Title: Optimizing the primary stability of dental implants in type IV bone: in-vitro comparison of machine-driven and ratcheting insertion protocols

Running title: Comparison of dental implant insertion techniques

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Abstract

Purpose: The objective of this study was to assess the effects of various implant insertion techniques on the primary stability of dental implants in both type II and type IV cadaveric bovine.

Materials and Methods: A total of 48 dental implants (BEGO Semados RSX, BEGO Implant Systems GmbH & Co. KG, Germany) with a diameter of 3.75 mm and a length of 12 mm were used in the experiments. Bovine bone ribs were adjusted to mimic type II and type IV bone characteristics. Following the preparation of recipient sites, implants were inserted using three different protocols: machine-driven insertion (Standard group, Std group), ratchet insertion (Ratcheted, R Group), and a combination of both (Std + R group). The Osstell® Beacon device was used to record the implant stability quotient (ISQ) of each implant immediately after insertion. Two-way analysis of variance and Bonferroni tests were used for statistical evaluation.

Results: Bone type significantly influenced the ISQ values ($p<0.05$). However, when comparing insertion protocols separately for type II and type IV bone, no significant differences were observed. In type IV bone, both the Std group and R group exhibited significantly lower ISQ values compared to the same groups in type II bone ($p<0.05$ for each). Nevertheless, there were no significant differences in the ISQ values when employing the Std+R technique between the two types of bone.

Conclusion: Combining machine-driven and ratchet insertion techniques may prove beneficial in optimizing ISQ values in bovine samples simulating type IV bone.

Key words: dental implants, oral surgical procedures, osseointegration, resonance frequency analysis

Türkçe öz:*Tip IV kemikte dental implantların primer stabilizasyonunun optimize edilmesi amacıyla angldruva ve raşetle yerleştirme protokollerinin in-vitro karşılaştırılması. Amaç: Bu çalışmanın amacı farklı implant yerleştirme tekniklerinin implant stabilitesi üzerindeki etkilerinin Tip II ve Tip IV kemiği taklit eden sığır kadavrasında karşılaştırılmasıdır. Gereç ve Yöntem: 12 mm uzunluğunda, 3,75 mm çapında toplam 48 adet dental implant (BEGO Semados RSX, BEGO İmplant Sistemleri Lmt. Şti & Kom. Şti, Almanya) tip II ve tip IV kemiği taklit etmesi için hazırlanan sığır kaburga kemiklerinin içine yerleştirildi. İmplant yataklarının standart frezleme tekniği ile hazırlanmasından sonra dental implantlar kemik içerisine 3 farklı protokol ile yerleştirildi. Bu protokoller ile implant motoru yardımıyla yerleştirilen grup (Std grubu), raşet ile yerleştirilen grup (R grubu) ve iki yöntemin kombinasyonu şeklinde yerleştirilen grup (Std + R grubu) oluşturuldu. Her bir implantın primer stabilitesi, kemik içerisine yerleştirilmesinden hemen sonra, Osstell Beacon cihazı ile ölçülen implant stabilite katsayısı (ISQ) ile değerlendirildi. İstatistiksel analiz için iki yönlü varyans analizi ve Bonferroni testleri yapıldı. Bulgular: Kemik tipinin ISQ değerlerini anlamlı derecede etkilediği gözlendi ($p<0.05$). Ancak tip II ve tip IV kemik için yerleştirme protokolleri ayrı ayrı karşılaştırıldığında anlamlı bir fark gözlenmedi. Tip IV kemikte hem Std grubu hem de R grubu, tip II kemikte aynı gruplarla karşılaştırıldığında anlamlı derecede düşük ISQ değerleri gösterdi (her biri için $p<0,05$). Bununla birlikte, iki kemik türü arasında Std+R tekniği uygulandığında ISQ değerlerinde anlamlı bir fark bulunamadı. Sonuç: Tip IV kemiği taklit eden sığır numunelerinde, implant motoru ve raşet yerleştirme tekniklerinin birlikte kullanılmasının ISQ değerlerinin optimize edilmesinde faydalı olabileceği sonucuna varılmıştır. Anahtar kelimeler: dental implant, oral cerrahi işlemler, osseointegrasyon, rezonans frekans analizi*

