# Investigation to Predict Primary Implant Stability Using Frictional Resistance Torque of Tap Drilling

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## ABSTRACT

**Objectives:** The purpose of this experimental study was to investigate the correlation between the frictional resistance torque of tap drilling prior to implant placement and the primary stability after implant placement.
**Material and Methods:** Solid rigid polyurethane bone blocks of four different densities were used in this study. A computerized surgical implant motor device was utilized to measure the frictional resistance torque of tap drilling. After the tap torque was measured, the dental implants were inserted at the prepared sites. During the implantation, the insertion torque was recorded, and resonance frequency analysis was performed, the value of which was calculated as the implant stability quotient. Thereafter, the correlation between the tap torque and the primary stability of the implant was evaluated and compared with the standard drilling protocol.
**Results:** A significant positive correlation was found between the tap torque and insertion torque (Pearson's $r = 0.88$, $P < 0.0001$). Similarly, there was a positive correlation between the tap torque and implant stability quotient (Pearson's $r = 0.69$, $P < 0.0001$).
**Conclusions:** These results suggest that measurement of the frictional resistance torque of tap drilling prior to implant placement could provide helpful information for implant primary stability.

**Keywords:** bone density; dental implantation; experimental implants.

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## INTRODUCTION

Achieving favourable primary stability is a crucial determinant of long-term implant success in dentistry [1]. Primary stability is defined as the mechanical adaptation between the placed implant and surrounding bone tissue, which is affected by a variety of factors, including bone quantity, bone density, implant design, and surgical protocols [2-4]. Among these, the most influential factors are the quantity and quality of the bone. Measurement of insertion torque (IT) and resonance frequency analysis (RFA) are two approaches applied in clinical practice to evaluate primary implant stability [5-7]. RFA values are calculated as the implant stability quotient (ISQ) and expressed as a number between 1 and 100. High IT and ISQ values indicate acceptable primary stability. In contrast, low values indicate poor primary stability.

In practice, the primary stability is assessed after implant placement, and the obtained results are used to make treatment decisions, such as applying immediate loading or delaying the unloading period until secondary surgery. However, if the primary stability could be predicted during the drilling and before implant placement, it would be possible to select the proper implant size or drilling protocol depending on the bone density in each individual case. Therefore, we hypothesized that measuring the frictional resistance torque of a tap drilling (tap torque) with the same twist drill diameter used in the standard protocol and clarifying its correlation with IT and ISQ can be used to predict primary stability before implant placement.

The classification of bone density given by Misch [8,9] comprises the following four groups based on the macroscopic cortical and trabecular bone characteristics: D1, dense cortical bone; D2, dense to thick, porous cortical bone on the crest and coarse trabecular bone; D3, thin, porous cortical bone on the crest and fine trabecular bone; and D4, minimal to no crestal cortical bone. Misch classification is based on the surgeon's tactile perception during implant socket preparation. Trisi and Rao [10] examined the correlation between bone density assessed using histomorphometric analysis and that determined based on Misch classification. They observed that D1 and D4 bone could be recognized easily; however, D2 and D3 bone is difficult to detect [10]. Therefore, an objective method, such as computerized tomography (CT) value measurement, is needed for intraoperative assessment. Clarifying the correlation between the cutting torque value of the implant placement socket and primary stability could enable prediction of the primary stability objectively as well as through preoperative CT value measurement.

The American Society for Testing and Materials (ASTM) has approved artificial polyurethane bone blocks as standard material for testing orthopaedic devices and instruments and has declared it an ideal material for comparative testing of bone screws (ASTM F-1839-08) [11]. Corresponding to the different bone densities specified above, the densities of polyurethane bone blocks are also classified into four types as D1 = 0.48 g/cc, D2 = 0.32 g/cc, D3 = 0.16 g/cc, and D4 = 0.08 g/cc [12-14]. Several studies have demonstrated that IT and ISQ are correlated with the bone strength or density of the polyurethane bone blocks [15,16].

The purpose of this experimental study was to investigate the correlation between the tap torque prior to implant placement and primary stability after implant placement.

