

Research Article

Assessment of the Correlation between the Implant Distance and Primary Stability by Resonance Frequency Analysis

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Received 9 April 2015; Accepted 3 June 2015

Academic Editor: Heng-Li Huang

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Objective. The aim of this study was to assess the influence of the interimplant distance on the implant primary stability (ISQ) by Resonance Frequency Analysis (RFA). **Method.** Forty-five implants were placed in the mandible of human cadavers and 108 in artificial bone substrates in the form of polyurethane foam blocks. Primary implant stability was successively measured first by RFA immediately after the placement of the first implant (A) and then after two other implants (B and C) proximal and distal to the first implant. The interimplant distances were defined from 1 to 6 mm and the three primary stability values measured were compared. **Results.** On the mandibles, no correlation was observed between the interimplant distances and primary stability. On the polyurethane foam block, the primary stability of implant A increased significantly ($p < 0.001$) after the placement of implant B but remained constant after placement of implant C. **Conclusion.** Reducing the interimplant distance does not affect the primary stability on dry bone or artificial substrate.

1. Introduction

Primary stability is defined as the degree of mechanical anchoring established when placing an implant [1]. It reflects the resilience of the implant to axial, lateral, and rotational forces and is a fundamental parameter that contributes to the success of the osseointegration of implant [2].

As a whole, implant primary stability is affected by three interrelated factors:

- (i) The amount of bone and quality of bone implant contact are important, as described by Gomes de Oliveira et al. [3]; primary stability is greater in a higher density bone than in a low density one. Also, bone cortex thickness highly affects primary stability [4–6].
- (ii) Implant morphology (diameter, shape, and macrogeometry) plays an effective role on the primary stability as shown by Coelho et al. [7] and Krafft et al. [8].

- (iii) Surgical procedure to prepare the implant bed (thread tapping, subpreparation, or use of an osteotome) is also correlated with the implant primary stability [7, 8]. So, to optimize the implant primary stability, the characteristics of each of these factors must be well used.

The implant primary stability depends on the quality and quantity of peri-implant bone; then reducing the interimplant distance involves a decrease in the amount of interimplant bones. According to Tarnow et al. [9] and Kupershmidt et al. [10], the minimum interimplant distance is set at 3 mm. Below 3 mm, a bone lysis of the interimplant spectrum occurs. The reduction of this distance to 2 mm has been previously described in the literature by Elian et al. [11], Hermann et al. [12], and Atieh et al. [13], but it consists of reducing the diameter of the abutment compared to the diameter of the implant collar. According to Maeda et al. [14], the gap between the implant collar and the abutment should

allow movement at the bone implant-abutment junction and protection of the biological space [15].

To date, no study has focused on the biomechanical influence of the interimplant distance on the primary stability. The objective of this study was to assess the correlation between the interimplant distance and the implant primary stability by RFA using the ISQ values. It was of interest to provide a biomechanical approach contributing to define the minimum interimplant distance. The assumption was that the reduction of the interimplant distance would decrease their primary stability.

2. Material and Methods

We used natural human bone and an artificial material whose characteristics are similar to human bone.

2.1. Natural Bone. Fifteen fully toothless hemimandibles were taken from embalmed cadavers (fixed in 10% formalin), with a mean age of 75 years (± 10 years), regardless of gender, at the Laboratory of Anatomy of Bordeaux University. Mandibles with fracture sequelae, any deformities, implants, or bone reconstructions (plaque, screws), were excluded and all soft tissues were removed.

2.2. Artificial Bone. A laminated polyurethane foam block of $120 \times 170 \times 42$ mm, meeting the ASTM F-1839-08 norms was used (model 1522-399, Sawbones, Pacific Research Laboratories, US). The block body and surface had two different densities, simulating the mandibular posterior bone and its cortex [16, 17]:

- (i) The block body was composed of 20 pcf polyurethane foam corresponding to a density of 850 Hounsfield units (HU), simulating the posterior mandibular trabecular bone.
- (ii) The block surface was laminated with a 2 mm thick inflexible 30 pcf polyurethane sheet, corresponding to a density of 1250 HU, simulating the posterior mandibular cortical bone.

2.3. Implants. Artificial Mk III Groovy implants (Brånemark System, Nobel Biocare, Sweden) of 3.75 mm in diameter and 13 mm in length were used. These implants are recommended by the producer for their anchoring qualities in bone, due to their cylindroconical shape with parallel sides, a standard straight collar, and an external hexagonal connection.

