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Primary Stability of Dental Implants: A Comparative Evaluation of Five Implant Systems Using Insertion Torque and Resonance Frequency Analysis

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Primary stability is a critical indicator of successful osseointegration in dental implants. Despite the variety of dental implants available with different designs, their impact on primary stability remains unclear. The objective of this study was to evaluate and compare the primary stability of five different implant systems using two methods: insertion torque (IT) and resonance frequency analysis (RFA).

Twenty implants, each with unique designs from five different systems, were evaluated and divided into Groups A to E. Five Styrofoam polyurethane resin

models were used to simulate B2 bone quality, with implants motor-driven into prepared osteotomy sites. The IT values were recorded, and the implant stability quotient (ISQ) was measured using a magnetic resonance frequency analyzer.
The data were statistically analyzed. The mean IT values were highest in Groups A and E, demonstrating a statistically significant difference ($p < 0.05$) from Groups B to D. However, no significant differences were observed in ISQ values across the groups. Additionally, Pearson correlation coefficient testing revealed an insignificant correlation between IT and ISQ values.
These findings suggest that tapered, self-tapping implants may be particularly suitable for use in higher-density bone due to their enhanced primary stability.
Keywords: Primary stability, tapered implants, screw threads, self-tapping, insertion torque, implant design.

1. Introduction

Osseointegrated dental implants have emerged as a predictable treatment option for rehabilitating partially and completely edentulous patients. The Branemark protocol favored a prolonged healing period to promote bone growth around dental implants. According to this protocol, premature loading of the implant soon after surgery creates micromotion, which could lead to fibrous tissue formation around the implant, ultimately resulting in implant loss. However, studies suggest that a tolerable range of micromotion exists—typically between 50-150 µm—and this range is suitable for immediate loading protocols, potentially varying according to implant design and surface topography [1].

An important aspect of the success of early or immediately loaded dental implants is the primary stability achieved in the bone at the time of implant placement [2]. Primary stability can be defined as the mechanical stability achieved immediately after implant insertion, serving as a critical prognostic factor for osseointegration [3,4]. Higher primary stability reduces micromotion between the implant and the bone, creating favorable conditions for undisturbed peri-implant bone healing [5].

The three main factors contributing to primary stability are implant design (including geometry, length, diameter, and surface characteristics), surgical technique, and the bone quality of the recipient site. Implants are available in various geometries, such as cylindrical, conical, screw-shaped, and stepped hollow cylindrical designs. Screw-threaded implants are particularly favored due to their proven success and strong initial retention. The most common thread configurations include V-shaped, thin thread, reverse buttress, and square thread. Thread pitch, depth, and height also influence the primary stability of implants [6]. However, the correlation between primary stability and implant geometry remains a subject of debate [7].

Understanding the primary stability of different implant designs would assist in making informed decisions about implant selection in poor bone quality or immediate load scenarios. Several clinical methods are available to evaluate implant stability, including the Clinical Percussion Test, Reverse Torque Test, Cutting Torque, Periotest, and Resonance Frequency Analysis (RFA). Among these, the final torque value at placement is often the preferred clinical parameter for measuring immediate load [3]. The Magnetic Resonance Frequency Analyzer (RFA) assesses implant stability using the Implant Stability Quotient (ISQ), a scale ranging from 1 to 100.

Gaurag Mistry, Omkar Shetty, et al., in their review, concluded that further research is needed to develop more accurate instruments for gauging implant stability [8]. Similarly, Vidya (2018) reported a lack of precise information correlating ISQ values with short- and long-term implant outcomes [9].

The aim of the present study was to evaluate the influence of implant design on the primary stability of different implant systems by measuring insertion torque values and resonance frequency values. Additionally, the study aimed to explore the correlation between insertion torque and ISQ values across different implant systems. The null hypothesis was that different implant systems with varying geometrical features would have no significant influence on primary stability.

2. MATERIAL AND METHODS

Five Styrofoam polyurethane resin models (Sawbones, Pacific Research Laboratory Inc., Vashon, Washington) were used to simulate D2 bone quality. These models resembled the base of a dental cast, with a surface area of 23.45 cm^2 and a thickness of 28 mm.

Implants with varying surface geometries from five different implant systems were utilized in the study. The implants were categorized into five groups: Group A (NobelBiocare Active), Group B (NobelBiocare Tapered Groovy; Nobel Biocare AB, Gothenburg, Sweden), Group C (Implant for Classical Esthetics [ICE], Alpha-Biocare, Zurich, Switzerland), Group D (MIS, Biocom, San Diego, California, USA), and Group E (Toureg, ADIN Dental Implant Systems, Northern Israel). Each group consisted of four implants, yielding a total of twenty implants for the study [Figure 1,2].

