

Research Article

Mechanical Stability of the New Modified Tapered and Conventional Tapered Design Implants in the Anterior Maxilla. A Pilot In-Vitro Trial

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ABSTRACT

Background: Immediate implant placement in the anterior maxilla has become an increasingly used treatment approach because it may reduce the number of surgical procedures, shorten treatment time, and assist in preservation of the alveolar architecture. Achieving adequate primary stability remains essential for successful implant integration, particularly in extraction sockets where complete implant-to-bone contact may not be present. Implant macro-design, bone density, osteotomy preparation, and insertion technique can influence initial mechanical stability. However, evidence remains limited regarding the comparative performance of different tapered implant designs in simulated anterior maxillary extraction sockets.

Objective: To compare the primary mechanical stability of conventional tapered Osstem TS-III implants and new modified tapered Osstem TS-IV implants placed in simulated anterior maxillary extraction sockets at 1-mm and 2-mm subcrestal depths.

Methods: This pilot in-vitro experimental study was conducted at BPP Dental Institute using a custom-made drilling system for standardized osteotomy preparation and implant placement from March 2019 till August 2021. This study used ten standardized osteotomies prepared in polyurethane synthetic bone blocks representing D3 bone density. Five conventional tapered TS-III and five modified tapered TS-IV implants, each measuring 4.5 mm in diameter and 11.5 mm in length, were inserted using a standardized custom drilling system. Implant Stability Quotient (ISQ) values were measured using resonance frequency analysis with an Osstell ISQ device from the mesial, distal, buccal, and palatal aspects. Each measurement was repeated three times and averaged. Primary stability was evaluated at 1-mm and 2-mm subcrestal placement depths, and the two implant designs were compared using the Mann-Whitney U test.

Results: The conventional tapered TS-III implants demonstrated greater primary stability than the modified tapered TS-IV implants at both placement depths. At 1 mm, the conventional tapered implants had an overall mean ISQ of 4.60 compared with 1.00 for the modified tapered implants. ... The overall Mann-Whitney comparison at 1 mm showed higher mean ranks for TS-III than TS-IV (7.50 vs 3.50; U=2.500), while at 2 mm the corresponding mean ranks were 7.90 and 3.10 (U=0.500). The conventional implant design also generally demonstrated superior stability across the different measurement aspects.

Conclusion: Under standardized in-vitro conditions, the conventional tapered TS-III implant provided greater primary mechanical stability than the new modified tapered TS-IV implant in simulated anterior maxillary extraction sockets. A greater degree of implant taper did not necessarily translate into superior primary stability. Further experimental and clinical investigations are required to determine whether these findings are reproducible in biological bone and clinical immediate implant placement.

Keywords: Dental Implants, Primary Stability, Implant Stability Quotient, Resonance Frequency Analysis, Tapered Implants, Anterior Maxilla, Immediate Implant Placement.

INTRODUCTION

Immediate dental implant placement following tooth extraction has become an important treatment approach in contemporary implant dentistry, particularly in the aesthetically demanding anterior maxillary region. Compared with delayed implant placement, immediate placement may reduce the number of surgical interventions and overall treatment duration while contributing to preservation of the existing alveolar architecture. Nevertheless, placement of an implant into a fresh extraction socket presents important mechanical challenges because the implant may not achieve circumferential contact with the socket walls. Consequently, obtaining sufficient primary stability at the time of insertion remains one of the major considerations for successful immediate implant therapy. (1-3)

Primary stability represents the mechanical engagement of an implant with the surrounding bone at the time of placement and is considered important for subsequent biological stability and osseointegration. Inadequate initial stability may permit excessive micromotion at the implant-bone interface, potentially interfering with normal osteoblastic activity and contributing to fibrous encapsulation rather than predictable osseointegration. The degree of primary stability is influenced by several interacting factors, including bone quality and quantity, surgical preparation technique, implant dimensions, and implant macro-design (4, 5).

