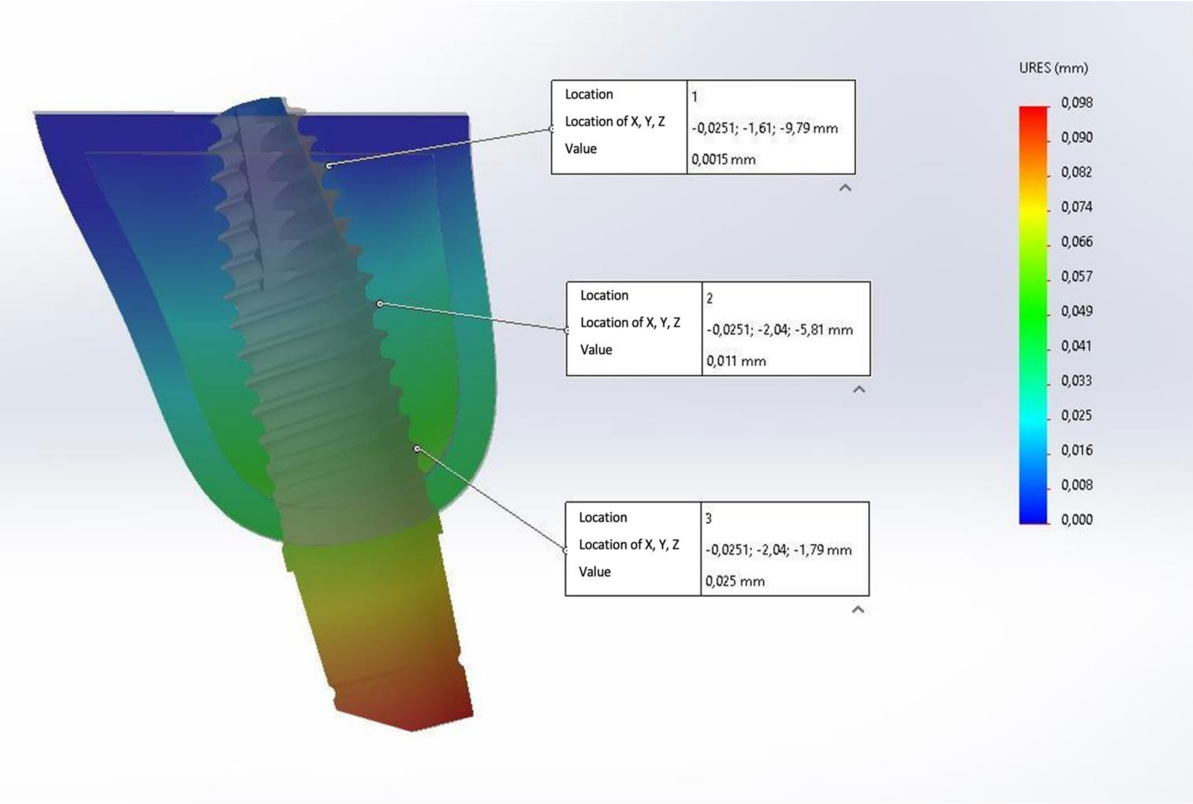

Figure 3: Example of functional force applied over an Straumann BLT implant 4.1 x 12 placed bicortically.