All the implants used had a uniform length of 13 mm. The internal diameters were 4.3 mm for Groups A and B, and 4.2 mm for Groups C, D, and E.

The implant placement sites were marked on the models at equal distances of 10 mm from the periphery. To ensure parallel implant placement, osteotomies were performed using an implant micromotor handpiece connected to a surveyor (Figure 1). The Styrofoam polyurethane models were secured on a surveying table, and the osteotomies were sequentially prepared using a Physiodispenser (RTC Systemi SNC, Italy-Toscana) with a 20:1 gear reduction handpiece attached to the surveyor (Ney Surveyor) [Figure 3,4].

Figure 1: Implant Osteotomy Preparation using Handpiece connected to Surveyor

Figure 2: Insertion Torque Value measurement

Figure 3: Smart Peg Connected to Implant

Figure 4: ISQ Value Measurement Using the Ostell Device

Implant Osteotomy Sequence

For the Nobel Biocare Active system, osteotomies were performed in the following sequence: 2 mm, 2.4/2.8 mm, 2.8/3.2 mm, and 3.2/3.6 mm. For the Nobel Biocare Tapered Groovy system, the sequence was 2 mm, 3.5 mm, and 4.3 mm. The Alpha Biocare ICE system followed a sequence of 2 mm, 2.8 mm, and 3.6 mm, while the MIS–Biocom system used a sequence of 2 mm, 2.8 mm, 3.2 mm, and 3.8 mm. Lastly, for the Adin Touareg system, the osteotomy sequence was 2 mm, 2.8 mm, 3.2 mm, and 3.6 mm.

Insertion Torque Analysis

After completing the osteotomies, each implant was motor-driven into place at 100 rpm (Figure 2). The implant placement began with an initial insertion torque of 20 Ncm, which was incrementally increased by 5 Ncm until the implant was fully inserted. The final insertion torque values for each implant were recorded in Ncm.

Resonance Frequency Analysis (RFA)

For the second method, magnetic resonance frequency analysis (RFA) was used, employing a non-invasive device (Osstell Device, Integration Diagnostics AB, Gothenburg, Sweden). A Smartpeg transducer, specifically designed for each implant system, was attached to the implant body. A magnetic pulse from the measurement probe of the handheld instrument excited the Smartpeg. The resulting Hertz wave from the RFA measurements was converted into numerical values on a scale of 1 to 100, called the Implant Stability Quotient (ISQ).

After implant placement, the corresponding Smartpeg was connected (Figure 3) to the implant body. Measurements were taken at a distance of 2-3 mm, with the probe tip pointing toward the small magnet on the Smartpeg. To ensure reproducibility, measurements were taken three times in both mesiodistal and buccolingual directions (Figure 4). Four ISQ values were recorded for each implant system, and the mean value was used for statistical analysis.

Statistical Analysis

Statistical analysis of insertion torque and RFA was conducted using a one-way ANOVA test, followed by the LSD Post-Hoc Multiple Comparison Test. The correlation between insertion torque and mesiodistal and buccolingual ISQ values was analyzed using Pearson's correlation coefficient.

3. Results

Insertion Torque Values (IT)

The maximum insertion torque (IT) values obtained for the 20 implants were tabulated. Table 1 displays the mean and standard deviation (SD) values of the maximum insertion torque for the five implant systems. The mean values were highest in the Nobel Biocare Active group (Group A) and the ADIN group (Group E), indicating higher primary stability in these systems.

Table 1: Mean and Standard DeviationD of of maximum Insertion torque values (Ncm)

S.No	IMPLANT SYSTEM	N	MEAN (Ncm)	SD	ANOVA	
					F	P
1	Nobel Bio care Active(A)	4	48.75	2.5	4.69	0.012
2	Nobel Bio care Tapered Groovy (B)	4	41.25	2.5		
3	Alpha Biocare (C)	4	43.45	2.5		
4	MIS –Biocom (D)	4	43.75	4.7		
5	ADIN –Touareg (E)	4	48.75	2.5		
	TOTAL	20	45.25	4.2		

A one-way ANOVA test (Table 1) revealed a statistically significant difference in the IT values among the five implant systems ($p = 0.012$; $p < 0.05$). However, the LSD Post-hoc test (Table 2) showed no significant differences in insertion torque values between Groups A and E, Groups B and C, Groups B and D, and Groups C and D.

