Comparison of Primary Stability of Straight-Walled and Tapered Implants Using an Insertion Torque Device

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Purpose: Implant geometry has a major impact on insertion torque values and primary stability, and bone engagement during implant insertion differs according to implant morphology. Primary stability of straight-walled and tapered implants was compared using insertion torque monitoring. ***Materials and Methods:*** A total of 57 implants (36 straight-walled OSSEOTITE and 21 tapered OSSEOTITE NT) were inserted in 20 patients. Implant torque values and insertion times were recorded, and the data were processed and interpolated to determine torque as a function of time. ***Results:*** Tapered implants required less insertion time and a higher insertion torque than straight-walled implants; this provided better primary stability, although the success rate was 86% for tapered and 100% for straight-walled implants. ***Conclusions:*** Tapered implants showed better primary stability than straight-walled implants but had a lower success rate. The authors suggest that in low-density bone, in which only a thin dense cortical layer can contribute to primary stability, a higher insertion torque can lead to the destruction of peri-implant bone, compromising osseointegration. *Int J Prosthodont 2012;25:465–471.*

Primary stability is influenced by the host bone's microscopic and macroscopic features together with the employed surgical skills and technique. It has also been reported that an implant's design and surface could improve primary stability in low-density or so-called poor quality bone.[1–8] This popular conviction is gleaned from published evidence showing a higher bone-implant contact (BIC) ratio and contact osteogenesis associated with specific microscopic and macroscopic aspects in implant design.[8–12] A possible direct correlation between primary implant stability and successful osseointegration has been postulated and has led to the development and use of specific implant designs as well as insertion torque instrumentation as a possible predictor of favorable treatment outcomes.

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Orenstein et al[13] argued that implant stability at the time of placement is desirable but not a prerequisite for achieving osseointegration. Other authors[14] have found that the achievement of high insertion torque was related to higher primary fixation, which is particularly essential in low-density bone, especially when immediate or early loading or even a nonsubmerged healing approach is planned in soft bone.[15] Friberg et al[16] reported that the level of initial stability influenced the percentage of successful outcomes and observed a 32% failure rate in correlation with inadequate initial stability. Furthermore, Ivanoff et al[17] reported in an animal study that osseointegrated implants with partial initial mobility had a significantly lower initial BIC than did those that were initially stable after 12 weeks, although the lack of primary stability did not lead to inferior integration in any type of bone.

In a recent in vitro study, Trisi et al[18] examined the relationships among primary stability, insertion torque, and bone density in straight-walled implants; they found a significant correlation between peak insertion torque and implant micromotion and significant differences in hard and medium bone compared to soft bone.

Because implant geometry is believed to play a major role in insertion torque values,[19] clinical protocols that combine suitable implant morphology with torque value recording are now commonly accepted. For example, tapered OSSEOTITE NT implants (Biomet 3i) are reported to be successful when the following

Fig 1 Calibration of torque on the Elcomed motor.

bone morphology limitations are encountered: reduced bone thickness in the coronoapical direction, undercut bone, and adjacent roots that converge toward the center of the edentulous space.[20]

Ideal sites for using a tapered implant are considered to be ones where bone quality and quantity are poor, such as anterior regions of the maxilla,[21,22] and this consideration prompted studies on how implant morphology might affect primary stability.[23,24] Therefore, a preliminary study was conducted to compare the primary stability of tapered (TP) OSSEOTITE NT and straight-walled (SW) OSSEOTITE implants (Biomet 3i) in a selection of such sites while employing insertion torque monitoring as a basis for clinical comparison.

Materials and Methods

Fifty-seven implants were placed in a convenience sample of 20 patients, including 9 women (45%) and 11 men (55%) between the ages of 42 and 63 years (mean: 52.5 years) at the time of implant placement. Patient selection excluded all subjects with local or systemic contraindications.

Implants were placed at least 4 months after tooth extraction and were allowed to heal for 3 months before stage-two surgery was performed. On the basis of bone site anatomy, 36 SW implants and 21 TP implants were placed (Table 1).

