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The Effect of Primary Stability on Implant Osseointegration: A Clinical Comparison of Four Implant Systems

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Abstract

Aim: This prospective clinical study aimed to evaluate and compare the effect of primary stability on osseointegration and success rate of four different implant systems. ***Material and Method:*** Eighty implants were placed on the maxillary and mandibular arch of 45 patients. The four implant systems used in this study were Straumann SLA bone level implants, BIOMET 3i OSSEOTITE, Astra Tech Dental (OsseoSpeed) Implant System, and Nobel Replace Conical Connection implant system. A two-stage implant placement procedure was followed. During the implant placement, maximum insertion torque was recorded. The implant stability quotient (ISQ) was also recorded using Ostell, which was further assessed using resonance frequency analysis (RFA). Descriptive data were analyzed using median and percentage. For Pairwise Comparison, the Shapiro-Wilks Rank Sum test was utilized. The p-value was set to 0.05 for all the measurements. ***Results:*** The insertion torque value was similar among all four implants. All the implants have almost similar ISQ values post-surgery. However, Nobel and 3i implant systems showed a lower ISQ value in the second and third quartile. Kruskal Wallis Rank Sum Test showed that the distribution of ISQ in all directions was not the same across all Implant systems (Chi-square=21.588, df=3, p-value = 0.001). The success rate of Straumann and Astra was 100%, while Nobel and 3i were 90% and 80% respectively. ***Conclusion:*** Primary stability has no effect on osseointegration and implant success rate. Moreover, Ostell device was found to be a significant predictor for implant osteointegration after successful placement and healing of dental implant site.

Keywords: Implant stability, Straumann implants, 3i OSSEOTITE, Astra Implant System, Nobel implant system, comparison, Implant stability quotient.

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INTRODUCTION

In recent years, scientific advancements have increased the clinical application of implants in prosthetic rehabilitation for missing teeth. These advancements include simplified surgical methods, and surface treatments [1,2]. Furthermore, the evolution of surgical procedures has improved surgeons' confidence in the outcome measures among healthy patients with implant treatment [3,4]. Studies have reported that the success rate of dental implants placed in the maxilla and mandible is high compared to fixed and removable partial dentures [5,6].

In the compromised maxillary and mandibular bones, the selection of the implant system directly influences the survival rates. Previous clinical studies have demonstrated that bone quality and thickness are

directly affected by the surface roughness of the implants [3,7,8]. During the initial stages of osseointegration, osteoblast cells do not adhere to the implant surface. Early adhesion of osteoblast is the prerequisite for the formation of mesenchymal cells [9,10]. Augmenting the surface roughness of implants facilitates the retention of osteogenic cells and advances the migration of these cells to the implant surface through osteoconduction, thereby accelerating the osseointegration process [9,10].

The long-term success of implants depends on various factors like bone quality and thickness, surgical procedures, micro-agricultural properties, and properties of implant systems [11-13]. Moreover, a dental implant requires atraumatic surgical interventions to attain primary stability. Furthermore, the biocompatibility, surface characteristics, and implant designs should be recorded to minimize the inflammatory responses contributing to the primary stability [11-13].

Modifications applied to the surface topography, structure, chemistry, surface charge, and wettability of implants play pivotal roles in influencing the process of osseointegration [9,14,15]. The principal objective of these modifications is to engineer surfaces that are more conducive to bone formation, hence deemed osteophilic, by attracting bone-forming cells [16,17]. Both industrial bodies and academic researchers have extensively investigated modified titanium implant surfaces. Much attention has been directed towards subtractive manufacturing techniques like sandblasting and acid etching, as well as methods involving the deposition of calcium phosphate crystals. Surface chemistry alterations aimed at inducing extensive hydroxylation/hydration of the oxide layer have also been a focal point of investigation. Such modifications are envisaged to promote interactions between surface atoms and the hydration shell surrounding biomolecules, notably proteins [18,19]. Hydrophilic titanium surfaces have demonstrated the ability to expedite and augment bone apposition in animal models through the adsorption of proteins that influence the initial regulation of cellular adhesion. Additionally, the stabilization of blood clots and early vascularization, potentially influenced by implant surfaces, are deemed crucial during the initial stages of peri-implant wound healing [18,19]. Collectively, these modifications to bone-implant interfaces have led to reduced healing periods associated with the utilization of titanium implants.

Non-hydrophilic surfaces of implants have demonstrated the ability to enhance bone apposition during the initial healing phase, particularly when early-load protocols are implemented [5,9,20]. This enhancement is attributed to a bone-bonding phenomenon characterized by the interdigitation of the cement line matrix of bone with surface features of the underlying implant. Research conducted by Jonge *et al.,* has indicated increased adhesion of osteoblast-like cells to these coatings [21]. Calcium phosphate (CaP) coatings have been identified for their capacity to promote in vitro cell attachment and extracellular matrix (ECM) production, with in vivo studies confirming their heightened osteoconductive properties compared to non-coated implants [22]. This beneficial attribute of CaP coatings is attributed to the chemical resemblance between synthetic CaP and natural CaP. However, it's noteworthy that despite this chemical similarity, deposited coatings do not exhibit structural or biological resemblance to bone tissue, as natural bone also comprises an organic matrix of collagen and non-collagenous proteins [22]. Consequently, novel techniques such as electrostatic spray deposition of CaP have been explored to enhance osteoconductivity, osteogenesis, and, ultimately, osseointegration [18,23]. Electrostatic CaP deposition holds promise in promoting osteoblast attachment, thereby facilitating cell differentiation and proliferation.