## MATERIAL AND METHODS

### Materials

In the present study, solid rigid polyurethane bone blocks of different densities (0.48, 0.32, 0.16 and 0.08 g/cc) (block size: 13 cm × 18 cm × 4 cm, blocks SAW 1522-23/01/03/04; Sawbones® - Pacific Research Laboratories, Inc.; Vashon Island, Washington, USA) were prepared as artificial substitutes (Figure 1).

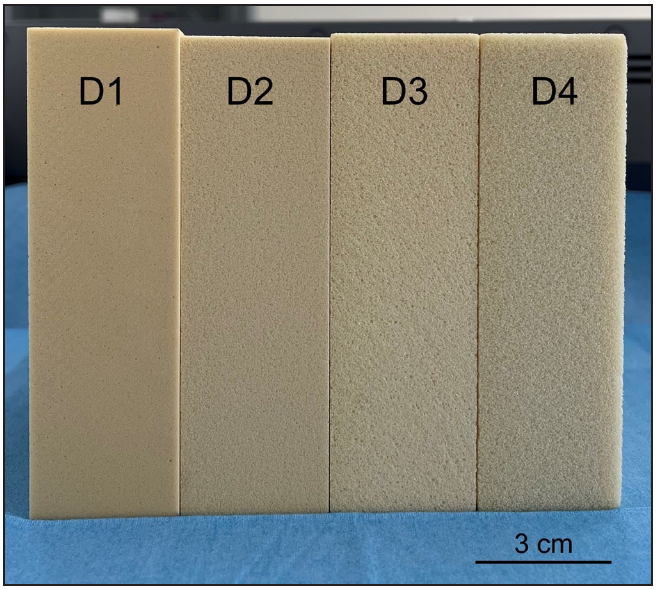


**Figure 1.** Bone block.
D1 = 0.48 g/cc, dense cortical bone.
D2 = 0.32 g/cc, dense to thick, porous cortical bone on the crest and coarse trabecular bone.
D3 = 0.16 g/cc, thin, porous cortical bone on the crest and fine trabecular bone.
D4 = 0.08 g/cc, minimal to no crestal cortical bone.

This material exhibits mechanical properties similar to those of human cancellous bone, as described in the ASTM F-1839-08 standard specification [11].

## Methods

The operating protocol is illustrated in Figure 2. Preparation of the implant socket was performed according to the instructions for the Brånemark System® implants in medium-density bone (Brånemark System® pure titanium implant with a machined surface of 3.75 × 10 mm RP - Nobel Biocare; Kloten, Switzerland, https://www.nobelbiocare.com/en-us/manuals). To prevent the influence of structural changes on bone blocks, the implant sockets were kept at a distance of 20 mm from each other [15] and 15 implant sockets were prepared in each block. A computerized surgical implant motor device (Surgic Pro2; Nakanishi, Tochigi, Japan) was used for torque detection. This device can detect a low torque of 1 Ncm or less. First, a 2.0 mm diameter round shaped drill was used to determine the drilling site, and a 2.0 mm diameter twist drill was used for preparing the implant socket up to a depth of 12 mm to avoid picking up the resistance hitting the bottom of the bone block when measuring the torque. Thereafter, the upper part of the bone block was drilled up to a depth of 3 mm using a 3.0 mm diameter pilot drill. In the tap drilling group, intra-drilling evaluation was performed and the tap torque was measured with a 3.0 mm diameter tap drill (GC Corp.; Tokyo, Japan) at a speed of 35 rpm