All subjects underwent preoperative dental scans to obtain optimal imaging of the selected implant sites, and all implants were placed by one operator. An Elcomed motor (W & H) with a speed range from 20 to 50,000 rpm, a torque calibration of 2 to 70 Ncm, and the option of recording data on a chip card (DOC) that allows the data to be recorded throughout the treatment phase was used to place the implants. Implant torque values and insertion times were recorded using the DOC card. The data were subsequently processed using ImpDAT Plus software (W & H) and interpolated using MATLAB (MathWorks) to determine torque as a function of time. Before each implant was placed, the motor was calibrated and reset to a fixed insertion torque of 35 Ncm (Fig 1).

Whenever the implant could not be seated successfully, the torque was increased and only the effective insertion time was recorded; this occurred in three cases. The operator evaluated bone quality using the classification system of Trisi and Rao.[25] Appropriate insertion techniques for the different implant morphologies were used according to the respective protocols.

Analysis was based on the evaluation of 1 mm of implant insertion, calculated as total implant insertion time/implant length (in millimeters), and the insertion times required for different implant lengths were compared.

Statistical Methods

Sample Size. According to the results of a pilot study conducted with a small sample of patients, 3.55 ± 4.7 Ncm was designated as the clinically meaningful difference in insertion torque. A sample size of 57 implants was intended to achieve a power of 80% ($\alpha = .05$) in detecting such a difference between SW and TP implants.[26,27]

Statistical Analysis. Data are presented as means, standard deviations, medians, and 95% confidence intervals (CIs) for TP and SW implants and the various bone types. From a purely descriptive point of view, the CIs were used to detect differences between groups; these differences were then further investigated using the Mann-Whitney nonparametric test.[28–30]

Results

The resulting data are based on an analysis of torque plots for the SW and TP implants as a function of time. The following parameters were considered for each implant: the end-of-test torque recorded on completion of implant seating (final torque), the mean torque required for complete implant insertion (insertion torque), and the insertion time for 1 mm of implant insertion (Table 1). Mean final and insertion torque values and insertion times for the SW and TP implants are presented in Table 2.