Introduction

In recent decades, dental implant treatments have increasingly been regarded as a viable solution for providing functional rehabilitation to both partially and completely edentulous patients. This shift in perception is largely attributable to significant advancements in oral implantology (1). Therefore, it is of paramount importance that research efforts are directed toward fostering a consensus on achieving implant success through optimal treatment options (2). The success of dental implants hinges on both biological processes and mechanical factors, with the osseointegration process standing out as the predominant parameter in oral implantology (3, 4).

One crucial step in establishing optimal osseointegration based on long-term clinical experience is achieving primary stabilization (5, 6). Primary stabilization is a mechanical aspect that refers to the implant's ability to withstand axial, lateral, and rotational loads within the bone at the time of implant placement (5-7). This initial mechanical stability arises from the difference in stiffness between the implant and the surrounding bone. The ultimate goal is to attain a level of primary stability sufficient to support biological processes during the subsequent healing phase (5, 6).

Various techniques can be employed to assess the initial mechanical stability, such as surgical insertion torque, removal torque, damping capacity analysis, and resonance frequency analysis (8). Resonance frequency analysis (RFA) stands out as one of the most widely used clinical techniques for measuring the implant stability quotient (ISQ) and, thus, evaluating the primary stability of an implant (9). RFA offers a non-invasive and objective approach, enabling clinicians to monitor implant stability over time and make necessary adjustments to treatment protocols, such as immediate loading in dental implants (10, 11).

Multiple factors, including implant design, bone quality, osseous morphology at the surgical site, bone vascularity, drilling techniques, insertion protocols, and clinicians' skill, have been shown to influence primary stability in various studies (3, 12). Maintaining optimal primary stability is especially critical in cases with poor bone density, as it can significantly impact the long-term success of implant procedures (9, 13). Consequently, this investigation has two primary objectives. First, by examining changes in primary stability under different insertion protocols for dental implants, we aim to determine the significance of the chosen protocol. Second, through a comparison of different bone types, we seek to offer guidance to clinicians regarding protocol preferences for cases with poor bone density. The null hypothesis for this study is that the utilization of different insertion protocols would not result in any differences in the primary stability achieved after implant placement.

Materials and Methods

All preparations of bone specimens and surgical procedures described below were carried out at room temperature by the same oral surgeon (N.M.T) to ensure standardization.

Selection and preparation of bone specimens

The macroscopic composition of cortical and medullary bone makes ribs a suitable choice for simulating edentulous human bone (14-17). For this study, fresh bovine ribs were purchased from a slaughterhouse. After removing all soft tissues and the periosteum from the bones using scalpels and periosteal elevators, 7 cm-long bone block pieces were cut under copious amount of saline irrigation in room temperature using a surgical saw. A total of 12 fresh bone blocks were checked macroscopically for irregularities. Subsequently, they were randomly assigned to three groups representing different insertion protocols: manual insertion group, handpiece insertion group, and combination group. In each group, the preparation of the bone blocks was conducted in accordance with established procedures from previous studies (18-21).

For half of the bone blocks, the cortical bone layer was thinned using 220-grit sandpaper until it reached a thickness of 2 mm, mimicking type II bone, which represents corticocancellous bone (18, 19, 21). For the other half, the distal epiphysis along the longitudinal axis of the bone blocks was selected to mimic type IV bone, representing cancellous bone (18-20). Each block received four implants (Figure 1).