2.4. Determination of the Implant Sites

2.4.1. In Natural Bone. Radiopaque markers with Gutta-percha cones were fixed on each hemimandibular angle. The CT-scan was performed (Lightspeed PRO 32, GE, Germany). All hemimandibles were maintained in the real acquisition position using a stabilizing base. Using radiopaque markers, 45 implant sites were defined on the CT-scan acquisition with the Simplant Pro software (Materialise, version 14, Leuven, Belgium). Three implant sites were defined on each

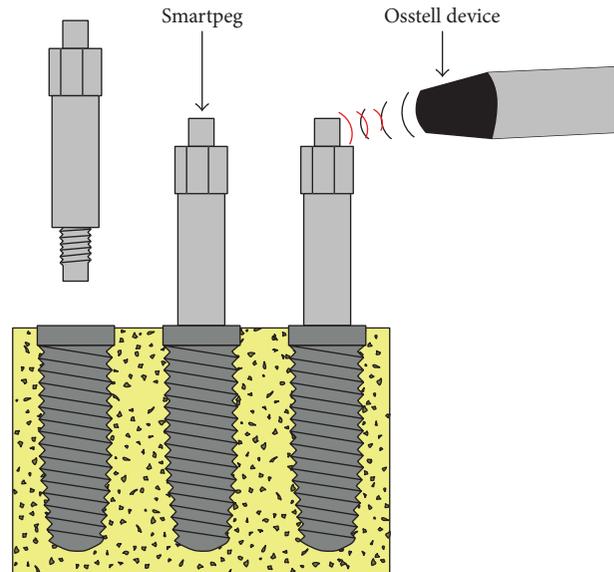


FIGURE 1: Osstell ISQ measurement procedure.

hemimandible: A, B (proximal sites), and C (distal site). Sites A and B were equidistant (distance Y) from site C:

- (i) on 3 hemimandibles, the intersite distance Y was 1 mm;
- (ii) on 4 hemimandibles, the intersite distance Y was 2 mm;
- (iii) on 4 hemimandibles, the intersite distance Y was 3 mm;
- (iv) on 2 hemimandibles, the intersite distance Y was 4 mm;
- (v) on 2 hemimandibles, the intersite distance Y was 5 mm.

The bone density (expressed in HU) and cortical thickness of the implant sites were measured with the Simplant Pro software.

2.4.2. In Artificial Bone. Six territories were determined on the polyurethane foam block. Each territory included six areas where three implant sites were defined: A, B (proximal sites), and C (distal site). Sites A and B were equidistant (distance Y) from site C. An intersite distance Y of 1, 2, 3, 4, 5, or 6 mm corresponded to each territory and 108 implant sites were defined.

2.5. Implant Placement. Forty-five implants were placed on the mandibles and 108 on the polyurethane block. All implants were placed by the same practitioner. The drilling for each bone type was performed using a single procedure. An Implanteo motor (Anthogyr, France) was used at a rotational speed of 1500 rev/min, with a drilling sequence of successive diameters of $\varnothing 2.0$, $\varnothing 2.4/\varnothing 2.8$, and $\varnothing 3.2$ at the length of each implant. The tactile sensation of bone density was recorded by the practitioner during the pilot drilling.