Implant design has therefore received considerable attention as a potentially modifiable determinant of mechanical stability. Tapered implants were developed partly to increase mechanical engagement by producing greater lateral compression of the surrounding bone during insertion. Their geometry may be particularly advantageous in lower-density bone and extraction sockets where the available bone-to-implant contact is reduced. However, findings from previous investigations have not been entirely consistent. Some experimental studies have reported greater primary stability with tapered implant designs, whereas other comparative investigations have failed to demonstrate a significant advantage. Differences in bone density, implant dimensions, drilling protocols, implant surface characteristics, and experimental models may partly explain these conflicting observations (6, 7).

Standardization is especially important when investigating the isolated effect of implant

macro-design. Natural bone demonstrates considerable variation in density and internal architecture, which may influence insertion behavior and stability measurements. Synthetic polyurethane bone blocks offer a homogeneous experimental medium and have therefore been used for mechanical implant testing when control of bone density is required. In the present experiment, D3-density polyurethane bone was selected to reproduce the relatively low-density bone environment encountered in the anterior maxilla while reducing variability associated with animal or cadaveric bone (8, 9). Resonance frequency analysis provides a non-destructive method of evaluating implant stability and expresses the measurement as an Implant Stability Quotient. It permits repeated assessment from different orientations without physically disturbing the implant. In the current experimental model, ISQ measurements were obtained from the mesial, distal, buccal, and palatal aspects to provide a broader assessment of mechanical stability. The use of standardized implant dimensions, a controlled drilling apparatus, identical synthetic bone density, and repeated ISQ measurements was intended to minimize confounding and allow implant macro-design to remain the principal variable under investigation (10, 11).

Despite numerous studies investigating implant geometry and primary stability, the available literature provides limited standardized evidence directly comparing different tapered implant designs in simulated extraction sockets of the anterior maxillary region. The newer Osstem TS-IV design has a more pronounced taper and modified apical configuration than the conventional TS-III design, but whether these macro-design modifications translate into greater primary mechanical stability under controlled immediate-placement conditions remains uncertain.

Therefore, the present pilot in-vitro experimental study was undertaken to compare the primary mechanical stability of conventional tapered Osstem TS-III and new modified tapered Osstem TS-IV implants placed in standardized simulated anterior maxillary extraction sockets using Implant Stability Quotient measurements at 1-mm and 2-mm subcrestal placement depths.

METHODOLOGY

This pilot in-vitro experimental study was conducted at BPP Dental Institute using a custom-made drilling system for standardized osteotomy preparation and implant placement

from March 2019 till August 2021. This study was carried out to compare the primary mechanical stability of two different tapered dental implant designs placed in simulated extraction sockets of the anterior maxilla. The experimental model represented the maxillary anterior region, with the new modified tapered Osstem TS-IV implant serving as the test implant and the conventional tapered Osstem TS-III implant serving as the comparison implant. The main outcome variable was primary implant stability, assessed in terms of the Implant Stability Quotient (ISQ) using resonance frequency analysis. As this investigation was conducted entirely as an in-vitro laboratory experiment using synthetic polyurethane bone blocks, no human participants, identifiable patient information or animals were involved.

Two bone-level tapered implant systems manufactured by Osstem Implant Co., Busan, Korea were used. Five TS-IV new modified tapered implants and five TS-III conventional tapered implants were included, giving a total of 10 implants. Both implant designs had the same dimensions, measuring 4.5 mm in diameter and 11.5 mm in length, in order to minimize the influence of implant size on primary stability. The principal macro-design difference was the degree of taper, with the modified TS-IV implant having a more pronounced taper of approximately 6 degrees compared with approximately 1.5 degrees for the conventional TS-III design. Other implant characteristics were kept as similar as possible so that the influence of macro-design could be assessed more directly.

Two solid polyurethane synthetic bone blocks of D3 density (PCF 10) were used as the experimental bone medium. These blocks were obtained from Sawbones, USA, and measured approximately 13 cm in width, 18 cm in length and 4 cm in depth. The use of a homogeneous synthetic medium allowed the same bone density to be maintained throughout the experiment and reduced the biological variability that would have been encountered with cadaveric or animal bone. The selected density was intended to simulate D3-type bone of the maxillary anterior region.