Numerous studies have analyzed oral implants' macroscopic, microscopic, and nanoscale characteristics to understand their impact on bone regeneration [9,10,19-21]. Despite this, there remains a significant knowledge gap regarding the clinical effect of modified physicochemical properties of implant surfaces, particularly concerning primary stability, even though surface treatments have been demonstrated to improve primary stability. Various surface treatments for the implant have recently been available; however, the effect of this treatment on osteointegration during primary stability remains debatable. Hence, the present prospective study aims to assess the osseointegration for implants with low primary stability both clinically and by resonance frequency analysis for four different implant systems. The null hypothesis was drawn as there is no significant difference in the assessment of osseointegration for implants with low primary stability, both clinically and by resonance frequency analysis, across different implant systems.

METHOD

Subjects

Eighty implants were placed on 45 patients (16 males and 29 females) referred to Prince Sultan Military City Clinics between 2021 and 2023. The included patients were free from oral pathologies and were partially edentulous. The exclusion criteria were patients with periodontitis, parafunctional habits, uncontrolled diabetes, and medications that might hinder osseointegration. Patients with a bone circumferential area of less than 2mm were also excluded. Maximum implants were placed in the maxillary and mandibular molar areas compared to premolars and incisors (Table 1).

Table 1: Number of implants placed at various sites

Implant system	Sample size	Site of placement					
		Maxilla			Mandible		
		Incisors	Premolars	Molars	Incisors	Premolars	Molars
Straumann	20	2	2	9		2	5
Astra	20		1	7		2	10
Nobel	20		4	6	1	5	4
3I	20		5	6		4	5

Implant Characteristics

Four different dental implant types were used. Straumann SLA Bone Level implants, BIOMET 3i OSSEOTITE, Astra Tech Dental Implant System (OsseoSpeed), and Nobel Replace Conical Connection implant system (Nobel Biocare AB, Goteborg, Sweden), Distributed as shown in table 1.

Initial examination

An initial consultation with all the patients was done before considering implant placement. A Prosthodontist and a Periodontist surgeon planned the surgical measurements. Treatment procedures, risks, and benefits were explained to all the patients, and informed consent was obtained. A prosthodontist did a thorough intraoral examination of all the patients after detailing patients' treatment outcomes. This evaluation also included panoramic radiographs and cone beam computed tomography. Past medical and dental histories were taken from all the patients.

Surgical procedure

A standard surgical technique was used to place the implant. Manufacturers' guidelines were followed for each type of implant. All the surgical procedures were done under local anesthesia. The mucoperiosteal flap was retracted with the help of a surgical knife, and 2mm of pilot bone drilling was performed for Straumann SLA Bone Level implants and Nobel Replace Conical Connection implants; bone drilling of 3mm was done for type 2 and 3 bone quality, with the final diameter of 3.5 mm for each bone type. The same diameter drilling was done for the other two implants to compare the factors affecting primary stability. Implants were placed into the sites at bone level according to manufacturer instructions.

The implants were placed at the surgical site, and a calibrated torque wrench was carried out. A cover screw was placed over the implants, and the surgical site was sutured with nylon 5.0 (Biopharma, USA) using an interrupted suturing technique. The stitches were removed two weeks after the surgery. All the patients were instructed to eat soft and cold food for three days post-surgery. To control the formation of biofilms, patients were instructed to use a soft bristle toothbrush and 0.2% hexedine mouthwash. All the patients were given painkillers (paracetamol 500mg) for three days.

Healing of abutment placement

The second stage of surgery was performed 4-6 months of the initial surgery to anticipate osseointegration. This surgical procedure involved the reflection of a full-thickness flap to expose the bone surrounding the implant, facilitating the assessment for any dehiscence or bone loss. Following this, the Osstell device (figure 1) was utilized to check implant stability quotient (ISQ). Implants with ISQ readings below 60 underwent torque testing to confirm the presence of osseointegration failure. The Resonance Frequency Analysis (RFA) measurements were conducted twice for each surface (mesial, buccal, lingual, distal), and the average ISQ values were documented for further analysis.

Resonance frequency analysis

According to the method described by Meredith *et al.,*1996, [24] implants' resonance frequency analysis (RFA) was measured. The experimental resonance frequency system was commercially produced as Osstell® (Osstell AB, Göteborg, Sweden). A measurement of Osstell is identified as ISQ ranging from 1 to 100. Where, 1 signifies no stability and 100 with highest implant stability.

Resonance Frequency Analysis (RFA) works on the principle of resonance frequency, wherein the application of a frequency within the audible range onto an implant result in vibrations. A stronger interface between the bone and the implant corresponds to a higher frequency of these vibrations. The initial RFA device utilized stainless steel or titanium and consisted of an offset cantilever beam embedded with piezoceramic elements. One of the beams was vibrated by a single piezoelectric element, typically operating within a frequency range of 5 to 15 kHz, facilitated by a frequency response analyzer and a personal computer. A second piezoelectric element was employed to measure the response of the beam to these vibrations. ISQ of successful implant measured by osstell ranges between 52 to 87, respectively.