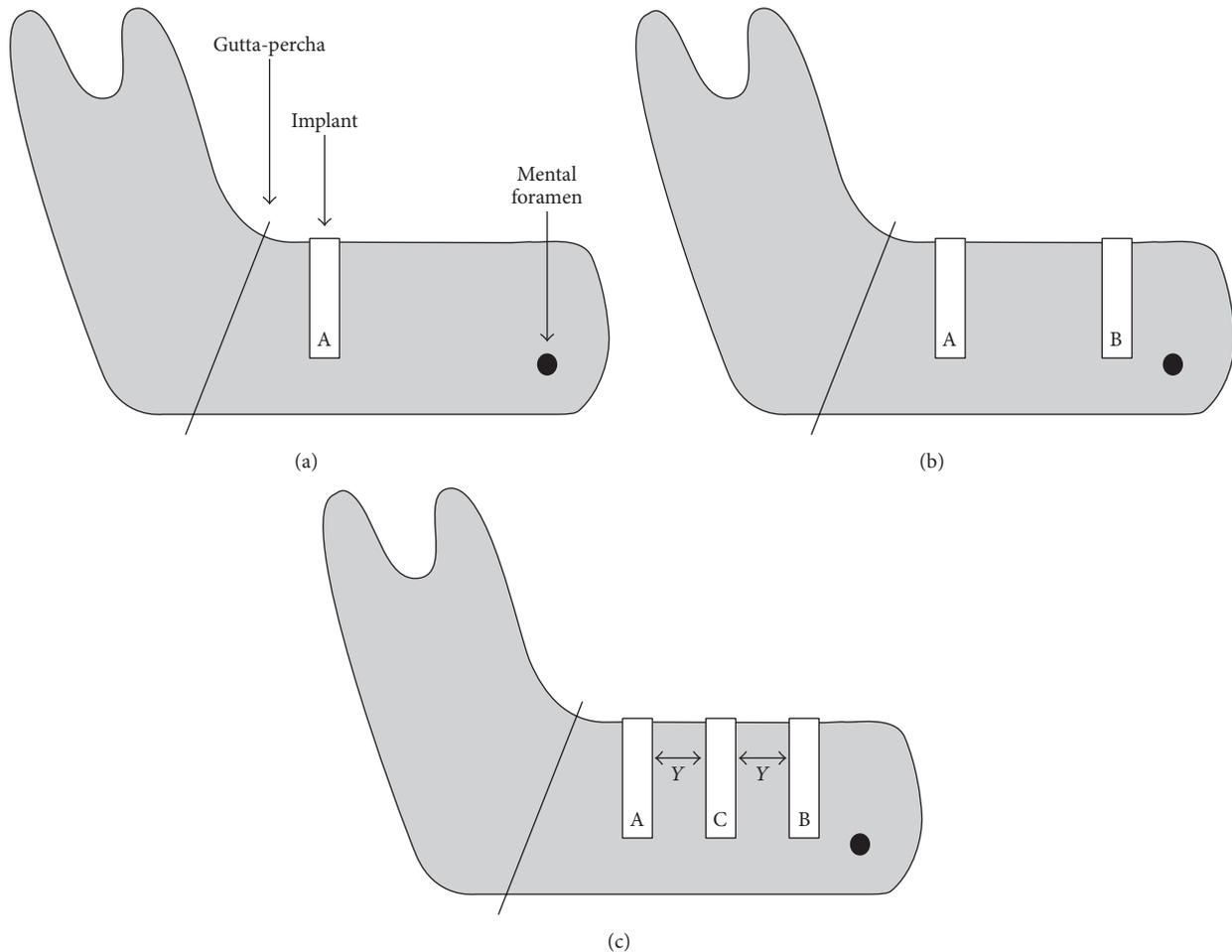


FIGURE 2: (a) Placement of implant A. (b) Placement of implant B. (c) Placement of implant C.

Implants A, B, and C were placed parallel to each other and perpendicular to the support, at a maximum torque of 40 Ncm.

2.6. Measurement of Primary Stability. The Osstell ISQ (Implant Stability Quotient) device accurately and objectively measures the primary stability of an implant placed in both natural and artificial bones [18, 19]. The Osstell device is a digital probe emitting electromagnetic pulses to measure the implant stability by RFA of a SmartPeg screwed on the implant.

Immediately after the implant placement, a SmartPeg Osstell type 1 was manually screwed (Figure 1). The measurements of the associated buccolingual and mesiodistal primary stabilities (ISQBL and ISQMD) were recorded. The mean of these two measurements corresponded to the overall implant primary stability. To verify the reproducibility, all measurements were performed twice.

2.7. Placement and Measurement Chronology. The following placement and measurement chronology was applied in natural and artificial bones.

2.7.1. Implants A and B. Firstly, implant A was placed and the measurements of its ISQ on buccolingual side (ISQA1VL) and mesiodistal side (ISQA1MD) were performed. Secondly, implant B was placed according to the protocol described above, and its ISQ measurements on buccolingual (ISQB1VL) and mesiodistal (ISQB1MD) sides were also performed (Figures 2(a) and 2(b)).

To ensure that implant B placement did not modify implant A primary stability, implant A ISQ on buccolingual and mesiodistal sides were measured again.

2.7.2. Implant C. Implant C was placed equidistantly (distance Y) from implants A and B (Figure 2(c)). After implant C placement, a second primary stability of implants A (ISQA2VL, ISQA2MD) and B (ISQB2VL, ISQB2MD) was measured. Then the primary stability of implant C (ISQCVL and ISQCMD) was also measured on both sides.