A custom-made drilling apparatus was used to standardize preparation of the simulated extraction sockets and implant osteotomies. The polyurethane block was fixed securely to the platform of the device so that its position remained stable throughout preparation. A Surgibone® surgical motor (Silfradent Co.,

Sofia, Italy) was connected to a handpiece, which was secured within the custom-made drilling mechanism. The device controlled the direction of handpiece movement and helped maintain a reproducible drilling path. An overlying pulley-assisted weight system was used to provide constant vertical pressure during drilling. This arrangement was intended to minimize operator-related variability in drilling force and angulation. Irrigation was not used because moisture could have acted as a lubricant in the synthetic material and potentially altered the mechanical behavior of the preparation.

Ten standardized sockets were prepared to reproduce the morphology of extraction sockets in the maxillary central incisor region. The socket design was developed using sequential Salvin trephine drills of progressively decreasing diameters. The preparation sequence included trephines with internal diameters of approximately 6.0 mm, 5.0 mm, 4.25 mm, 3.50 mm and 2.0 mm, with the depth gradually extended to approximately 9 mm. During socket preparation, drilling was performed at approximately 1200 rpm, under a 790-g pulley load and approximately 77 Ncm torque, without irrigation. After each stage, the preparation was checked to ensure that the intended socket dimensions and depth had been achieved. Each trephine drill was used once to reduce variation related to drill wear.

Following formation of the simulated sockets, osteotomy preparation for implant placement was carried out according to the protocol specified for the two Osstem implant systems. Both TS-III and TS-IV implants underwent an underprepared osteotomy, with a final drill diameter of approximately 4.2 mm, which was smaller than the 4.5-mm implant diameter. Both implant designs had self-cutting characteristics, which allowed the implants to engage the synthetic bone without requiring an additional tapping procedure. This helped remove tapping as a potential confounding variable.

Implant positioning was planned to resemble the clinical placement of an immediate implant in a maxillary anterior extraction socket. A gap was intentionally maintained between the implant and the simulated labial socket wall, while an appropriate space was also maintained on the palatal aspect. For orientation, the longer side of the polyurethane block was regarded as the labial or buccal surface, while the opposite long surface was designated as the palatal aspect. The shorter sides represented

the mesial and distal surfaces. The side closer to the drilling apparatus was labelled mesial, whereas the opposite side was labelled distal. This orientation was used consistently for all subsequent stability measurements.

The ten implants were allocated to the prepared osteotomies in an alternating manner. The new modified tapered TS-IV implants were placed in osteotomies numbered 2, 4, 6, 8 and 10, whereas the conventional tapered TS-III implants were inserted in osteotomies numbered 1, 3, 5, 7 and 9. Implant insertion was performed using the same surgical motor and custom-made placement device. The insertion protocol consisted of a motor speed of approximately 15 rpm, a pulley load of 790 g, and 30 Ncm torque, with no irrigation. The manufacturer's pilot drill was initially used to establish the intended apical position, and the implant was then attached to the handpiece using the appropriate implant adaptor before controlled insertion into the prepared osteotomy.

Primary implant stability was evaluated at two different subcrestal placement depths. Initially, the implants were positioned 1 mm below the level of the simulated alveolar crest, and the stability measurements were recorded. The implants were subsequently evaluated at 2 mm below the crest to determine whether greater submergence altered the mechanical stability of either design. The same experimental conditions and measurement approach were maintained for both depths to permit direct comparison between the implant systems.

The primary outcome was assessed using resonance frequency analysis (RFA) with an Osstell ISQ® device (Osstell/Integration Diagnostics, Göteborg, Sweden). A compatible SmartPeg was attached to each implant before measurement. Ten new SmartPegs were used in the experiment so that a separate compatible component was available for each implant. During measurement, the Osstell probe was positioned approximately 2–3 mm from the SmartPeg, and the ISQ value was recorded after activation of the device.