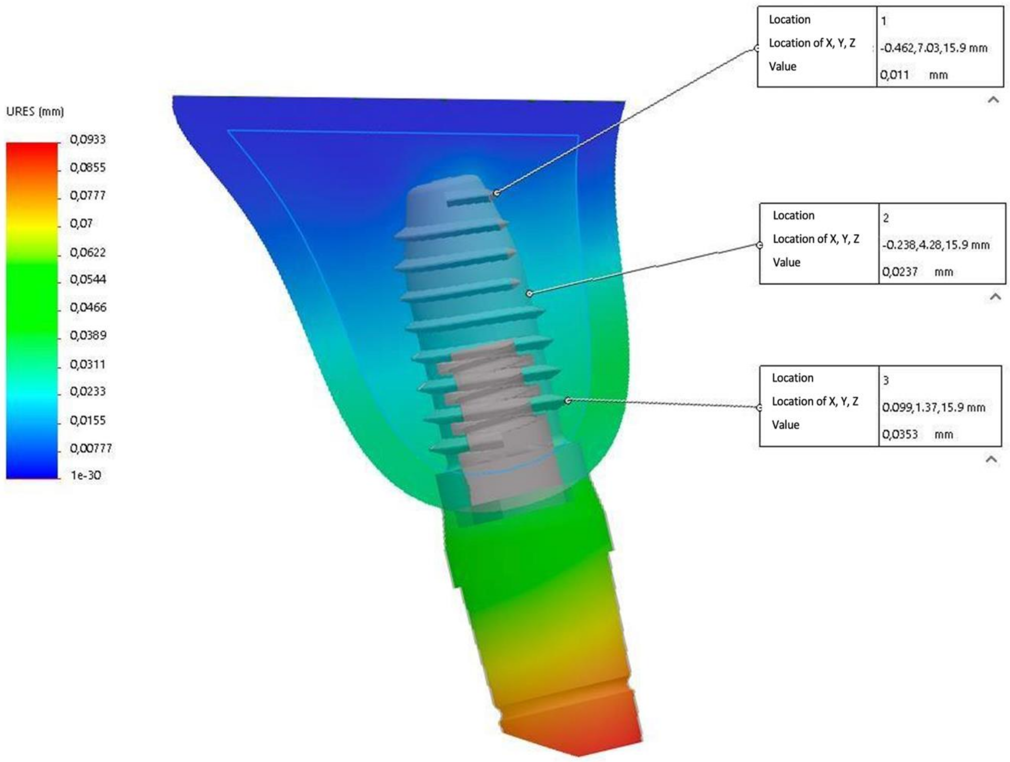

Figure 4: Example of functional force applied over a BIOMET 3i Full Osseotite Tapered implant 4.1 x 8.5 placed monocortically.

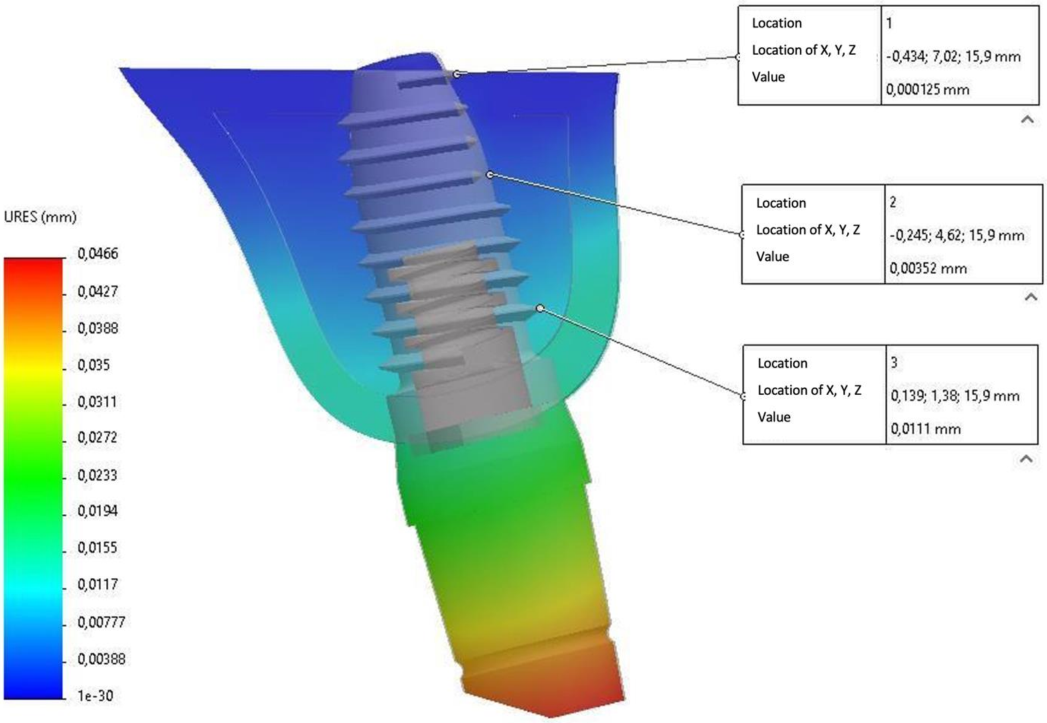

Figure 5: Example of functional force applied over a BIOMET 3i Full Osseotite Tapered implant 4.1 x 8.5 placed bicortically.