2.8. Statistical Analysis. The statistical analysis was performed using the statistical software Matlab version R2012b, Natick, USA. An alpha-error probability of $p < 0.05$ was adopted as the statistically significant level to determine the correlation between the primary stability and the multiple

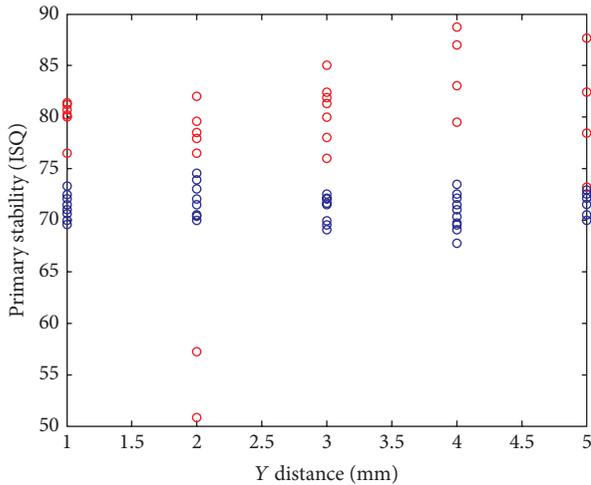


FIGURE 3: Data visualization: postoperative primary stabilities of implants A and B (blue: implant primary stability in polyurethane foam; red: implant primary stability in human mandible).

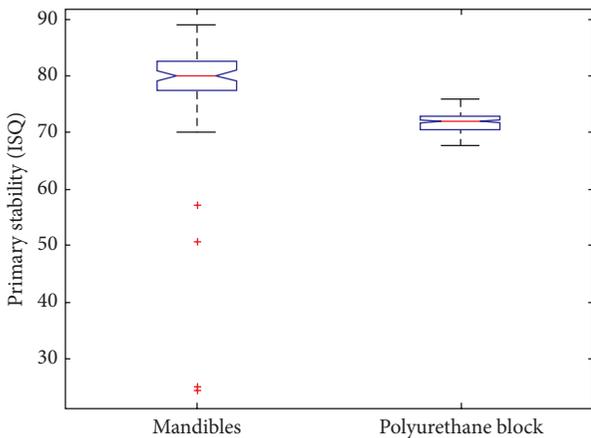


FIGURE 4: Postoperative primary stabilities depending on the support type.

variables identified. Nonparametric tests (Kruskal-Wallis) were used to compare medians of the groups.

3. Results

We compared the primary stability on each type of bone substrate (natural and artificial) such as the comparison of implant A stability before and after the placement of implant B and the comparison of the stability of implants A and B before and after the placement of implant C (Figure 3).

3.1. Primary Implant Stability Depending on the Bed Type (Human Mandible and Polyurethane Foam). Differences in variability, normality, and mean (Figure 4) allowed separate testing of the effects on the mandibles and on the polyurethane foam block.

3.2. Comparison of the Primary Implant Stabilities on Human Mandibles. No effect was observed on the primary stability of implant A after the placement of implant B (Figure 5(a)).

After the placement of implant C, no effect was observed on the primary stability of implants A and B (Figure 5(b)).

3.3. Comparison of the Primary Implant Stabilities on the Polyurethane Foam Block. In the polyurethane foam, the value of primary stability (ISQ) of implant A was significantly higher ($p < 0.001$) after the placement of implant B (Figure 6(a)).

However no effect was observed on the primary stability of implants A and B after the placement of implant C (Figure 6(b)).

4. Discussion

The results of this study demonstrated that reducing the interimplant distance does not affect their primary stability (Figures 5(b) and 6(b)).

Based on a biological approach, Tarnow et al. [9], Kuper-shmidt et al. [10], and Elian et al. [11] have shown that the minimum interimplant distance currently recommended is of 3 mm. Reducing the minimum interimplant distance implies a decrease in the bone amount between the implants. Therefore, the biomechanical constraints of the interimplant distance on their primary stability was of interest to investigate.