Table 1 Characteristics of Implants Placed

Patient	Site*	Implant morphology	Diameter (mm)	Length (mm)	Bone type[25]	Final torque (Ncm)	Insertion torque (Ncm)	Insertion time (s/mm)
1	11	SW	3.75	13.0	2	18.5	6.2	5.5
	12†	TP	4.00	15.0	2	28.4	15.5	2.8
	14	SW	3.75	15.0	3	8.5	7.4	5.2
	21	SW	3.75	11.5	2	21.1	9.5	4.8
	23	SW	3.75	13.0	2	33.9	10.3	5.4
	24	SW	3.75	15.0	3	18.4	11.7	5.6
2	31	SW	3.75	13.0	1	21.1	6.6	5.4
	32	SW	3.75	13.0	1	34.2	15.9	3.3
	41	SW	3.75	13.0	1	39.0	21.2	5.1
	42	SW	3.75	13.0	1	39.0	18.0	4.7
3	11	SW	3.75	13.0	2	20.1	8.9	6.3
	13	SW	4.00	15.0	3	34.7	18.6	6.3
4	45	TP	5.00	13.0	3	21.2	11.2	1.8
5	13	TP	4.00	15.0	2	34.8	14.0	1.5
	15	TP	4.00	11.5	3	24.5	19.0	2.7
	21	TP	4.00	13.0	2	20.3	9.3	1.7
	23	SW	3.75	15.0	2	15.2	12.3	6.8
	24	TP	4.00	5.0	3	33.5	14.9	1.6
	25	SW	4.00	11.5	3	29.7	14.7	4.1
6	32	SW	3.75	15.0	2	34.8	12.5	5.8
	34	TP	4.00	5.0	2	34.8	15.2	1.5
	36	SW	3.75	10.0	1	34.8	13.5	4.6
	42	TP	4.00	13.0	2	34.8	17.0	1.1
	46	TP	4.00	11.5	3	34.7	14.7	2.1
7	11	TP	3.25	13.0	2	52.1	20.6	2.7
	13	TP	4.00	13.0	2	26.2	11.2	2.1
	14	TP	4.00	13.0	3	28.2	17.8	2.0
	21	SW	3.75	13.0	2	23.5	9.5	6.3
	23	SW	3.75	13.0	2	35.5	22.1	5.2
	24	SW	4.00	13.0	3	9.3	7.6	7.0
8	24	SW	3.75	15.0	2	21.1	6.6	4.6
9	36	SW	4.00	13.0	2	34.5	11.4	7.5
10	36	SW	3.75	13.0	2	34.8	8.3	6.0
	37	SW	4.00	10.0	2	32.7	13.9	5.1
	46	SW	3.75	11.5	2	34.9	16.6	4.5
	47	TP	4.00	10.0	2	34.9	17.5	1.0
11	33	SW	3.75	13.0	1	34.1	14.4	5.1
	43	SW	3.75	13.0	1	34.8	17.4	4.0
12	11	SW	3.75	13.0	3	7.9	3.8	4.2
	14†	TP	4.00	13.0	3	24.8	14.8	1.9
	21	SW	3.75	13.0	3	20.8	5.7	5.3
13	35	TP	4.00	11.5	3	35.1	9.3	1.8
	37†	TP	5.00	10.0	3	34.2	16.8	1.5
14	15	SW	3.75	13.0	3	26.2	9.7	6.0
15	24	TP	4.00	15.0	2	33.7	13.1	1.7
16	11	SW	3.75	11.5	2	34.0	18.1	5.3
	21	SW	3.75	11.5	2	31.0	17.0	4.5
	44	SW	3.75	11.5	2	34.0	13.0	6.1
17	46	TP	4.00	11.5	2	34.5	13.8	1.7
	47	TP	5.00	11.5	1	35.0	20.5	1.4
18	11	SW	3.75	13.0	3	8.4	7.7	1.9
	13	SW	4.00	13.0	3	5.0	6.4	1.6
19	45	TP	4.00	11.5	2	22.3	12.2	1.4
	46	TP	4.00	11.5	2	34.0	14.2	2.2
20	24	SW	3.75	15.0	2	34.7	12.5	5.5
	25	SW	3.75	13.0	2	15.1	6.6	5.9
	26	SW	4.00	13.0	2	3.7	2.8	4.2

SW = straight-walled; TP = tapered.
*FDI tooth-numbering system.
†Implant failure.

The operator's subjective evaluation of bone quality, according to the Trisi and Rao[25] classification, was recorded during insertion. Mean final and insertion torque values and insertion times for each implant type in the three different bone types are presented in Table 3.

Table 2 Descriptive Analysis of Mean Final and Insertion Torque and Mean Insertion Time for SW and TP Implants

	Final torque (Ncm)	Insertion torque (Ncm)	Insertion time (s/mm)
SW			
Mean	25.5	11.6	5.1
Standard deviation	10.8	4.9	1.2
Median	30.3	11.5	5.3
No. of implants	36	36	36
95% CI	22.0–29.0	10.0–13.2	4.7–5.5
TP			
Mean	31.5	14.9	1.8
Standard deviation	7.0	3.2	0.4
Median	34.0	14.8	1.7
No. of implants	21	21	21
95% CI	28.5–34.5	13.5–16.3	1.6–2.0

SW = straight-walled; TP = tapered; CI = confidence interval.

Insertion time was significantly shorter for TP than for SW implants ($P < .05$; Table 2 and Fig 2). As shown in Fig 2, the initial torque value was 0 Ncm at the moment of insertion and then increased as a function of time; it was influenced by both implant morphology and bone quality. The curves for the TP implants increased more rapidly than did the curves for the SW implants, which were characterized by an intermediate inflection point that represented an interval of time when the insertion torque remained constant or diminished.

The insertion curves for SW implants in type 1 bone (Fig 3) show an initial rapid increase in torque, an intermediate inflection point indicating torque reduction, and a final peak. Insertion curves for SW implants in bone types 2 and 3 show a more gradual rise, a longer intermediate inflection point, and a final peak. Two curves in bone types 2 and 3 show almost no insertion torque increase and even a final reduction.