As the product developed, the wired transducer of the Osstell device was replaced with a wireless aluminum rod equipped with magnets, known as the smartpeg (figure 2). This modification enabled non-contact measurements. In this updated device, magnetic pulses excite the magnet attached to the smartpeg. The magnetic resonance analyzers, such as the Osstell

Mentor and Osstell ISQ, then convert the resonance frequencies generated by the magnetic field—specifically at 3.5 kHz and 8.5 kHz—into ISQ values.

The transducer, known as the smartpeg, features a magnetic top and is securely attached to either the implant fixture or the abutment by a screw located below (figure 3). When the probe releases a magnetic resonance frequency, it activates the magnetic smartpeg. This activated smartpeg then vibrates, generating an alternative magnetic field. Because of this activation, electric voltage is induced into the probe coil by the alternative magnetic field. Subsequently, this electric voltage is sampled by a magnetic resonance frequency analyzer for analysis.

The ISQ readings were measured for each implant using the Ostell; if the readings were below 60, the implants were torqued to confirm osseointegration failure. The RFA measurements were repeated twice for each surface (mesial, buccal, lingual, distal), and the mean ISQ values were recorded.



Figure 1: The Osstell® ISQ device and its components.



Figure 2: Smartpeg type 47



Figure 3: Smartpeg fixed to implant and measurement is made in non-contact manner with Osstell ISQ

Ethical considerations

This prospective clinical study was conducted following the revised form of declaration of Helsinki, 2008, following the CONSORT guidelines. It aimed to evaluate the primary implant stability of four different types of implants and its effect on osseointegration. This perspective study was performed at the Prince Sultan military hospital and was ethically approved by the Ethics committee under protocol number FPGRP/43631004/168. All the participants included in the study provided signed informed consent and provided previous medical and dental histories.

Statistical analysis

The difference in stability of implants across different types of Implant systems was made by testing the difference in mean and median for all systems. This analysis used the R programming language for statistical computing and graphics. The Shapiro-Wilks test was used to test the normality of the data. Pairwise Comparison using the Kruskal Walis Rank Sum test was used to identify significant differences between Implant systems. A significant statistical value of 0.05 was set for all the measures.

RESULT

Table 2 and figure 4 present the sample sizes along with the median values and quartile ranges for the stability of each implant system. Specifically, the median stability value for the 3I implant system was recorded as 82.75%. Similarly, for the Astra implant system, the median stability value was determined to be 83.13%, while for the Noble implant system, it stood at 82.88%. Lastly, the Straumann implant system exhibited a median stability value of 83.75%, respectively.

The Shapiro-Wilk test was employed to assess the normality of the dataset, revealing an uneven distribution with a statistically significant p-value of 0.00, respectively. Secondary stability measurements were conducted at various anatomical sites including Buccal, Mesial, Distal, and Palatal\Lingual, utilizing Osstell instrumentation. The median value was extracted from these measurements for each implant, serving as a consolidated indicator of secondary stability (figure 4).

Table 2: Calculating the stability of Implant Systems

Implants System	N*	Median
3i Implant torque	20	82.75
Astra Implant torque	20	83.13
Noble Implant torque	20	82.88
Straumann Implant	20	83.75

*N= sample size

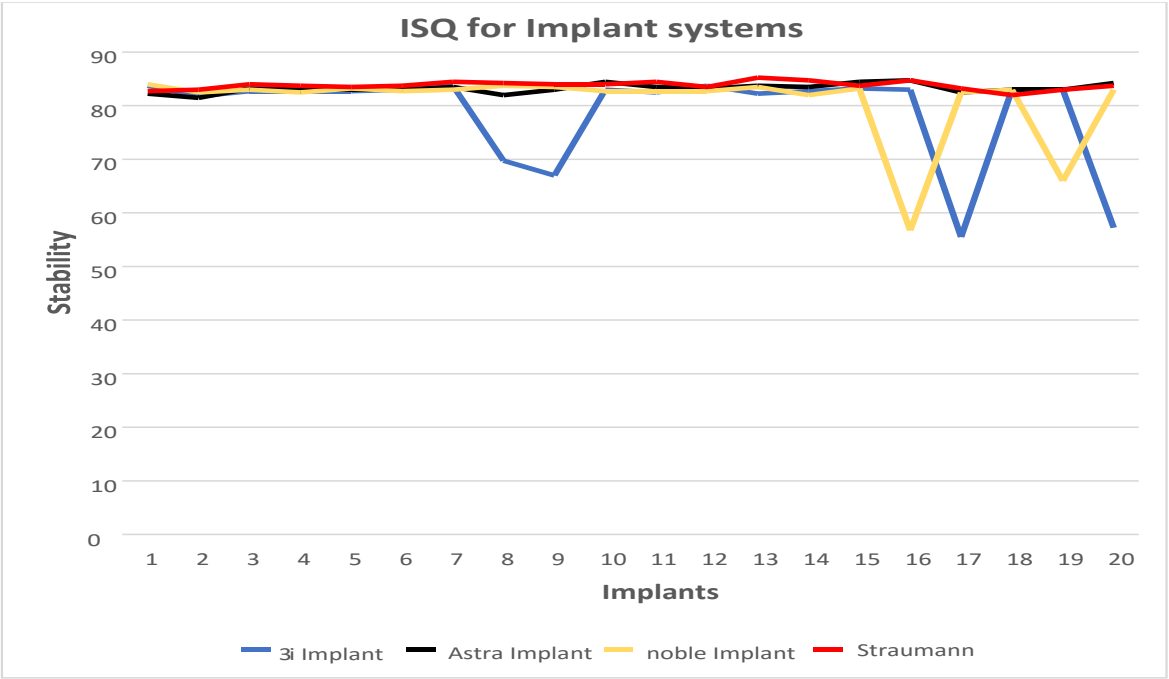


Figure 4: Shows Median and Percentile range (Quartiles) for the stability of each Implant System

The success rate was determined according to the implant's stability, representing a percentage greater than 80 in ISQ value. Table 2 showed that Straumann and Astra had a higher success rate (100%). Noble and 3i Implant systems had some failure implants with 90% and 80% success rates, respectively.