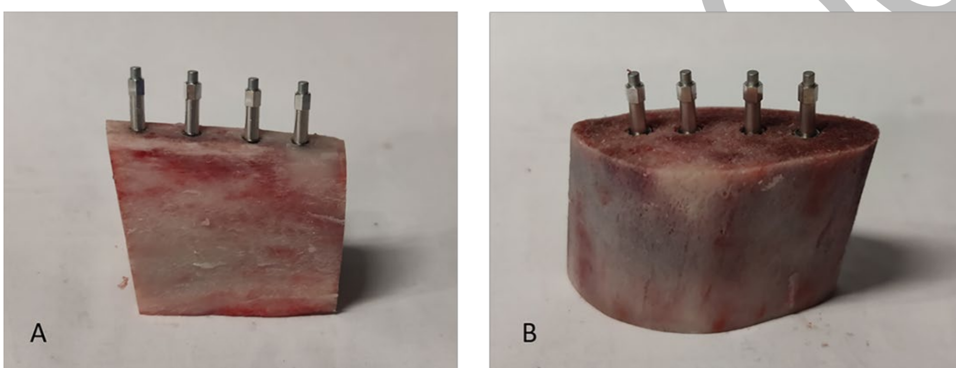

Figure 1: *Insertion of four dental implants for type II bone (A) and type IV bone (B).*

Experimental protocol and study groups

As part of the experimental protocol, bovine ribs were securely stabilized on a bench vise to prevent any micro-movements. The implant recipient site preparations for a total of 48 dental implants (BEGO Semados RSX, BEGO Implant Systems GmbH & Co. KG, Germany), each with a diameter of 3.75 mm and a length of 12 mm, were carried out in accordance with the BEGO Semados RS/RSX TrayPlus standard drilling protocol, following the manufacturer's recommendations. In the manual insertion group, 16 dental implants (8 implants for each bone type) were placed into the prepared sites using a ratchet connected to a torque wrench. The torque wrench was carefully adjusted to apply torque at a level of 35 Ncm, as per the manufacturer's guidelines. In the machine-driven group, the insertion of 16 dental implants (8 implants for each bone type) was executed using a 20:1 surgical contra-angle handpiece. The surgical motor was configured to operate at 25 rpm with a maximum torque of 35 Ncm, and no saline irrigation was used, as per the manufacturer's recommendations. In the combination group, the insertion of 16 dental implants was carried out in two steps. Initially, two-thirds of the dental implant's threads, approximately 8 mm in distance from the apex towards the neck of the implant, were inserted into the bone using a 20:1 surgical contra-angle handpiece. Subsequently, the dental implant was securely tightened to its final position using a ratchet connected to a torque wrench, with the torque wrench adjusted to apply torque at 35 Ncm, in accordance with the manufacturer's instructions.

Primary stability measurements

To assess primary stability measured in terms of ISQ values, we used the Osstell® Beacon device (W&H, Göteborg, Sweden) along with commercially available transducers (Smartpeg type 26, W&H, Göteborg, Sweden) attached to each implant. For each implant, two consecutive measurements were conducted, one from the frontal and another from the lateral direction, by positioning the probe laterally in relation to the transducer. The ISQ values acquired at the frontal site of each implant were recorded as buccolingual ISQ values, while those obtained at the lateral site were recorded as mesiodistal ISQ values. The second operator (S.S) was responsible for performing and recording all measurements. To validate ISQ values, the operator repeated both BL and MD measurements at least three times, and the average value of these measurements was established as the reference for statistical analysis.

Statistical analysis

Statistical Package for Social Sciences (SPSS) software, version 22 (IBM SPSS Inc., Armonk, NY, USA) was used for statistical analysis. The Kolmogorov-Smirnov test and Shapiro-Wilk test were applied to verify normal data distributions. Two-way analysis of variance was used to assess the effects of insertion techniques and bone types on the ISQ measurements. Bonferroni post hoc analysis was performed for pairwise comparisons. The confidence level was set to 95% and p values less than 0.05 were considered significant.

Results

Two-way ANOVA analysis revealed that the bone type variable significantly affected the ISQ values ($p<0.05$), unlike the insertion protocols (Table 1).