In our study, no correlation was observed between the interimplant distances assessed and the implant primary stability (Table 1). Indeed, bringing the implants closer involved a decrease in the amount of interimplant bone, but it did not affect the amount of bone directly in contact with the implant. Hsu [20, 21] showed that the surface contact at the bone implant interface is a major factor for its primary stability. The quantity of bone at the bone implant interface is closely related to the juxtaimplant bone density. On the other hand Ohashi et al. [22] described the biomechanical role played by peri-implant bone. Matsunaga et al. [23] performed analysis using an FE model that closely reproduced trabecular structure in three dimensions and reported that the peri-implant trabecular structure is closely connected with its biomechanical role. Bernhardt et al. [24] demonstrated that the analysis of the bone implant volume (BIV) gives information about the thickness of newly formed peri-implant bone, which is of interest in correlation to the determined bone implant contact (BIC). Differences in bone volume are of interest when comparing different implant surfaces and their possible influence on bone formation [25]. The proximity of the implants could cause a peri-implant bone condensation and thus promote the primary stability. Wirth et al. [26] proposed that the influence of the implant primary stability should be attributed to the juxtaimplant bone quality.

Other factors influence the primary stability. Indeed, on the human mandibles, a significant correlation was observed between the bone density and implant primary stability (Table 1). Seong et al. [27] have shown that the bone density and the thickness of the cortical bone can vary rapidly from

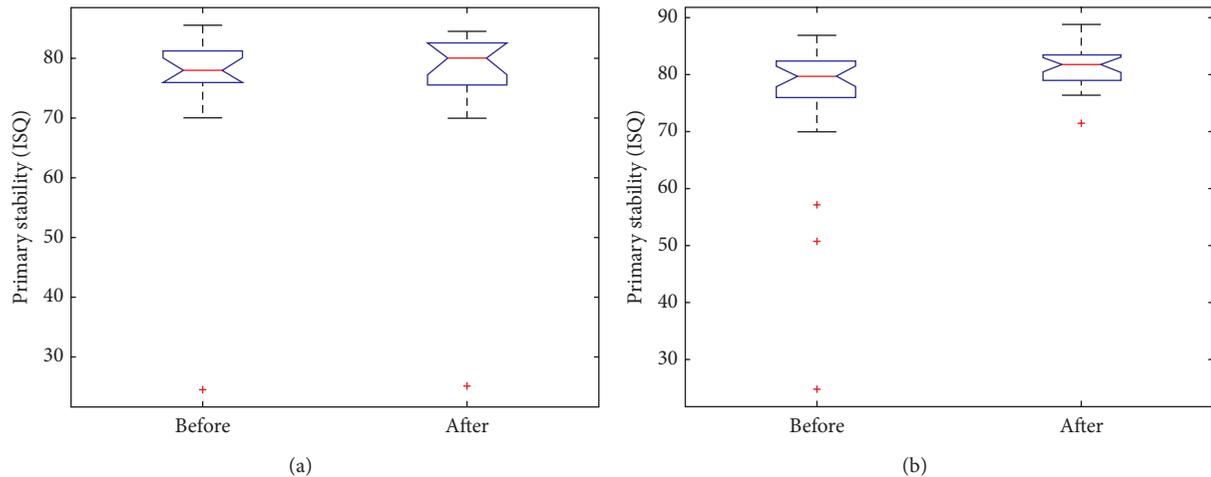


FIGURE 5: (a) Comparison of implant A primary stability between before and after the placement of implant B. (b) Comparison of implants A and B primary stability between before and after the placement of implant C.