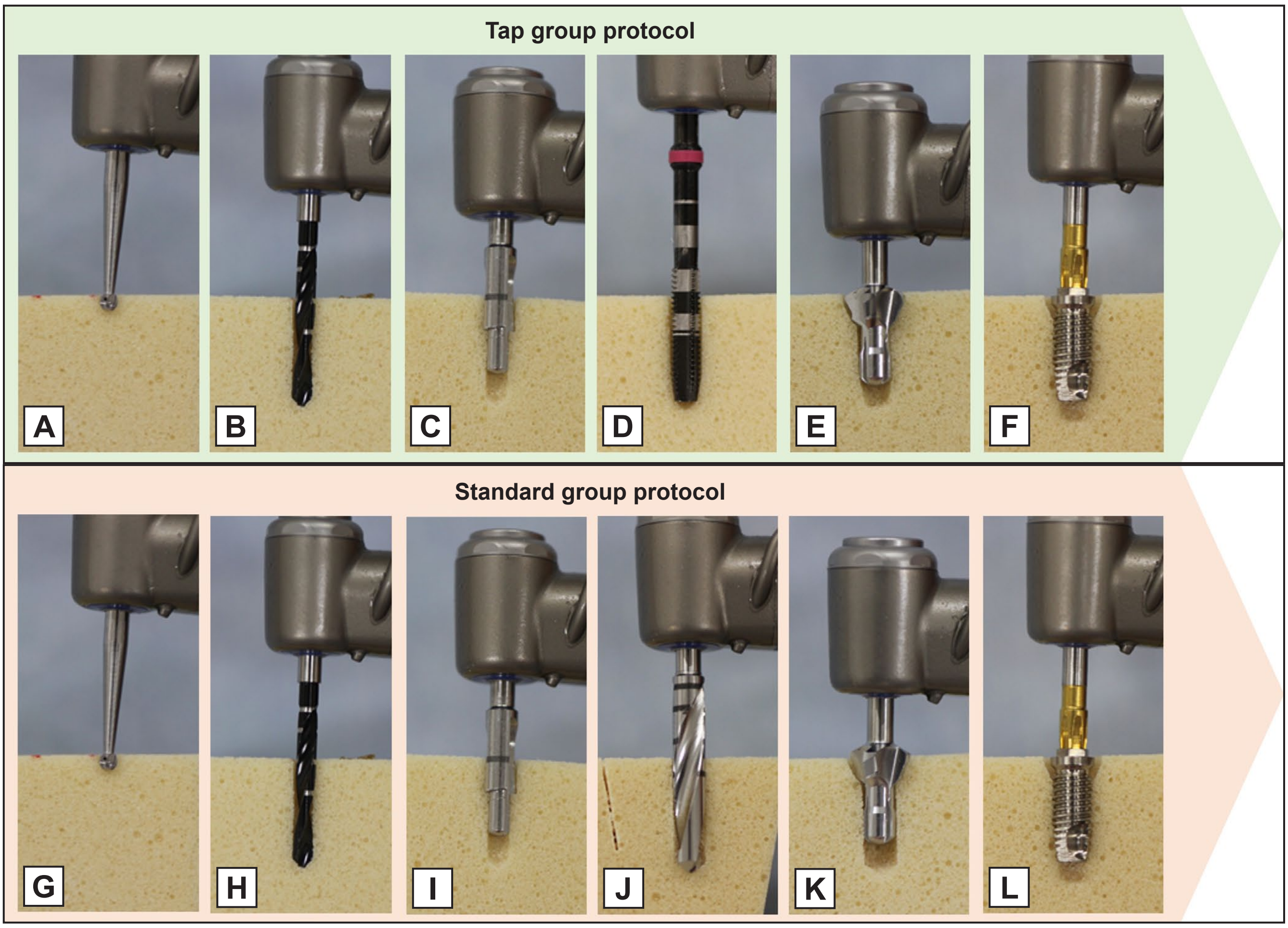


**Figure 2.** Drilling procedures for tap group and standard group.
A to F = tap group protocol.
G to L = standard group protocol.
A and G = round shaped drill (diameter: 2.0 mm) was used to determine the drilling site.
B and H = twist drill (diameter: 2.0 mm) was used for preparing the implant socket up to a depth of 12 mm.
C and I = pilot drill (diameter: 3.0 mm) was used to pinpoint the direction and depth of the perforation in the upper parts of the samples (depth: 3 mm).
D = tap torques were measured by tap drill (diameter: 3.0 mm), at a measurement depth of 10 mm (torque measurement length: 7 mm).
J = twist drill (diameter: 3.0 mm) was used for preparing the implant socket up to a depth of 10 mm.
E and K = counterbore drill was used to prepare upper part of bone block.
F and I = implant placement.