Table 3: Success rate for every implant system

Implant system	Success rate	Failure rate	Site of Failure
3i Implant	16(80%)	4(20%)	1-In max molar 1-In max premolar 2-In mandibular molar
Astra Implant	20(100%)	0	
Noble Implant	18(90%)	2 (10%)	1-In max molar 1-In mandibular molar
Straumann Implant	20(100%)	0	

Kruskal Wallis Rank Sum Test showed that the distribution of ISQ in all directions was not the same across all Implant systems (Chi-square=21.588, df=3, p-value = 0.000), which indicates that there are highly statistically significant differences in stability across all systems. Pairwise comparison using the Wilcoxon rank sum test was used to identify significant differences between implant systems. There was a highly statistically significant difference between Straumann and 3i implant (p-value= 0.00047). Straumann and Noble implants had a high statistically significant difference (p-value=0.001). Straumann and Astra had no statistically significant difference with p-value = 0.19, between Astra and Noble p-value=0.51, and between 3i implant and Noble p-value =1 (Table 4).

Table 4: P-values of comparing across Implant systems

Compare	Astra	Noble	Straumann
Noble Implant	0.51058*	-	
Straumann Implant	0.19494*	0.00138**	
3i Implant	0.12888*	1*	0.00047**

Bone Loss and Implant systems

Descriptive statistics in Table 5 showed that Straumann is the best implant system, with 100% of cases involving no bone loss or dehiscence and no implant mobility. 3I implants had minimum stability in comparison to other implant systems. Four cases out of twenty (20 %) of implants showed failure. Three cases (15%) had no bone loss but had a mobile implant. One case (5%) of 3I implants was mobile with bone loss of 6 mm. Astra Implant system showed 90% of cases with no bone loss. Two cases (10%) with bone dehiscence were measured at 5 mm. The Noble implant system showed 17

implants (85%) without bone loss. One case (5%) of implants showed bone dehiscence 5mm. One case showed a mobile implant with bone loss of 6mm, and 5% showed no bone loss but mobile implants. The mobile implants are considered failure implants and are removed (Table 5; Figure 5).

Table 5: Crosstabulation between Bone Loss and Implants

	Bone Loss			
Implants System	**No Bone Loss**	**Bone dehiscence = 5mm**	**Bone loss 6mm mobile implant**	**No Bone loss mobile implant**
Straumann	20 (100%)	0%	0%	0%
Astra Implant	18 (90%)	2(10%)	0%	0%
Noble Implant	17(85%)	1(5%)	1(5%)	1(5%)
3i Implant	16(0.80%)	0(0%)	1(5%)	3 (15%)