For each implant, stability readings were obtained from four aspects: mesial, distal, buccal and palatal. Each reading at every aspect was repeated three times, and the average of the repeated readings was recorded for analysis. This repeated-measurement approach was used to improve consistency and reduce the effect of any single measurement variation. The same measurement protocol was used for both implant types and at both the 1-mm and 2-mm placement depths.

Several standardization measures were incorporated to reduce experimental bias and isolate implant design as the main variable under investigation. Both implant groups had the same implant diameter and length, were inserted into the same type of D3 synthetic bone medium, underwent comparable osteotomy preparation, and were placed using the same surgical kit and controlled drilling apparatus. The use of a custom drilling system also helped maintain constant angulation and drilling force, while the same insertion settings were used for all implants. These measures were intended to minimize the potential effects of bone density, implant dimensions, osteotomy preparation and operator variability on the final ISQ measurements.

The recorded data were entered into SPSS for statistical analysis. Descriptive statistics were generated to summarize the ISQ values for the conventional tapered and modified tapered implant groups at the two placement depths and at the different measurement aspects. The thesis reported that the experimental data were not equally distributed; therefore, an independent-samples parametric t-test was not considered appropriate. The Mann–Whitney U test was consequently applied to compare primary stability between the two implant designs. Overall comparisons as well as mesial, distal, buccal and palatal comparisons were performed for implants positioned at 1 mm and 2 mm below the crest. A p-value <0.05 was considered statistically significant.

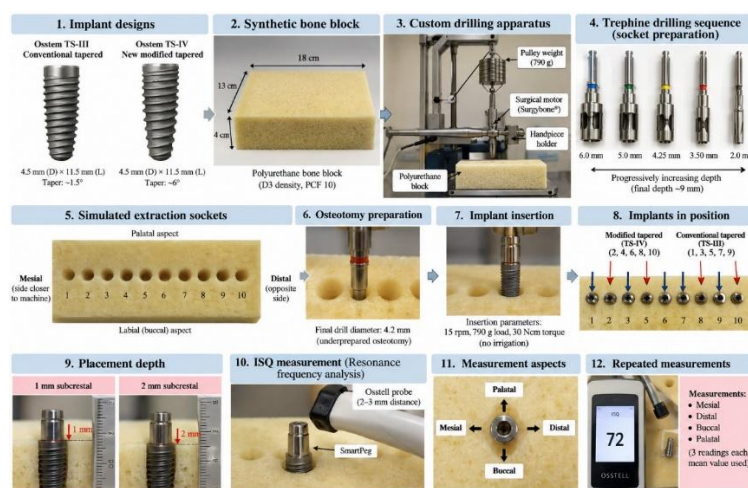


Figure 1. Schematic Representation of the In-Vitro Experimental Methodology for Comparison of Primary Stability between Conventional Tapered Osstem TS-III and New Modified Tapered Osstem TS-IV Implants. The Figure Illustrates Implant Designs, D3 Polyurethane Bone Block Preparation, Standardized Drilling And Osteotomy Protocol, Implant Insertion, 1-Mm And 2-Mm Subcrestal Placement Depths, Resonance Frequency Analysis Using The Osstell ISQ Device, Four-Directional Measurements (Mesial, Distal, Buccal And Palatal), And Triplicate ISQ Recordings At Each Measurement Site.

RESULTS

The data indicate that conventional tapered implants generally achieved higher ISQ values,

with values ranging from 1–10 at 1 mm and 10–28 at 2 mm, whereas the modified tapered design showed substantially lower values.