Only one TP implant was inserted in type 1 bone; the insertion curve shows a reduction (inflection point) in the initial insertion phase, followed almost immediately by a rapid rise (Fig 4). A few TP curves in bone types 2 and 3 show a more gradual torque increase or even a sudden torque reduction in the final insertion phase when torque values > 25 Ncm were reached.

Table 3 Descriptive Analysis of Mean Final and Insertion Torque and Mean Insertion Time for SW and TP Implants in Different Types of Bone*

	Final torque (Ncm)			Insertion torque (Ncm)			Insertion time (s/mm)		
	1	2	3	1	2	3	1	2	3
SW									
Mean	33.8	27.0	16.9	15.3	11.5	9.3	4.6	5.6	4.7
Standard deviation	6.0	9.3	10.5	4.6	4.7	4.4	0.7	0.8	1.7
Median	34.8	32.7	13.8	15.9	11.4	7.6	4.7	5.5	5.3
No. of implants	7	19	10	7	19	10	7	19	10
95% CI	29.4–38.3	22.8–31.2	10.3–23.4	11.9–18.7	9.3–13.6	6.6–12.1	4.1–5.1	5.2–5.9	3.6–5.8
TP									
Mean	35.0	32.6	29.5	20.5	14.5	14.8	1.4	1.8	1.9
Standard deviation	–	8.0	5.5	–	3.0	3.2	–	0.5	0.3
Median	–	34.2	30.9	–	14.1	14.8	–	1.7	1.9
No. of implants	1	12	8	1	12	8	1	12	8
95% CI	–	28.0–37.1	25.7–33.4	–	12.8–16.2	12.6–17.1	–	1.5–2.1	1.7–2.2

SW = straight-walled; T = tapered; CI = confidence interval.
*Bone type based on Trisi and Rao classification.[25]

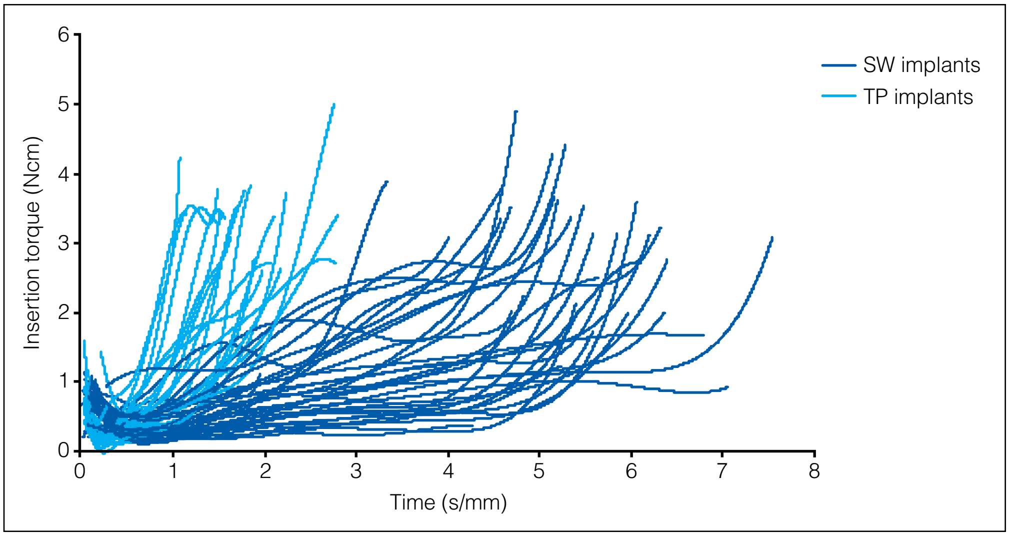

Fig 2 Insertion torque of SW and TP implants as a function of time.