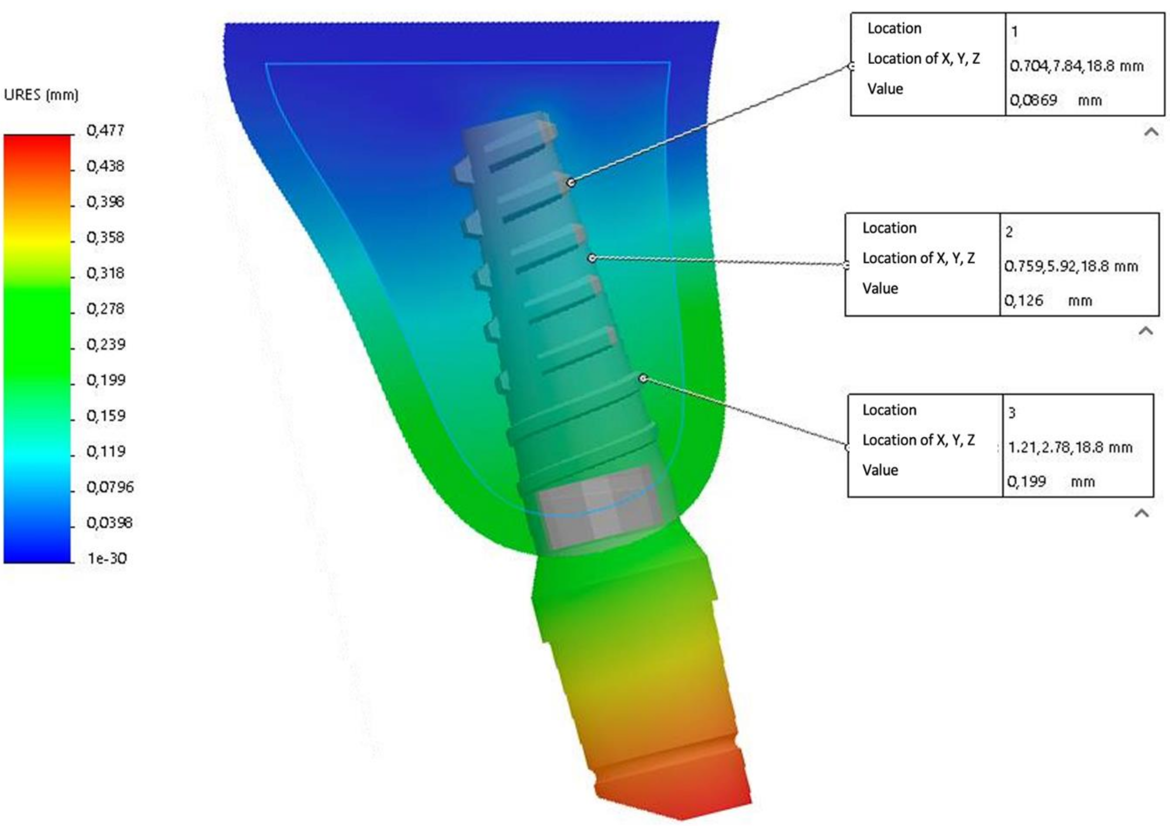

Figure 6: Example of parafunctional force applied over an ML SHi Implant 3.75 x 11.5 placed monocortically

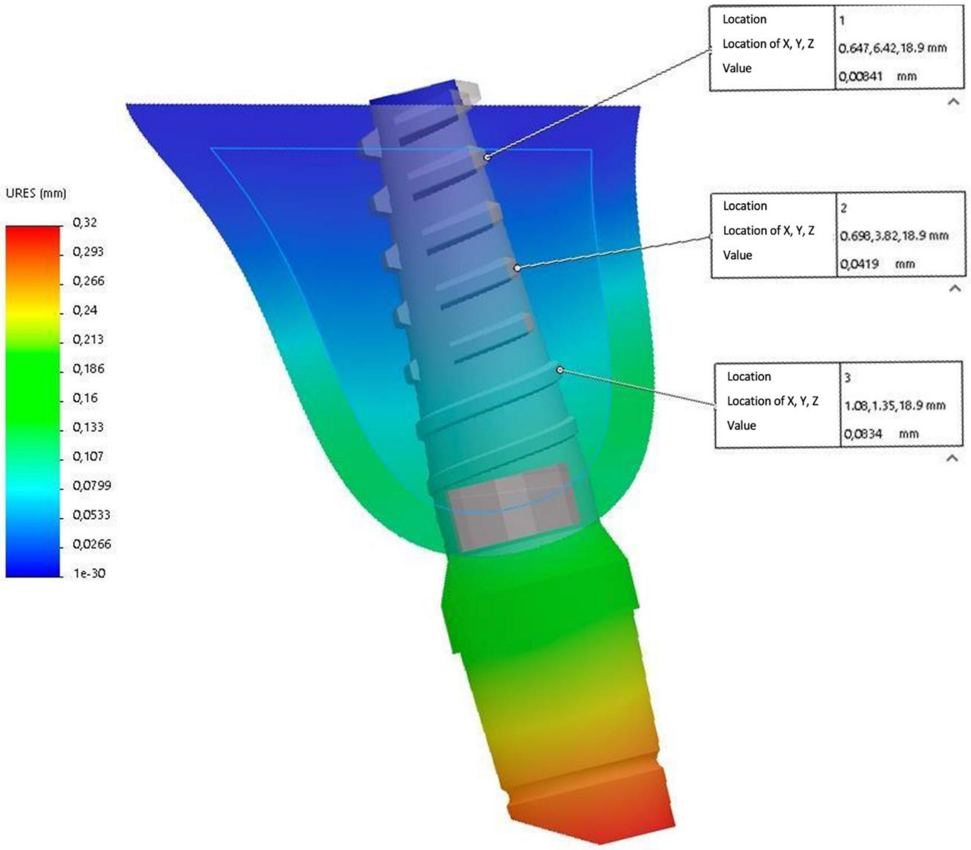

Figure 7: Example of parafunctional force applied over an ML SHi Implant 3.75 x 11.5 placed bicortically