Table 1. Overall Descriptive Statistics of Implant Stability According To Implant Design and Placement Depth

Placement depth	Implant design	n	Mean ISQ	Median ISQ	SD	Minimum	Maximum
1 mm submerged	Conventional tapered (TS-III)	5	4.60	3.00	3.78	1.00	10.00
	Modified tapered (TS-IV)	5	1.00	1.00	0.00	1.00	1.00
2 mm submerged	Conventional tapered (TS-III)	5	20.35	21.50	6.57	9.25	26.50
	Modified tapered (TS-IV)	5	4.40	3.00	3.97	1.00	10.00

Abbreviations: ISQ, Implant Stability Quotient; SD, standard deviation.

The descriptive analysis confirms substantially greater overall primary stability for the conventional tapered implant at both insertion

depths. At 1 mm, the conventional design had a mean ISQ of 4.60 compared with 1.00 for the modified design.

Table 2. Overall Comparison of ISQ Values between Conventional and Modified Tapered Implants

Placement depth	Conventional TS-III mean rank	Modified TS-IV mean rank	Mann–Whitney U	Z	Asymptotic p-value	Exact p-value
1 mm submerged	7.50	3.50	2.500	−2.353	0.019	0.032
2 mm submerged	7.90	3.10	0.500	−2.530	0.011	0.008

The conventional tapered implant demonstrated significantly higher overall stability than the modified tapered implant at both depths. At 1 mm the mean ranks were

7.50 versus 3.50, respectively, with a Mann–Whitney U value of 2.500. At 2 mm, the corresponding mean ranks were 7.90 and 3.10, with U=0.500.

Table 3. Site-Specific Descriptive ISQ Values at 1-Mm Subcrestal Implant Placement

Measurement aspect	Implant design	n	Mean ISQ	Median	SD	Minimum	Maximum
Mesial/distal	Conventional tapered (TS-III)	5	4.80	3.00	3.63	1.00	10.00
	Modified tapered (TS-IV)	5	1.00	1.00	0.00	1.00	1.00
Buccal/palatal	Conventional tapered (TS-III)	5	4.40	3.00	3.97	1.00	10.00
	Modified tapered (TS-IV)	5	1.00	1.00	0.00	1.00	1.00

At 1-mm subcrestal placement, the mesial/distal mean ISQ of the conventional tapered implant was slightly higher than its buccal/palatal value. In contrast, the modified implant demonstrated a uniform mean ISQ of 1.00 across the evaluated aspects. The thesis

reports a mean ISQ of 4.80 for the conventional design versus 1.00 for the modified design for the mesial/distal assessment. The corresponding buccal/palatal means were 4.40 and 1.00.

Table 4. Site-Specific Descriptive ISQ Values at 2-Mm Subcrestal Implant Placement

Measurement aspect	Implant design	n	Mean ISQ	Median	SD	Minimum	Maximum
Mesial	Conventional tapered (TS-III)	5	19.20	22.00	7.05	7.00	25.00
	Modified tapered (TS-IV)	5	4.40	3.00	3.97	1.00	10.00
Distal	Conventional tapered (TS-III)	5	19.40	20.00	5.64	10.00	25.00
	Modified tapered (TS-IV)	5	4.40	3.00	3.97	1.00	10.00
Buccal/palatal	Conventional tapered (TS-III)	5	21.40	22.00	6.84	10.00	28.00
	Modified tapered (TS-IV)	5	4.40	3.00	3.97	1.00	10.00

At 2-mm subcrestal placement, the conventional tapered implant showed its highest mean stability in the buccal/palatal aspect (21.40), followed by distal (19.40) and

mesial (19.20) measurements. The modified tapered implant demonstrated a mean ISQ of 4.40 across the corresponding assessments.

Table 5. Merged Mann–Whitney U Analysis of Implant Stability According To Measurement Aspect and Depth

Depth	Measurement	TS-III mean rank	TS-IV mean rank	Mann–Whitney U	Z	Asymptotic p	Exact p
1 mm	Overall	7.50	3.50	2.500	−2.353	0.019	0.032
1 mm	Mesial/distal	7.50	3.50	2.500	−2.362	0.018	0.032
1 mm	Buccal/palatal	7.00	4.00	5.000	−1.928	0.054	0.151
2 mm	Overall	7.90	3.10	0.500	−2.530	0.011	0.008
2 mm	Mesial	7.90	3.10	0.500	−2.530	0.011	0.008
2 mm	Distal	7.90	3.10	0.500	−2.530	0.011	0.008
2 mm	Buccal/palatal	7.90	3.10	0.500	−2.530	0.011	0.008

Bold p-values indicate statistical significance at $p < 0.05$.