Table2: Mean LSD Post-hoc multiple comparison test result for Insertion torque (Ncm) values

MEAN (I)	MEAN(I)	׀MEAN DIFFERENCE׀	P-VALUE
A	B C D E	7.50 5.0 5.0 0.0	0.004 0.037 0.037 1
B	C D E	2.5 2.5 7.5	0.271 0.271 0.004
C	D E	0.00 5.00	1.0 0.037
D	E	5.0	0.037

Resonance Frequency Analysis (RFA)

Resonance frequency analysis (RFA) was performed for the 20 implants. Table 3 presents the mean and standard deviation of the RFA-Implant Stability Quotient (ISQ) values in the mesio-distal direction for the five different implant systems. The RFA mean values across the five implant systems showed minimal variation.

A one-way ANOVA and LSD Post-Hoc test were used to compare the mean RFA values among the different implant systems. The p-value for RFA in the mesio-distal direction was 0.608, indicating that the differences among the implant systems were not statistically significant.

Table -3: Mean of ISQ values in Mesio-distal direction

SL.NO	IMPLANT SYSTEM	N	MEAN (ISQ)	SD		
					F	P
1	NobelBiocare Active (A)	4	78	3.6		
2	NobelBiocare Tapered Groovy (B)	4	75	1.4		
3	AlphaBiocare (C)	4	74.7	4.3		
4	MIS –Biocom (D)	4	75.7	3.3	0.694	0.608
5	ADIN –Touareg (E)	4	76	1.25		
	TOTAL	20	75.9	3.0		

Table-4: Mean of ISQ values in Bucco-lingual direction

SL.NO	IMPLANT SYSTEM	N	MEAN (ISQ)	SD	ANOVA TEST	
					F	P
1	NobelBiocare Active (A)	4	77	2.5		
2	NobelBiocare Tapered Groovy (B)	4	74.5	1.7		
3	AlphaBiocare (C)	4	77	1.4		
4	MIS –Biocom (D)	4	77.2	3.3		
5	ADIN –Touareg (E)	4	75.5	0.57	1.154	0.370
	TOTAL	20	76.2	2.2		

Table-4 shows the mean and standard deviation of RFA-ISQ from bucco-lingual direction of implants. From One way ANOVA test and LSD Post-hoc test obtained P value is 0.370 against a significant p value of < 0.05, hence the difference is not significant.

Pearson correlation coefficient(r) between MD and BL resonance frequency analysis (RFA) and maximum insertion torque (IT) Table-5 showed the relationship between mesial and buccal direction of implant resonance frequency analysis and insertion torque. The significant correlation between mesiodistal and Bucco-lingual ISQ infers that whenever the ISQ level increase in mesiodistal direction, the ISQ level increase in Bucco-lingual direction of implant and vice versa.

Table-5: Pearson correlation coefficient(r) between MD and BL ISQ values and Maximum insertion torque (IT) Values.

RFA	BUCCOLINGUAL	IT
MESIO-DISTAL	0.528^{*}	0.320
BUCCO-LINGUAL	--	0.443

The insignificant correlation coefficient between insertion torque and mesiodistal and Bucco lingual (0.320, 0.443 repectively against significant p value of < 0.05) direction of implants infers there are no statistical relationship between insertion torque and mesio-distal and Buccal direction RFA values.

4. Discussion

Smoking and vaping both adversely affect dental implant success rates by impairing healing and blood flow due to nicotine, increasing infection risk, and compromising bone health. Smoking exacerbates these risks further through reduced bone density and dry mouth, while vaping, though less harmful, still poses risks due to nicotine's effects [9].

The findings of this study indicate that implant geometry significantly influences primary stability. Literature suggests that implants with insertion torque values greater than 32 Ncm are associated with successful outcomes [10,11,12]. All implants in this study achieved insertion torque values exceeding 40 Ncm. Statistically significant differences in torque values were observed between implant systems. The highest insertion torque values were recorded for the Nobel Biocare Active and ADIN groups, with values of 48.75 Ncm. This high primary stability can be attributed to their tapered implant bodies with self-tapping capabilities and narrow implant collar diameters. The only difference between these two implants was the thread type. While thread design may not directly affect osseointegration, bone-implant contact (BIC), or stress distribution, it can influence the speed of implant insertion. Self-tapping implants, often designed with vertical cutting blades in the apical third, compress the bone during insertion, potentially increasing primary stability. The tapered design with spiral flutes of the Group A and E implants also contributed to superior initial stability compared to non-fluted designs. This finding aligns with Shu-Wei Wu et al.'s study, which showed that tapered implants with flutes exhibited higher initial stability [13].