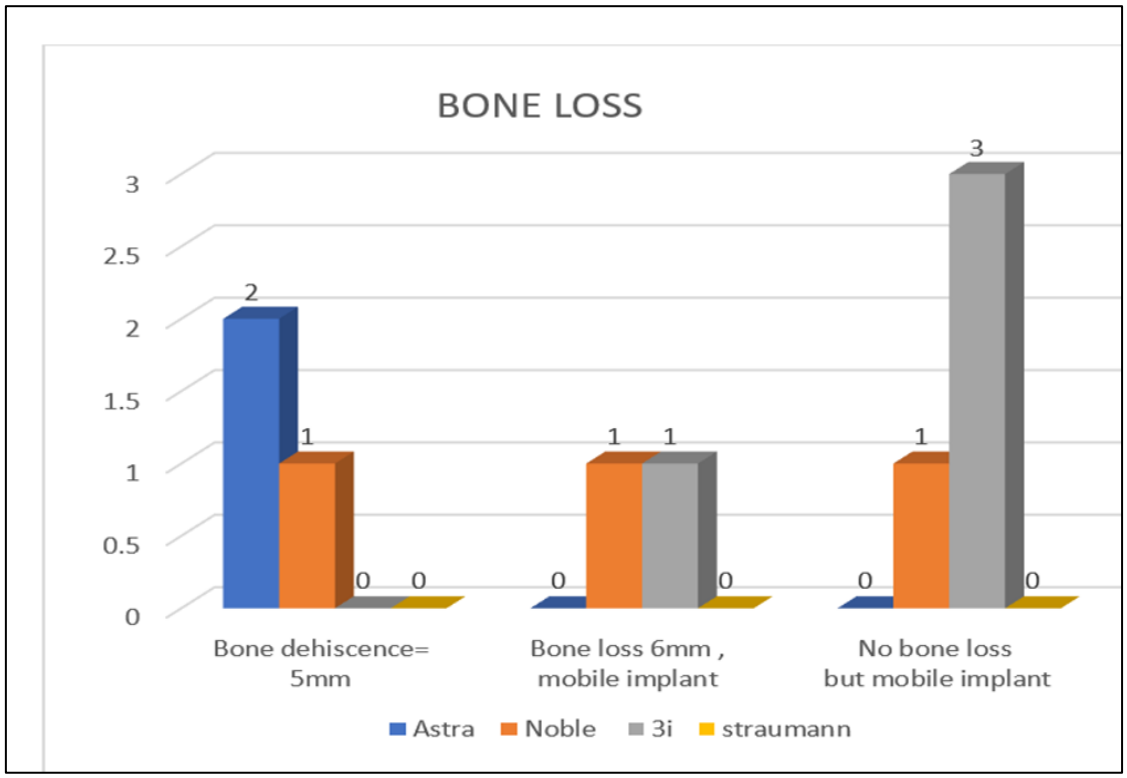


Figure 2: Bone loss for different Implant systems

Table 6 and figure 6 represent the success of implant systems during prosthodontic torque trial for all Implant systems. Astra and Straumann have a 100% success rate. Noble implants achieved 90% implant success during the prosthodontic torque trial, with two implant placement failures (10%). One of them had no bone loss but a mobile implant, while the other had mobility and 6 mm bone loss. 3I Implant system achieved 80% implant success during the prosthodontic torque trial, while four implants (20%) showed failure and were removed (Table 6).

Table 6: Percentage of success or failure for implant systems during prosthodontic torque trail

Implants Systems	**Failed Implants %**	**Successful implants %**
Straumann	0%	20(100%)
Astra Implants torque	0%	20(100%)
Noble Implants torque	2(10%)	18(90%)
3i Implants	4(20%)	16(80%)

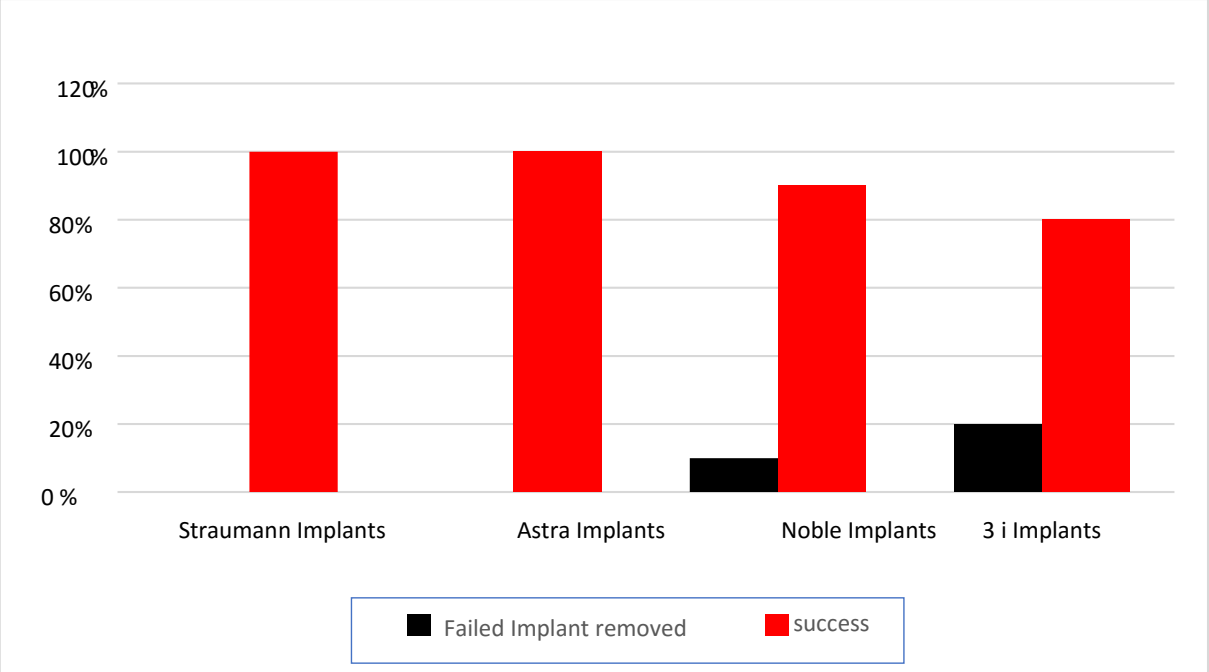


Figure 6: Successful or failure of implant systems during prosthodontic torque trail

DISCUSSION

The importance of primary stability on implant placement is well-established. Poor retention and stability of implants are directly associated with the method of implant placement and quality of bone coupled with insufficient healing. The primary stability of the implant depends upon the quality of the bone, implant shape, and placement techniques. Prosthodontic surgeons commonly suggest that bone quality and quantity are directly related to the primary stability of implants. However, significant differences in the primary stability due to specific design and placement of implants have not been quantified. The current prospective study aimed to demonstrate and compare the effect of primary stability on the process of osteointegration and success rate of four different implant systems. The result of the current study supports the null hypothesis that no difference was reported in the process of osteointegration and success rate during the primary stability stage of implant systems.

The quality of the bone and bone density measured in the studies ranges between grades 0-4. Johansson and Strid, in 1994, designed a quantitative technique to measure the cutting resistance of the bone by utilizing a low-speed handpiece [25]. The current study used the Leckholm and Zarb scoring and measurement of torque to quantify bone quality at each implant site [26]. It is important to understand the mechanism of implant placement and interpreting torque. Theoretically, lack of irrigation during implant placement affects lubrication and bone clearance but does not affect torque insertion. Knowledge regarding implant insertion is important, but different aspects of implant placement must be considered.