For type II bone, primary stability recorded in the Std + R group was the highest at 75.4 ± 5.3 ISQ, followed in order by the value for the R group at 74.9 ± 7.0 ISQ and that of the Std group at 72.6 ± 2.7 ISQ (Table 2). No significant differences were observed when comparing the insertion protocols in type II bone.

In type IV bone, the primary stability of the samples in the Std group was the lowest at 62.7 ± 3.7 ISQ, while those of the other samples were 66.0 ± 6.8 and 69.8 ± 5.4 ISQ, respectively, for the R and Std + R groups. Comparing the three insertion protocols within type IV bone, no significant differences were found in primary stability values of the samples (Table 2).

When comparing the two bone types, the mean ISQ values of the Std and R groups in type II bone were significantly higher than those of their counterparts in type IV bone ($p<0.05$ for each).

However, there were no significant differences in ISQ values when employing the Std+R technique between the two types of bone.

Table 1. *Effects of insertion method and bone type on the ISQ measurements according to the two-way analysis of variance.*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1035.042 [a]	5	207.008	6.291	.000
Intercept	236742.521	1	236742.521	7195.105	.000
Method	193.948	2	96.974	2.947	.063
Bone	800.333	1	800.333	24.324	.000
Method × Bone	40.760	2	20.380	.619	.543
Error	1381.937	42	32.903		
Total	239159.500	48			
Corrected Total	2416.979	47			

Note: [a] R Squared = .428 (Adjusted R Squared = .360)

Table 2. *Means and standard deviations of the ISQ measurements and post-hoc analysis for pairwise comparisons. p-values written in bold indicated significant differences for pairwise comparison related to bone types calculated by post hoc Bonferroni test. Parameters were described as mean ± SD. Different uppercase superscript letters present significant difference between insertion methods written in the same column (Std group:machine-driven insertion, R group: ratchet insertion, Std+R group: machine-driven and ratchet insertion).*

Bone Type	**Insertion Methods**		
	Std group	**R group**	**Std + R group**
Type II	72.6 (2.7) ^{A}	74.9 (7.0) ^{A}	75.4 (5.3) ^{A}
Type IV	62.7 (3.7) ^{A}	66.0 (6.8) ^{A}	69.8 (5.4) ^{A}
P-Value	**0.0185**	**0.0495**	0.8475

Discussion

Osseointegration, defined as the direct structural and functional connection between the implant surface and the patient's bone, plays a crucial role in the success of dental implant procedures (22). Osseointegration, resulting from initial mechanical stability combined with biological stability, occurs at two stages: primary and secondary stabilization (23). Primary stabilization stands out as a key clinical objective during implant insertion (24). Achieving primary stability depends on numerous factors, including the implant's diameter, length, shape, thread design, as well as the surgical techniques employed by the operator and the type/density of the bone into which the implant is placed (25). Although advancements in oral implantology can assist in achieving predictable osseointegration even with low or non-primary stability, optimal primary stability can expedite and enhance the predictability of achieving strong secondary stability, especially when employing immediate loading protocols (26, 27). Furthermore, challenges in achieving optimal primary stability are common in clinical scenarios where medullary bone density is notably low, such as in the maxilla and posterior mandible, particularly among elderly patients (28). Multiple strategies exist to enhance primary stability in situations with poor bone density, including aspects of bone bed preparation like the osteotomy drilling process, drilling speed, irrigation during osteotomy to prevent overheating, and implant body insertion (3, 29, 30).

The aim of this study was to compare the effects of three different insertion protocols on the primary stability of dental implants placed in type II and IV bone. We hypothesized that advocating specific insertion protocols for a particular bone type could enhance primary stability and help clinicians select the appropriate protocol. To test this hypothesis, we specifically aimed to compare and evaluate ISQ values of dental implants inserted into type II and type IV bone using three insertion protocols: standard insertion (Std group), ratchet insertion (R group), and a combination of both (Std + R group) protocols. According to the main findings of this study, selecting the combination of insertion protocols may yield improved implant primary stability in conditions characterized by poor bone density.