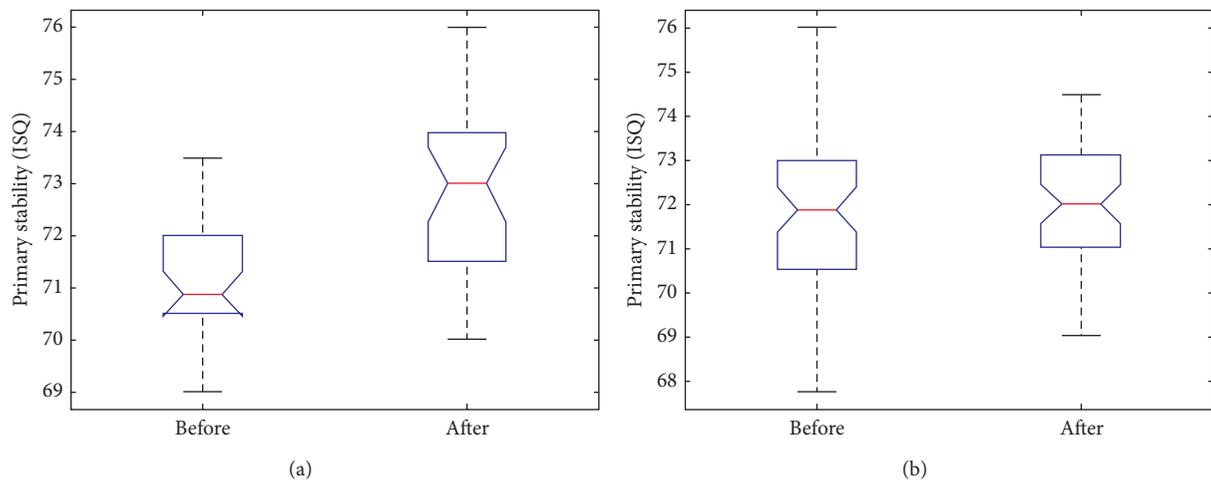


FIGURE 6: (a) Comparison of implant A primary stability between before and after the placement of implant B. (b) Comparison of implants A and B primary stability between before and after the placement of implant C.

one human mandible to another and also vary from one site to another on the same human mandible. Due to the fact that this variability can be observed within the same site, it justifies the choice of an area. Otherwise, Hsu et al. [28] have shown a specific sensitivity of the Osstell device to these variability factors of bone density.

Despite the reproducibility of the protocol on the two substrates, a direct comparison was not possible between human dry bone (mandible) and polyurethane foam because of their different properties.

However, the implant stability varied between the polyurethane foam block and the human mandibles (Figure 4). Implant stability was significantly improved on the human mandibles compared with the polyurethane foam block, but implant stability was also much more variable. Implant B placement on the polyurethane foam block increased implant A primary stability (Figure 6(a)) unlike what was observed on the human mandibles (Figure 5(a)).

The polyurethane foam block and the mandibular bone have different mechanical properties that could explain these results. Their elastic properties differ, so, according to van Eijden [29], the transmission of the constraints varies between a heterogeneous anisotropic material such as the mandibular bone and a homogeneous isotropic material such as the polyurethane foam block.

Linde and Sorensen [30] showed bone mechanical properties undergo postmortem change and can also be affected by the storage conditions and duration. The human mandibles taken were stored at 21°C on average.

The implant site drilling was performed without irrigation. Overheating the polyurethane could cause a thermal dilation around the implant, responsible for the increase in primary stabilities in this substrate. In addition, the polyurethane foam block density was at 850 HU, whereas the human mandibular body average density was at 540 HU. Because of this difference, an objective comparison

TABLE 1: Correlation analysis (alpha = 0.05).

Type	Variable 1	Variable 2	R	p
Hemimandible	Distance Y	Primary stability	0.122	0.252
Hemimandible	Density	Primary stability	0.271	0.010
Hemimandible	Cortical bone	Primary stability	0.162	0.128
Hemimandible	Tactile sensation	Primary stability	-0.185	0.081
Hemimandible	Torque	Primary stability	0.175	0.099
Polyurethane foam	Distance Y	Primary stability	-0.112	0.136

This table shows the variables that can modify the primary implant stability. Bone density is the only variable correlated to the primary stability ($p = 0.01$) in the natural bone and the artificial bone.

could not be made between the results of these two implant substrates.

There are some limitations associated with the current study.

According to Eliasa et al. [31] and O'Sullivan et al. [32], the implant geometry is one of the factors influencing its primary stability. So the use of only one implant type in our study could have limited the results.

As another limitation, the density variability within the mandibular bone could also be a bias factor.

To limit this disadvantage of heterogeneity of the mandibular bone, we used a polyurethane foam block. This substrate allowed comparison of the primary stability measured without being influenced by the density variability factor from one site to another.

O'Mahony et al. [33] have shown that factors such as blood, heterogeneity, or anisotropy as well as the morphology are likely to influence the measurements; thus the results of the polyurethane cannot be extrapolated to the natural bone. However these results allow understanding the mechanical influence of interimplant distance on implant primary stability.

In conclusion, this study has demonstrated that the reduction of the interimplant distance does not affect the implant primary stability in a dry human bone. However, since the conditions of the living bone were not taken into account in this experiment, it would be interesting to reproduce this study in vivo to assess the influence of the interimplant distance on their primary stability and the evolution of this stability after implant placement, during peri-implant bone healing.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

The authors thank Jean-Jacques, José, André, Bernard, and Etienne for their technical expertise and help in harvesting the fresh cadaver samples for this research in the Laboratory of Anatomy of Bordeaux University, France.

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