The utilization of ISQ represented a noninvasive approach aimed at quantifying both primary and secondary stability, facilitated through evaluation by the Osstell Mentors utilizing Resonance Frequency Analysis (RFA). However, at the point of implant placement, this measurement failed to serve as a reliable predictor of implant outcome. During the six months of the study, the studied implant systems (Straumann SLA implant, BIOMET 3i OSSEOTITE, Astra Tech Implant System, and Noble implant system) showed acceptable primary stability with a mean ISQ of 80. However, 3i had the lowest ISQ values compared to different implant types. Similarly, in the study by He et al., the primary stability of SLA implant was higher than that of the SLActive implant system [9]. A study determining the influence of osteointegration of bone concluded that bone density and diameter affect the primary stability of implants [5]. Furthermore, no statistical difference was recorded in ISQ values in third quartiles depending upon the surface and diameter of implants. This behavior could be attributed to the dependency of implant stability on bone remodeling (osseointegration). Therefore, bone quality and remodeling interfere with bone-implant contact during osseointegration.

The authors selected homogenous bone density and quality (mainly type 2 and 3) to standardize this study's sample population. This led to a favorable ISQ result. Sam and Lang demonstrated the density of bone, implant structure and length, and position of implant placement on resonance frequency analysis and concluded that variations among ISQ values do not depend upon the measurement device's position [8]. Instead, implant length and bone structure surrounding the implant influence the ISQ values. Unfortunately, it is

not easy to control confounding factors in comparison studies due to the variation in the manufacturer's guidelines. In the studies by Sim and Lang, and Shim *et al.,*2023, the variations in ISQ values for implants with lengths of 10mm-13mm were significantly different only at the time of the surgery [1,27].

Ostmann *et al.,*[28] underscore the significance of implant surface characteristics in determining biological responses. They hypothesized that novel surface textures, particularly those incorporating nanoscale calcium phosphate, exhibit enhanced early osseointegration and morphometric bone formation, as evidenced in preclinical and clinical studies [28]. However, the authors suggest that the clear cost-benefit advantage of these surfaces is most apparent when immediate loading protocols are employed. The current study's clinical implications align with this suggestion, revealing that implants with diverse surface properties can achieve comparable levels of implant-bone interface stability, notwithstanding slight yet noteworthy disparities in ISQ values. Consequently, when single-sitting prosthetic rehabilitation via immediate loading is not imperative, clinicians should prioritize patient-specific considerations and surgical expertise over evaluating available implant surface modifications [5,20].

Novellino *et al.,*[29] advocate for the superior osseointegration capacity of hydrophilic surface implants compared to those treated with sandblasting and acid etching techniques. Their research demonstrates a notable 2.25 times increase in Implant Stability Quotient (ISQ) for hydrophilic implants [29]. However, this prospective clinical study investigation reveals contrasting results. Specifically, implants with 3i, Straumann (sandblasted Al2O3 cored and acid-etched), and Astra (chemically treated sandblasted and acid-etched surfaces with hydrophilic properties) surfaces exhibit heightened biological activity compared to Nobel implant (double acid-etched) surface implants by the end of 6 months evaluation period. Additionally, Straumann and Astra surfaces significantly outperform Nobel and 3i implant surfaces ($P<0.05$). Gupta and Padmanabhan [30] suggested that mechanical factors including local bone quality and quantity, implant type, surgical techniques, and installation procedures, influence primary implant stability. They emphasize implementing simple, clinically feasible, noninvasive methods for assessing implant stability and osseointegration [30]. Hence, the clinical utility of Resonance Frequency Analysis (RFA) is advocated for evaluating implant suitability for immediate loading protocols (ISQ ≥70), determining biological prognosis, and monitoring long-term implant behavior.

The secondary stability of an implant depends on bone remodeling and implant adaptation. In the study's third quartile, the ISQ was increased and constant among all four implants. This finding aligns with several studies that have evaluated implant stability and success. The ISQ values changes indicate the bone-implant interface changes during osseointegration. The research suggests that Straumann implants are more stable than the other three implants in this study. Oates *et al.,* measured a significant increase in implant stability in four weeks post-surgery; however, due to less study time, it failed to demonstrate the failure rates [15].

The present study showed significant bone loss with Astra and 3i dental implant systems inserted using conventional techniques. It could be explained by the fact that the activation of osteoclasts directly influences bone microdamage. In addition, the conventional method is believed to put pressure on the cortical bone, leading to peri-implantitis and bone loss. After six months postoperatively, a minimum of 0.89 and 3mm mean bone loss was observed with both implants. Striezel et al., in their radiographical study, observed a bone loss of 0.8mm for the conventional technique after five months. In the current study, there was no significant bone loss among all four groups of implants [31]. It could be related to complete bone regeneration after six months. As described earlier, bone remodeling requires a minimum of 3 months to repair the micro-damage [10,18,21]. In the current study, all the implants achieved osteointegration. Thus, although there was a difference in the primary stability of different implant systems, it is of no clinical relevance after six months. Moreover, monitoring the transition from mechanical to biological stability will allow the clinician to understand the process of osseointegration for primary implant stability.