ISQ values represent the predictability of the primary stability of a dental implant, at least on a macroscopic level, and provide the clinician with an idea of the prognosis they can expect for that specific implant or how soon it can be loaded (31). This study reaffirms that ISQ values were lower in low-density bone compared to high-density bone. This supports the findings of several studies (24, 32, 33) that have suggested that the accuracy of primary implant stability measurements obtained through resonance frequency analysis depends on bone density and can be influenced by different protocols. Orban *et al.* (34), in a prospective and randomized clinical study, evaluated the accuracy of implant placement by comparing the insertion torque for two types of insertion protocols: machine-driven and manual insertion. They concluded that there was no significant difference between the insertion protocols in terms of the accuracy of implant placement and mean insertion torque. In an in vivo study, Aliabadi *et al.* (35) focused on marginal bone loss around dental implants using two insertion methods, manual and mechanized. They observed that manually inserted implants showed less long-term marginal bone resorption. Similarly, Novsak *et al.* (36) aimed to evaluate differences between manual and mechanized techniques for orthodontic mini-implants in pig ribs and demonstrated higher stability and less bone resorption for manually inserted implants.

Furthermore, Misch *et al.* (37) stated that in compromised bone density situations, manual insertion of dental implants with the use of a handpiece is more suitable for providing the necessary force. Similarly, Cavallaro *et al.* (29) suggested that hand-ratcheting two to three threads was reasonable, but they emphasized not applying high hand-torque forces to seat the entire implant. However, in another article, Kim *et al.* (38) compared the success rates of manual and machine-driven methods for inserting mini screws. Regarding the insertion site, they claimed that the overall success rate of insertion with an engine driver was significantly higher than that with a hand driver for both the mandible and maxilla.

In our study, when comparing the effect of insertion protocols on primary stability within each bone type, no significant difference was observed in ISQ values. ISQ values measured following the utilization of standard insertion protocol or ratchet insertion protocol were significantly lower in type IV bone compared to type II bone. Importantly, the Std + R group did not exhibit a significant decrease in ISQ levels for type IV bone compared to type II bone. If proven clinically, this may suggest that the utilization of the combination protocol may be beneficial as it allows ISQ values to remain stable even in cases of lower bone density. Therefore, it may be a more promising and preferable insertion method for patients with poor bone density, as well as for immediate implant placement.

In a previous in vitro study, wood blocks were used as an alternative to low-density bone, simulating D4 and D3 bone. In this study, 32 implants were inserted using either a low-speed machine-driven handpiece or hand ratcheting, and a pull-out test was conducted (39). The results revealed that D3 bone exhibited statistically significantly higher pull-out strength than D4 samples. Additionally, implants inserted using the machine-driven handpiece seemed to exhibit enhanced stability compared to those placed manually. However, the authors acknowledged a limitation in using pullout force as a measure of stability, suggesting that Resonance Frequency Analysis (RFA) would have been a better choice for analyzing primary stability. RFA has become one of the most widely used techniques for assessing implant stability in both clinical trials and experimental studies (9, 25). This analysis ensures accurate control of implant stability, with repeatable and reproducible measurements over time, and facilitates precise communication among professionals (22).

Numerous experimental studies have been conducted using various bone models, including animal bones, human cadaver bones, and artificial bone, to simulate situations with different bone densities (40-42). The objective of these studies is to highlight the challenges posed by poor bone quality and investigate methods to enhance primary stability. Concerning animal bones, the macroscopic composition of cortical and medullary bone in bovine ribs serves as an acceptable model for reproducing edentulous human bone, as reported in numerous studies (14-17). While these studies endorse the use of this animal model in implant research to gain insights into edentulous human bone, it's important to note that there are various experimental designs addressing bone type variations. For example, Lanchmann *et al.* (14) characterized the distal aspect of the rib, with a smaller diameter, as type II bone according to the Lekholm/Zarb classification (43) or D2 to D3 according to Misch (44). In their study, the bone region with a greater diameter at the end of the ribs, containing less cortical components and a higher content of bone marrow and spongy trabeculae, represented type III bone according to the Leckholm & Zarb classification (43) or D3 to D4 according to the Misch classification (44). García-Vives *et al.* (15) referred to the distal end of the ribs as type IV bone according to the Leckholm & Zarb classification (45) or D4 according to the Misch classification (44).