Conversely, the primary stability of Nobel Biocare Tapered Groovy (Group B) was lower compared to Groups A and E. These implants, with tapered bodies and round end apices, utilized less of the apical bone for stability. The Alpha Biocare ICE (Group C) implants, lacking self-tapping capabilities and featuring a double lead thread design, had the lowest insertion torque, indicating minimal primary stability. This result concurs with findings by Vladimir Kokovic et al. [14], suggesting these implants are better suited for low-density bone.

In contrast to studies comparing self-tapping and non-self-tapping implants, which found higher primary stability in non-self-tapping implants [3,15], this study found self-tapping implants to offer greater primary stability. The higher stability of non-self-tapping implants in Annette Rabel's study may be attributed to design features such as a progressive thread design and conical fit, which enhance frictional forces.

The MIS Implants (Group D), with a cylindrical body, domed apex, and acid-etched, sandblasted surface, had an average primary stability of 43.75 Ncm, which was lower than the 48.75 Ncm observed in Groups A and E. This result is consistent with studies by Mychelle Vianna dos Santos et al. [16], Dominic O’Sullivan et al. [7], and Shu-Wei Wu et al. [13], which suggest tapered implants provide greater frictional surface and lateral compressive stresses, contributing to higher primary stability. However, Browers et al. [17] found cylindrical implants to be more stable in dried human mandibles, a discrepancy that may be due to the dehydrated state of the bone.

This study found an insignificant correlation between insertion torque and resonance frequency analysis (RFA). Marianna Marquezan et al. [18] reported that insertion torque is often considered an indicator of primary stability. Paulo Trisi et al. [12] found that higher insertion torque reduces micromotion risk above a certain threshold, enhancing immediate implant loading success. However, the mean RFA ISQ values in mesio-distal and buccolingual directions did not reveal significant differences in primary stability among the five implant systems. Linishvidyasagar et al. [2] observed similar results, indicating that RFA values may not vary significantly in bone models of similar density. Dominic O’Sullivan et al. found that differences in implant designs are more pronounced in lower-density bone, suggesting that the polyurethane resin model used here, simulating D2 bone quality, may not exhibit significant variations in RFA values. Annette Rabel et al. [3] also concluded that RFA measurements are more predictive of implant stability when used over extended periods, rather than as single measurements. Jui-Ting Hsu et al. [20] found insertion torque to be more suitable for assessing implant stability.

To control for the effect of implant length and diameter on primary stability, this study standardized the implant size to 4.3 × 13 mm. Similar standardization was employed by Dominic O'Sullivan et al. [7], Hamidreza et al. [21], and Hamdan et al. [22]. The use of Styrofoam polyurethane resin as a study model, due to its common use in studies and difficulties with human/animal bone, provided a standardized artificial bone material [23,21,15]. Nathalia Ferraz et al. [24] found polyurethane to exhibit the highest torque and pullout resistance among artificial bone materials.

Emerging technologies such as immersive simulations and augmented reality (AR) could enhance the design, testing, and education related to implant stability. In the metaverse, dental professionals could use advanced visualization tools to simulate bone conditions, such as B2 bone quality, and virtually place implants with varying designs to observe their effects on insertion torque and resonance frequency. Such virtual environments could also facilitate interactive training on techniques to maximize primary stability in different bone types, potentially improving real-world outcomes [25,26].

5. Conclusion

Within the limitations of the present in vitro study, it was concluded that:

1. Geometric Influence: Implants with different geometrical features significantly influenced insertion torque values.

2. Tapered Self-Tapping Implants: Tapered self-tapping implants exhibited the highest insertion torque, indicating superior primary stability.

3. Implant Systems: Nobel Biocare Active and ADIN implants showed the highest primary stability values, making them suitable for use in dense bone conditions.

4. Implants for Soft Bone: Nobel Biocare Tapered Groovy had the lowest insertion torque value, suggesting it is better suited for conditions with soft bone quality.

5. Lack of Correlation: No significant correlation was found between insertion torque values and resonance frequency analysis.

It should be noted that the expansion coefficient of polyurethane resin blocks differs from that of living bone during implant placement. Consequently, the results of this study may not fully reflect clinical situation,

ABBREVIATIONS

- IT – Insertion Torque
- RFA – Resonance Frequency Analysis
- ISQ – Implant Stability Quotient

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