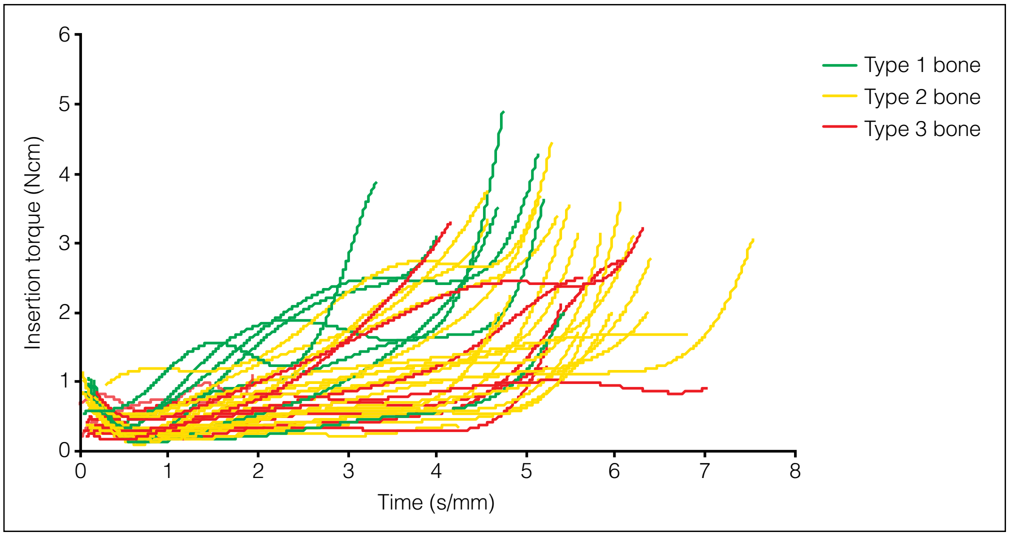

Fig 3 Insertion torque as a function of time for the placement of SW implants in bone types 1, 2, and 3.

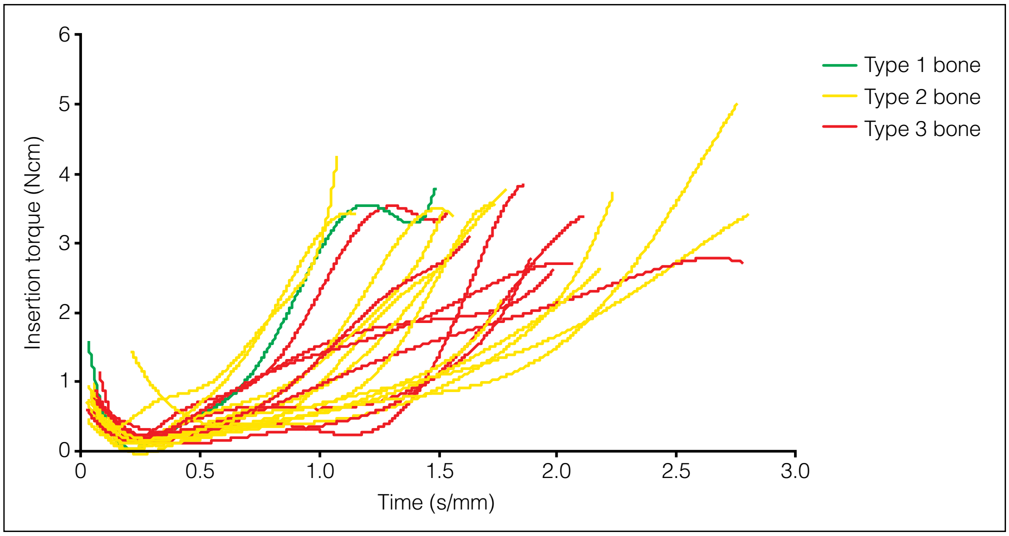

Fig 4 Insertion torque as a function of time for the placement of TP implants in bone types 1, 2, and 3.

TP implants showed a significantly higher mean insertion torque than did SW implants. The mean final torque value was also higher in TP implants, even at the lower limit for statistical significance (see Table 2).