In line with our experimental design, other relevant studies used the distal epiphysis on the longitudinal axis of bovine ribs, without any cortical bone, to mimic the morphological structure of type IV bone, resembling the human posterior maxilla (18). Toyoshima *et al.* (19) also used the distal epiphysis of the longitudinal axis of the bone block to represent the cancellous bone group. In their study, the authors adjusted the thickness of the cortical layer of bone blocks to 2 mm to reduce the effects of compressive forces, referring to them as the corticocancellous bone group. On the other hand, Moon *et al.* (20) and Anil and Aldosari (21) removed the entire cortical bone of bone rib blocks until trabecular bone was exposed to mimic type IV bone. In these two studies, the cortical bone was thinned to 1 mm to mimic type II bone.

Taking everything into consideration, we chose to use bovine ribs as an animal model for this study. This decision was based on well-established evidence in the literature demonstrating their effectiveness in evaluating the correlation between bone density and implant stability (14, 46, 47). Our experimental bone models were designed to resemble type II or type IV bone in line with the aforementioned literature. For the same reasons, we did not include type I or type III bone in the study, as each group represents a wider selection of bone density according to bone classifications.

The authors of this study acknowledge that the use of animal models may not perfectly represent human bones, which is a key limitation of the study. We recommend further studies in this area, including the assessment of bone type/density using advanced analysis methods such as micro-computed tomography or histomorphometric analysis. Therefore, the absence of any analysis defining the bone type may also be considered another limitation of the current study. Some other limitations of the present study include the fact that, we did not account for both the mechanical and biological aspects of in vivo conditions, such as access to the surgical site or the blood supply to the bone. Moreover, it should be noted that various types of implants with different geometrical designs may alter the ISQ values. Additionally, it should be considered that high ISQ values do not always correlate with successful osseointegration and the long-term survival of an implant. Further studies should also be conducted to estimate the long-term effects of insertion protocols, as the findings may influence clinicians' preferences for selecting the proper insertion protocols based on bone type.

Finally, ISQ values greater than 65 have been regarded as favorable for implant stability, whereas ISQ values below 45 indicate poor primary stability (48). In studies that investigated the predictive value of RFA analysis in the survival rates of dental implants, Baltayan *et al.* (49) showed that there was a significant difference in survival rate between early and traditional loading protocols for implants with ISQ values serving as cutoff points (ISQ of 45, 50, 55). It is emphasized that implants with ISQ values less than 60 are of questionable stability, while those with values greater than 70 are very stable, with the 60 to 70 range serving as the cutoff region (49, 50). Importantly, the values in our results for type IV bone fall within the cutoff region for each insertion protocol.

Conclusion

Considering the limitations of the present study, it can be concluded that utilizing a combination of machine and ratchet insertion techniques may prove beneficial in optimizing ISQ values in bovine samples simulating type IV bone.

Ethics Committee Approval: Not required.

Informed Consent: Not required.

Peer-review: Externally peer-reviewed.

Author contributions: NMT, AET, PE participated in designing the study. AET, SS participated in generating the data for the study. NMT, AET, SS participated in gathering the data for the study. AET, SS participated in the analysis of the data. NMT, AET wrote the majority of the original draft of the paper. NMT, AET, PE participated in writing the paper. NMT, AET, SS has had access to all of the raw data of the study. NMT has reviewed the pertinent raw data on which the results and conclusions of this study are based. NMT, AET, PE, SS have approved the final version of this paper. NMT guarantees that all individuals who meet the Journal's authorship criteria are included as authors of this paper.

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