until 10 mm (measurement length: 7 mm) (tap group). During tap drilling measurements, the peak torque value was recorded as the tap torque. In this study, a single new tap drill was used in all measurements and bone blocks were used in random order. In the standard protocol group, the implant socket was prepared to a depth of 10 mm using a 3.0 mm diameter twist drill at 800 rpm (standard group) instead of the tap drill used in the tap group. Subsequently, a counterbore drill was used to prepare the top of the bone block in both groups. All preparing steps for implant sockets were performed under continuous water irrigation. Then post-drilling evaluations of peak IT and ISQ values were performed in both groups. Dental implants were then inserted at a speed of 35 rpm in the implant socket, and the peak IT was recorded during implant insertion. After implant placement, ISQ was measured by RFA using Osstell® device (Osstell AB; Gothenburg, Sweden), according to the manufacturer's instructions (https://www.osstell.com). With a manual wrench, a SmartPeg™ (Osstell AB) was connected to the implant with 5 Ncm torque, and the probe was pointed at the peg in two orthogonal directions. Each measurement was performed five times by three experienced operators (n = 15).

### Statistical analysis

Tap torque were assessed by one-way analysis of variance (ANOVA), followed by Tukey's post-hoc test. Pearson's correlation and linear regression analyses were performed to investigate the relationship between IT and ISQ in the two groups. The correlations between the tap torque and IT, as well as tap torque and ISQ, were also investigated using Pearson's correlation and linear regression analyses. In all cases, results were regarded as significant at $P < 0.05$. Parametric data were expressed as mean SD (standard deviation) values.

## RESULTS

### Tap torque for bone density classes D1 to D4

The tap torque in the density classifications of D1 to D4 was as follows: D1 = 16.89 (5.79) Ncm, D2 = 4.31 (1.1) Ncm, D3 = 1.38 (0.2) Ncm, and D4 = 0.92 (0.16) Ncm. The mean tap torque values tended to be higher in blocks with higher density. The tap torque in each block was significantly different between classes D1 and D2, D1 and D3, D1 and D4, D2 and D3, as well as D2 and D4; however, there was no significant difference between D3 and D4 (Table 1).

**Table 1.** Class/density and frictional resistances of tap drilling

| Class/density (g/cc) | Frictional resistances of tap drilling |
|---|---|
| | Mean (SD) |
| D1/0.48 | 16.89 (5.79)[a] |
| D2/0.32 | 4.31 (1.1)[b] |
| D3/0.16 | 1.38 (0.2)[c] |
| D4/0.08 | 0.92 (0.16)[d] |

[a-b, a-c, a-d, b-c, b-d]Statistically significant.
[c-d]Not statistically significant.
All data were analysed at the 5% significance level using one-way analysis of variance (ANOVA) followed by Tukey's post-hoc test.
SD = standard deviation.

### Correlation between the tap torque and IT

The IT was higher in the tap group than in the standard group in each block. The tap torque was correlated with the IT measured after implant placement, with a Pearson's r of 0.88 ($P < 0.0001$, Figure 3A).

### Correlation between the tap torque and ISQ

The ISQ was higher in the tap group than in the standard group in each block. The tap torque was correlated with the ISQ measured after implant placement, with a Pearson's r of 0.69 ($P < 0.0001$, Figure 3B).

### Correlation between IT and ISQ

The IT was correlated with ISQ, with a Pearson's r of 0.83 ($P < 0.0001$) and 0.84 ($P < 0.0001$) in the tap (Figure 3C) and standard (Figure 3D) groups, respectively. In both protocols, there were strong correlations between IT and ISQ.