There are various limitations to this study. Firstly, the clinician's perception was utilized to measure the success rate of the implant. Secondly, the primary stability of implants was measured only by one method, osstell; the result could have varied if another method had been used. Finally, confounding factors were not considered, which could also have influenced the outcome of the study, mainly the failure rates. However, the study's strength is in comparing the effect of primary stability on the process of osteointegration of the four most utilized implant systems. Furthermore, more studies are required with large sample sizes and different clinical settings to support the findings of this study.

CONCLUSION

Within the limitations of this study, it could be concluded that there is no effect of primary stability on the process of osseointegration and long-term survival rates of implant systems. The Osstell mentor demonstrated the success and failure of all four implants; Straumann and Astra implant systems showed a 100% success rate compared to Nobel and 3i implants. However, more clinical studies are required to demonstrate the role of primary stability on ths process of osseointegration.

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Conflict of Interest: None

REFERENCES

1. Shim, J.S.; Kim, M.Y.; An, S.J.; Kang, E.S.; Choi, Y.S. Evaluation of Implant Stability According to Implant Placement Site and Duration in Elderly Patients: A Prospective Multi-Center Cohort Study. *J Clin Med* **2023**, *12*, doi:10.3390/jcm12155087.
2. Wu, H.C.; Huang, H.L.; Fuh, L.J.; Tsai, M.T.; Hsu, J.T. Influence of implant length and insertion depth on primary stability of short dental implants: An in vitro study of a novel mandibular artificial bone model. *J Dent Sci* **2024**, *19*, 139-147, doi:10.1016/j.jds.2023.05.019.
3. Okuhama, Y.; Nagata, K.; Kim, H.; Tsuruoka, H.; Atsumi, M.; Kawana, H. Validation of an implant stability measurement device using the percussion response: a clinical research study. *BMC Oral Health* **2022**, *22*, 286, doi:10.1186/s12903-022-02320-0.
4. Semenzin Rodrigues, A.; de Moraes Melo Neto, C.L.; Santos Januzzi, M.; Dos Santos, D.M.; Goiato, M.C. Correlation between Periotest value and implant stability quotient: a systematic review. *Biomed Tech (Berl)* **2024**, *69*, 1-10, doi:10.1515/bmt-2023-0194.
5. Fouda, K.; Fahmy, A.; Aziz, K.; Aal, M.A.; Naguib, A.; Nabi, N.A. Implant Stability Changes for a Single Implant Mandibular Overdenture. *Eur J Dent* **2022**, *16*, 619-626, doi:10.1055/s-0041-1736416.
6. Lee, H.N.; Kim, M.S.; Lee, J.Y.; Zihan, X.; Ryu, J.J.; Shim, J.S. Reliability of implant stability measuring devices depending on various clinical conditions: an in vitro study. *J Adv Prosthodont* **2023**, *15*, 126-135, doi:10.4047/jap.2023.15.3.126.
7. Naves, M.M.; Menezes, H.H.; Magalhães, D.; Ferreira, J.A.; Ribeiro, S.F.; de Mello, J.D.; Costa, H.L. Effect of Macrogeometry on the Surface Topography of Dental Implants. *Int J Oral Maxillofac Implants* **2015**, *30*, 789-799, doi:10.11607/jomi.3934.
8. Salah, A.; Foda, K.; Abdalla, M.F.; Aal, M.A.; Naguib, A.; Nabi, N.A. Implant Stability Changes for Nonsubmerged and Submerged Protocols for a Single Implant Mandibular Overdenture Using Ball Attachment. *Int J Dent* **2021**, *2021*, 8269197, doi:10.1155/2021/8269197.
9. He, W.; Andersson, M.; de Souza, P.P.; de Souza Costa, C.A.; Muñoz, E.M.; Schwartz-Filho, H.O.; Hayashi, M.; Hemdal, A.; Fredel, A.; Wennerberg, A.; *et al.*,Osteogenesis-inducing calcium phosphate nanoparticle precursors applied to titanium surfaces. *Biomed Mater* **2013**, *8*, 035007, doi:10.1088/1748-6041/8/3/035007.
10. Huwais, S.; Meyer, E.G. A Novel Osseous Densification Approach in Implant Osteotomy Preparation to Increase Biomechanical Primary Stability, Bone Mineral Density, and Bone-to-Implant Contact. *Int J Oral Maxillofac Implants* **2017**, *32*, 27-36, doi:10.11607/jomi.4817.
11. Lim, H.K.; Lee, S.J.; Jeong, Y.; Lee, J.S.; Ryu, J.J.; Shim, J.S.; Song, I.S. Clinical Validation of Dental Implant Stability by Newly Designed Damping Capacity Assessment Device during the Healing Period. *Medicina (Kaunas)* **2022**, *58*, doi:10.3390/medicina58111570.
12. MA, A.A.; El Far, M.; Sheta, N.M.; Fayyad, A.; El Desouky, E.; Nabi, N.A.; Ibrahim, M. Correlation of Implant Stability Between Two Noninvasive Methods Using Submerged and Nonsubmerged Healing Protocols: A Randomized Clinical Trial. *J Oral Implantol* **2020**, *46*, 571-579, doi:10.1563/aaid-joi-D-19-00130.
13. Mazzo, C.R.; Reis, A.C.; Shimano, A.C.; Valente, M.L. In vitro analysis of the influence of surface treatment of dental implants on primary stability. *Braz Oral Res* **2012**, *26*, 313-317, doi:10.1590/s1806-83242012005000006.
14. Makowiecki, A.; Hadzik, J.; Błaszczyszyn, A.; Gedrange, T.; Dominiak, M. An evaluation of superhydrophilic surfaces of dental implants - a systematic review and meta-analysis. *BMC Oral Health* **2019**, *19*, 79, doi:10.1186/s12903-019-0767-8.
15. Oates, T.W.; Valderrama, P.; Bischof, M.; Nedir, R.; Jones, A.; Simpson, J.; Toutenburg, H.; Cochran, D.L. Enhanced implant stability with a chemically modified SLA surface: a randomized pilot study. *Int J Oral Maxillofac Implants* **2007**, *22*, 755-760.
16. Ohta, K.; Takechi, M.; Minami, M.; Shigeishi, H.; Hiraoka, M.; Nishimura, M.; Kamata, N. Influence of factors related to implant stability detected by wireless resonance frequency analysis device. *J Oral Rehabil* **2010**, *37*, 131-137, doi:10.1111/j.1365-2842.2009.02032.x.
17. Sarfaraz, H.; Johri, S.; Sucheta, P.; Rao, S. Study to assess the relationship between insertion torque value and implant stability quotient and its influence on timing of functional implant loading. *J Indian Prosthodont Soc* **2018**, *18*, 139-146, doi:10.4103/jips.jips_203_17.
18. Buser, D.; Broggini, N.; Wieland, M.; Schenk, R.K.; Denzer, A.J.; Cochran, D.L.; Hoffmann, B.; Lussi, A.; Steinemann, S.G. Enhanced bone apposition to a chemically modified SLA titanium surface. *J Dent Res* **2004**, *83*, 529-533, doi:10.1177/154405910408300704.
19. Elias, L.S.; Costa, R.F.; Carvalho, M.A.; Batista, A.C.; Silva, T.A.; Leles, C.R.; Mendonça, E.F. Markers of bone remodeling in neoplastic and bone-related lesions. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* **2010**, *110*, 624-631, doi:10.1016/j.tripleo.2010.06.014.
20. Geckili, O.; Bilhan, H.; Bilgin, T. A 24-week prospective study comparing the stability of titanium dioxide grit-blasted dental implants with and without fluoride treatment. *Int J Oral Maxillofac Implants* **2009**, *24*, 684-688.