The mesial/distal comparison at 1 mm favored the conventional tapered implant, whereas the

buccal/palatal comparison did not reach the conventional 0.05 significance threshold

despite the higher rank observed with TS-III. The thesis reports mean ranks of 7.00 and 4.00 for the 1-mm buccal/palatal comparison. At 2

mm, the conventional design consistently produced higher ranks across the evaluated aspects.

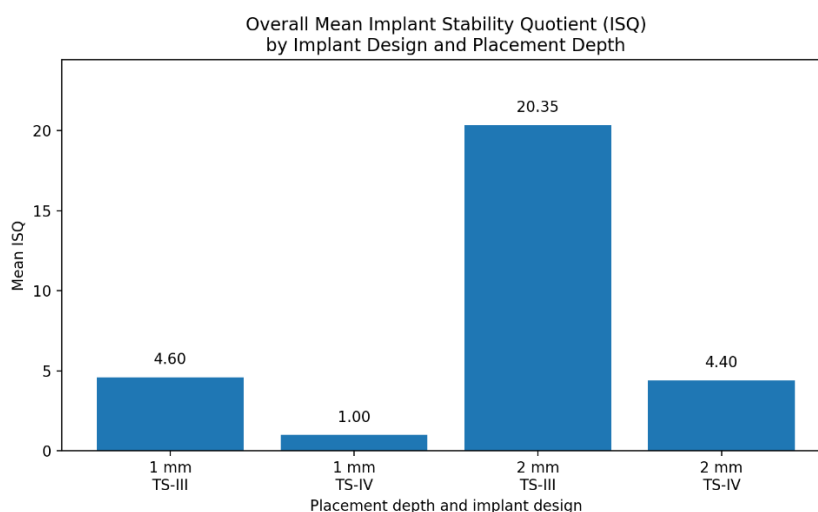


Figure 2. Overall Mean Implant Stability Quotient (ISQ) By Implant Design and Placement Depth. The Conventional Tapered Implant (TS-III) Showed Higher Mean ISQ Values Than the Modified Tapered Implant (TS-IV) At Both 1 Mm and 2 Mm Submerged Placement Depths.

DISCUSSION

The present in-vitro experimental study compared the primary mechanical stability of conventional tapered Osstem TS-III implants with new modified tapered Osstem TS-IV implants placed in simulated anterior maxillary extraction sockets. The main finding was that the conventional tapered implant consistently demonstrated greater primary stability than the modified tapered implant at both 1-mm and 2-mm subcrestal placement depths. At 1 mm, the conventional tapered implants showed a mean ISQ of 4.60, compared with 1.00 for the modified tapered implants. At 2 mm, the corresponding mean ISQ values were 20.35 and 4.40, respectively. These findings indicate that, under the standardized experimental conditions used in this study, the conventional tapered design produced superior mechanical engagement with the surrounding synthetic bone medium.

The inferential analysis further supported this difference. At 1-mm placement depth, the conventional tapered implants had a higher mean rank than the modified tapered implants, with a Mann-Whitney U value of 2.500 and a statistically significant overall difference. Similarly, at 2 mm, the conventional tapered group again demonstrated a higher mean rank, with a Mann-Whitney U value of 0.500, indicating a significant difference between the two implant designs. The mesial/distal comparison at 1 mm also favored the

conventional tapered implant, whereas the buccal/palatal comparison showed a numerical advantage without reaching the conventional threshold for statistical significance. At 2 mm, the superiority of the conventional tapered implant was consistently observed across the evaluated aspects. These findings suggest that the difference in primary stability was not limited to a single measurement orientation but was apparent across several aspects of the implant-bone interface (12, 13).