Analysis of the CIs calculated for SW and TP implants in type 3 bone showed significantly higher mean final and insertion torque values for TP implants ($P < .05$). No significant difference was found among TP implants on the basis of bone type (see Table 3). SW implants inserted in bone types 2 and 3 showed a significantly lower final torque value ($P = .003$) than did those inserted in type 1 bone.

The implants were left submerged for 90 days. Three of 21 (14%) TP implants failed to integrate by the time of the second operation and were removed (see Table 1). One failed TP implant (4 × 15 mm) was inserted in type 2 bone with a final torque of 28.4 Ncm (compared to the mean of 32.6 Ncm), and two failed TP implants (4 × 13 and 5 × 10 mm) were inserted in type 3 bone with final torque values of 24.8 and 34.2 Ncm, respectively (compared to the mean of 29.5 Ncm).

All SW implants were immobile at the time of the second surgical intervention and were determined to be 100% successful.

Discussion

As a direct consequence of implant morphology, the insertion times for TP implants were significantly shorter than those for SW implants (see Table 2). The apical half of the TP implant is tapered to allow passive insertion for approximately half of its total length, thereby reducing its insertion time.[31]

Most of the SW and TP curves showed a final torque increase at the end of insertion, indicating that stability was best when the implants were completely seated in the bone.

The SW implant insertion curves slope gently upward and have intermediate inflection points where the insertion torque remained constant or tended to decrease. When an SW implant is inserted into bone, most of the primary stability is obtained during the final insertion phase. This phase corresponds to the seating of the implant collar, which has a greater diameter than does the body of the implant, promoting the engagement of the bone cortex.

The mean final and insertion torque values of SW implants showed a decrease from type 1 to type 3 bone; this reduction may depend on the lower resistance offered by lower-density bone during implant insertion. Although the mean final and insertion torque values for some SW implants in bone types 2 and 3 indicated low primary stability, none of these implants failed to integrate.

The mean final and insertion torque values of TP implants showed no significant difference according to bone type. The TP curves show a steep rise until the end of insertion, which was achieved rapidly. This pattern indicates that the shape of the TP implants allowed the achievement of mechanical stability more rapidly than SW implants during insertion. Some TP implants showed a sudden short reduction in final insertion torque, even when the torque was > 25 Ncm. TP implants seem to offer good primary stability even in low-density bone. Nevertheless, 3 of 21 TP (14%) implants failed to integrate. This 14% failure rate is higher than that reported in the literature for this implant system.[31] Furthermore, the relatively low insertion torque values and primary stability of the SW implants in type 3 bone did not correlate with a higher rate of implant failure. These findings indicate that in this study, the higher primary stability achieved with TP implants did not correlate with a higher success rate in comparison with SW implants. The authors must acknowledge that implants placed in different bone densities may show similar insertion torque values but different clinical outcomes. For example, in a thin bone crest, bicortical anchorage may offer greater primary stability, especially when a TP implant is inserted. However, such thin bone may be readily damaged by insertion torque forces, resulting in implant failure.[19]

Conclusions

Although implant morphology and primary stability are strictly correlated, no positive correlation between different levels of primary stability and implant success has been demonstrated to date. This preliminary study compared the primary stability of SW and TP implants by measuring insertion torque. The results demonstrated that good primary stability could be obtained with the insertion of SW implants in bone types 1 and 2, whereas significantly lower primary stability was observed in type 3 bone. The TP implants showed better primary stability than SW implants in all three bone types, especially in type 3 bone, where insertion torque values were 75% higher than those for SW implants. Nevertheless, the higher primary stability of TP implants inserted in poor-quality bone was correlated with a lower implant success rate. Within the limits of this preliminary study, implant morphology, insertion torque, and primary stability appeared to be significantly correlated, but no relationship was found between these parameters and implant success. Given the small number of patients who were monitored for a short period of time and the subjective evaluation of bone thickness and density, the measurement of insertion torque alone does not seem to be a valid parameter for predicting a successful implant rehabilitation. Further investigations are needed to assess a possible relationship between marginal bone compression resulting from high insertion torque and peri-implant cortical bone resorption, which could lead to implant failure.

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