## DISCUSSION

The mechanism of the tap torque measurement was similar to that of IT measurement, measuring frictional resistance. It was the maximum torque value obtained by the immediately mechanical engagement between the screw shaped tap drill or implant and the surrounding bone. The torque value was influenced by the surrounding bone, thread design, implant surface, or protocols [15,17-19].
The results show that tap torque was correlated with the IT and ISQ values. IT recorded during

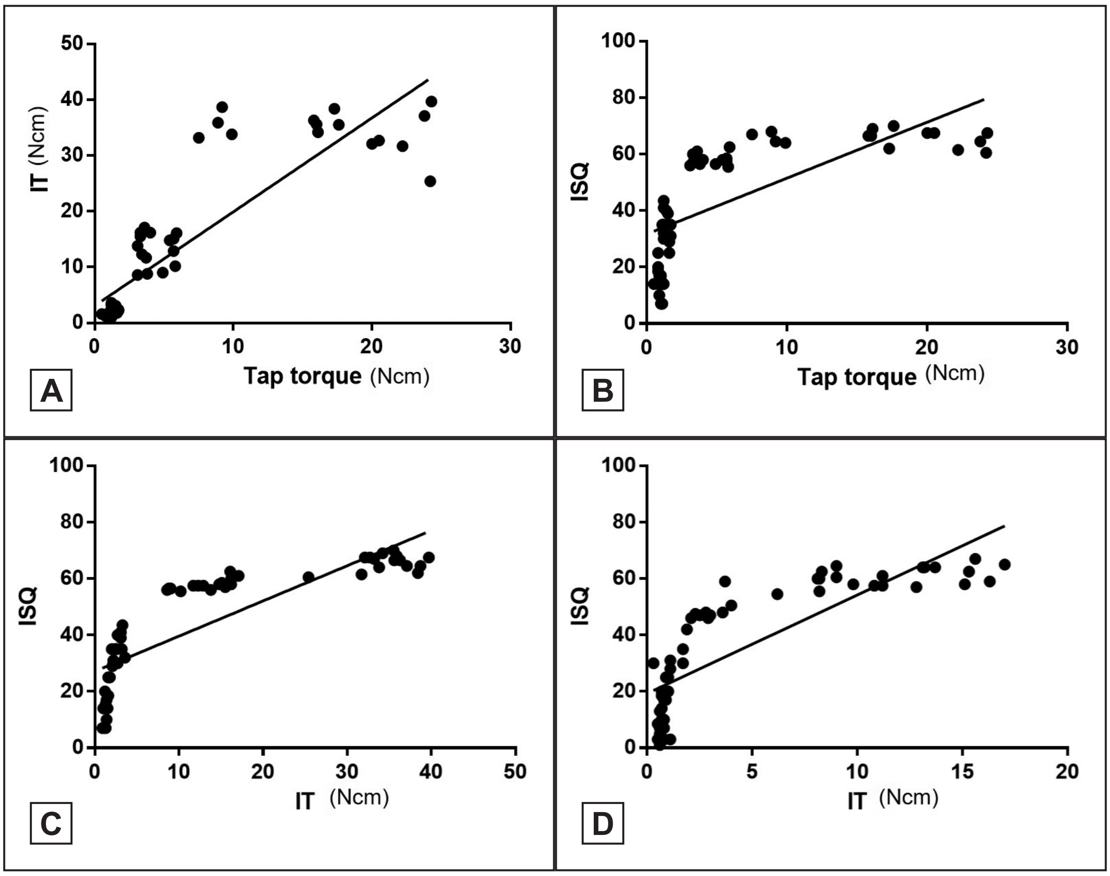


**Figure 3.** Correlation between the frictional resistances: A = tap torque and insertion torque (IT) (r = 0.88); B = tap torque and implant stability quotient (ISQ) (r = 0.69); C = IT and ISQ in tap group (r = 0.83); D = IT and ISQ in standard group (r = 0.82).

implantation and ISQ recorded immediately after implantation both indicated the primary implant stability. The tap drilling protocol indicated higher IT and ISQ values than the standard drilling protocol in every density block.

The ability to predict primary stability prior to implant placement can provide useful information to surgeons and increase the number of treatment options, particularly in cases of poor bone quality. As it is difficult to obtain the primary stability of the implant, we need to place an implant of a much larger size than the implant socket diameter. Therefore, undersized drilling or an increase in implant size can be considered prior to implant placement. Previous studies have reported that primary stability can be achieved using undersized drilling protocols even in a group of osteoporotic patients, whereas extending the healing period and choosing appropriate loading terms lead to good secondary stability [20,21].