One possible explanation for the superior performance of the conventional tapered implant is the difference in implant macro-design and the resulting contact with the simulated bone medium. Although both implant systems had the same diameter and length, the modified TS-IV implant had a more pronounced taper and narrower apical configuration, whereas the TS-III implant had a less tapered body. The thesis discussion proposes that the conventional tapered implant may have achieved a greater effective surface area of contact with the synthetic bone particles, thereby producing greater mechanical interlocking and higher primary stability. Because implant dimensions, bone density, osteotomy preparation, insertion protocol and operator-related factors were standardized, the observed differences are more likely to reflect the effect of the implant macro-design itself (12, 13).

The results are particularly relevant to immediate implant placement in the anterior maxilla, where primary stability is important because the prepared osteotomy may not provide complete circumferential contact between the implant and socket walls. In this experiment, a labial gap was intentionally preserved to reproduce the clinical situation of an immediate implant within an extraction socket. Both implant designs were inserted using an underprepared osteotomy, with a final drill diameter smaller than the implant diameter, and both possessed self-cutting characteristics. Despite these measures, the modified tapered design did not demonstrate the expected mechanical advantage. This finding is important because a more pronounced taper does not necessarily translate into greater primary stability when other implant and site variables are held constant (14, 15).

The study also evaluated whether deeper subcrestal placement altered implant stability. Both implant designs showed higher ISQ values when positioned at 2 mm below the simulated crest compared with the 1-mm position, but the magnitude of improvement was substantially greater in the conventional tapered implant group. Nevertheless, the original thesis interpretation was that the amount of submergence itself did not fundamentally change the overall pattern of results, as the conventional tapered design remained superior at both depths. Therefore, the results suggest that implant macro-design had a more consistent influence on primary stability than the change from 1-mm to 2-mm subcrestal placement under the conditions of this experiment (16-19).

The methodological standardization represents an important strength of this study. The use of D3-density polyurethane bone blocks reduced biological variability associated with natural bone, while the custom-made drilling system helped control drilling force and angulation. Both groups were tested using implants of identical diameter and length, the same surgical kit, comparable underprepared osteotomies, standardized insertion settings, and the same ISQ measurement technique. Furthermore, measurements were taken from four different aspects and repeated three times at each site. These procedures reduced the influence of potential confounding variables and enhanced the reproducibility of the experiment. (3, 4, 20) Despite these strengths, several limitations should be considered. The study was conducted

in a synthetic in-vitro model, and the mechanical characteristics of polyurethane cannot completely reproduce the heterogeneous cortical and cancellous architecture of living maxillary bone. Biological factors such as healing response, bone remodeling, vascularity, osseointegration and changes in secondary stability could not be evaluated. The sample consisted of only 10 implants, with five implants in each group, which limits the precision and generalizability of the findings. In addition, the experiment investigated only two implant designs from a single manufacturer and used one simulated bone density. Future studies should include larger experimental samples, additional implant macro-designs, different bone densities and extraction-socket morphologies, as well as animal or clinical studies where appropriate. Such research would help determine whether the mechanical advantage observed for the conventional tapered design is maintained under more clinically realistic conditions.

CONCLUSION

Within the limitations of this in-vitro experimental study, the conventional tapered Osstem TS-III implant demonstrated greater primary mechanical stability than the new modified tapered Osstem TS-IV implant when placed in simulated anterior maxillary extraction sockets. Higher ISQ values and mean ranks were observed for the conventional tapered design at both 1-mm and 2-mm subcrestal placement depths, with statistically significant overall differences between the two implant groups. The findings suggest that a greater degree of taper alone does not necessarily provide superior primary stability and that the overall implant macro-design and its interaction with the surrounding bone medium may be more important determinants of initial mechanical stability. Further well-designed experimental and clinical studies with larger samples are required before these findings can be generalized to routine clinical implant placement.

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