21. de Jonge, L.T.; Leeuwenburgh, S.C.; van den Beucken, J.J.; te Riet, J.; Daamen, W.F.; Wolke, J.G.; Scharnweber, D.; Jansen, J.A. The osteogenic effect of electrosprayed nanoscale collagen/calcium phosphate coatings on titanium. *Biomaterials* **2010**, *31*, 2461-2469, doi:10.1016/j.biomaterials.2009.11.114.
22. Fröjd, V.; Wennerberg, A.; Franke Stenport, V. Importance of Ca(2+) modifications for osseointegration of smooth and moderately rough anodized titanium implants - a removal torque and histological evaluation in rabbit. *Clin Implant Dent Relat Res* **2012**, *14*, 737-745, doi:10.1111/j.1708-8208.2010.00315.x.
23. Andreotti, A.M.; Goiato, M.C.; Nobrega, A.S.; Freitas da Silva, E.V.; Filho, H.G.; Pellizzer, E.P.; Micheline Dos Santos, D. Relationship Between Implant Stability Measurements Obtained by Two Different Devices: A Systematic Review. *J Periodontol* **2017**, *88*, 281-288, doi:10.1902/jop.2016.160436.
24. Meredith, N.; Alleyne, D.; Cawley, P. Quantitative determination of the stability of the implant-tissue interface using resonance frequency analysis. *Clin Oral Implants Res* **1996**, *7*, 261-267, doi:10.1034/j.1600-0501.1996.070308.x.
25. Johansson, P. Assessment of bone quality from cutting resistance during implant surgery. *Int J Oral Maxillofac Implants* **1994**, *9*, 279-288.
26. Lekholm, U. Patient selection and preparation. *Tissue integrated prothesis* **1985**, 199-209.
27. Sim, C.P.; Lang, N.P. Factors influencing resonance frequency analysis assessed by Osstell mentor during implant tissue integration: I. Instrument positioning, bone structure, implant length. *Clin Oral Implants Res* **2010**, *21*, 598-604, doi:10.1111/j.1600-0501.2009.01878.x.
28. Ostman, P.O.; Wennerberg, A.; Albrektsson, T. Immediate occlusal loading of NanoTite PREVAIL implants: a prospective 1-year clinical and radiographic study. *Clin Implant Dent Relat Res* **2010**, *12*, 39-47, doi:10.1111/j.1708-8208.2008.00128.x.
29. Novellino, M.M.; Sesma, N.; Zanardi, P.R.; Laganá, D.C. Resonance frequency analysis of dental implants placed at the posterior maxilla varying the surface treatment only: A randomized clinical trial. *Clin Implant Dent Relat Res* **2017**, *19*, 770-775, doi:10.1111/cid.12510.
30. Gupta, R.K.; Padmanabhan, T.V. Resonance frequency analysis. *Indian J Dent Res* **2011**, *22*, 567-573, doi:10.4103/0970-9290.90300.
31. Strietzel, F.P.; Karmon, B.; Lorean, A.; Fischer, P.P. Implant-prosthetic rehabilitation of the edentulous maxilla and mandible with immediately loaded implants: preliminary data from a retrospective study, considering time of implantation. *Int J Oral Maxillofac Implants* **2011**, *26*, 139-147.