Several reports have shown that IT correlates with ISQ [22]. Degidi et al. [23], in their investigation using an animal model, found that IT and ISQ were only partially correlated with bone quality. Our previous studies reported that both IT and ISQ values were low in osteoporotic rabbits in an induced glucocorticoid model compared to those in the standard model [24]. In addition, both IT and ISQ values were high when bone quality was improved via the administration of parathyroid hormone therapy [25,26]. As mentioned above, many reports have linked primary stability with IT and ISQ based on bone strength or density. However, the evaluations in all these studies were carried out by post-drilling evaluations. These post evaluations did not allow for the selection of operating procedures to obtain appropriate IT and ISQ.

In a study using bovine bone, Iezzi et al. [27] demonstrated that the classification of bone quality was determined according to the intra-drilling mean torque value. The bone quality was classified based on the range of mean torque values as D1: > 12 Ncm, D2: 8 to 11 Ncm, D3: 4 to 7 Ncm, and D4: 0 to 3 Ncm. However, as the torque values were measured with different shaped drills, the bone quality might deviate from our measured values.

In general, an implantation protocol with a larger diameter results in lower primary stability. In this study, a tap drill with a diameter of 3.0 mm was used to measure tap torque, which is consistent with the diameter of the conventional drill used for preparing the implant socket. The diameter of the tap drill was smaller than the implant size (3.75 mm). While Iezzi et al. [27] used the mean torque for bone quality classification in their study, we recorded the maximum torque values in this study to verify the correlation between the tap torque and IT because the maximum torque is usually considered an index of primary stability of implant placement. It was found that the tap torque was correlated with IT and ISQ. In particular, we were able to measure the low torque (tap torque: 0.92 [0.16] Ncm) in class D4, which simulated low bone density. The present findings suggest that measuring the tap torque can help predict the primary stability in the preparation phase of the implant socket immediately. Therefore, indications, such as undersized drilling or increased implant size, can be considered depending on the bone quality.

In this study, we compared the primary stability of implant placement using a tap drill and a twist drill with the same diameter of 3.0 mm during the final drilling step. The results show that the IT and ISQ of the tap protocol were higher than those of the standard protocol. This can be attributed to the shape of the tap thread leading to a high frictional resistance due to entrapment of small fragments in the interthread gap of the bone block during the tap drilling procedure. Dhore et al. [28] reported that bone debris occurring during implantation exhibited osteogenic potential. We found that while the ISQ of the standard protocol was lower than that of the tap protocol, all ISQ values were above 56 in class D1. ISQ values in the range from 57 to 82 indicate successful implant treatment [29]. Notably, the ISQ value depends on the quantity of the bone surrounding the implant. In addition, Ikar et al. [30] reported that a higher IT with excessive pressure during implant placement resulted in greater bone resorption, although implants maintain a greater total bone-to-implant contact during initial healing. Moreover, the effect of excessive compression of the bone wall on the secondary stability of the implant is unclear. Therefore, in cases with high bone quality, implant placement using a standard drilling protocol is considered suitable.

In this study, the tap torque was higher for the higher density blocks and was accurately recorded even at a low density. D3 tended to have higher tap torque than D4 without significant differences, indicating the need to detect D3 and D4 bone types more accurately prior to implant placement.

In this study using simulated bone block, the tap torque measurement was correlated with the primary stability of the implant. The intra-drilling evaluation was performed using a 3.0 mm tap drill in this study; however, it is difficult to accommodate narrow-type implants using this protocol because it is necessary to use a smaller drill than the final drill diameter for intra-drilling evaluation.

## CONCLUSIONS

The tap torque measurement prior to implant placement may provide valuable information for implant primary stability, and it may affect the implant treatment strategies such as undersized drilling or changing implant size in cases with low bone quality. Further studies using animal bone models should be conducted to determine the clinical applicability of these results.

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The authors have no financial interest in any company or any of the products mentioned in this article.

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