Comparison of Low-speed Drilling and Conventional Drilling in Implant Surgery: an Experimental Study

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Objective: *To compare accuracy, duration of drilling and accumulation of bone chips between low-speed drilling and conventional drilling in freehand implant placement surgery.*
Methods: *The implant surgery procedures were performed using identical drill bits on pig ribs in the low-speed drilling group and the conventional drilling group. CBCT images of the preoperative implant design and postoperative implant positions were compared by using the space vector formula to calculate the angular deviation of the implants between the two groups, as well as the horizontal and vertical deviations of the implant necks and roots. The duration of the procedure was recorded, and the bone chips were collected and compared using a screening method and scanning electron microscopy.*
Results: *There were no significant differences in any of the four primary outcome variables relating to accuracy between the low-speed and conventional drilling methods. However, the results revealed that the length of the procedure differed significantly between the two groups and more large bone fragments could be collected when performing low-speed drilling.*
Conclusion: *Low-speed drilling does not affect the accuracy of implant nest preparation, but it can harvest large bone chips which may have better osteogenic activity. Low-speed drilling could be an alternative to conventional drilling.*
Keywords: *bone graft, dental implant, low-speed drilling, surgical procedure*
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Oral implants have been proven to be more comfortable and efficient compared to other prostheses as they do not cause damage to adjacent teeth, and have become the preferred treatment option for restoring the morphology and function of missing teeth. The stability of oral implants is based on osseointegration, which is influenced by many biological and mechanical factors[1,2] and is related to primary stability.[3] Primary stability occurs immediately following placement and is a direct result of the mechanical engagement between the implant and surrounding bone,[3,4] which is influenced by several factors, including implant design, bone condition and surgical procedures.[4] During implantation, clinicians usually choose an appropriate procedure, such as simplified drilling or single bur drilling, to reduce damage while ensuring high initial stability. Conventional drilling initiated with a small-diameter drill before moving on to larger-diameter drills is the most common method, for which the drilling speed is approximately 1000 rpm,[5] depending on the implant system. The procedure must be carried out with irrigation throughout the implant bed preparation.

A novel technique referred to as low-speed drilling, and also known as biological drilling (50 to 100 rpm) without irrigation, has recently been proposed as an alternative to conventional drilling. It has been confirmed that this procedure will not make the temperature rise to 47°C without irrigation,[1,6-8] which will not

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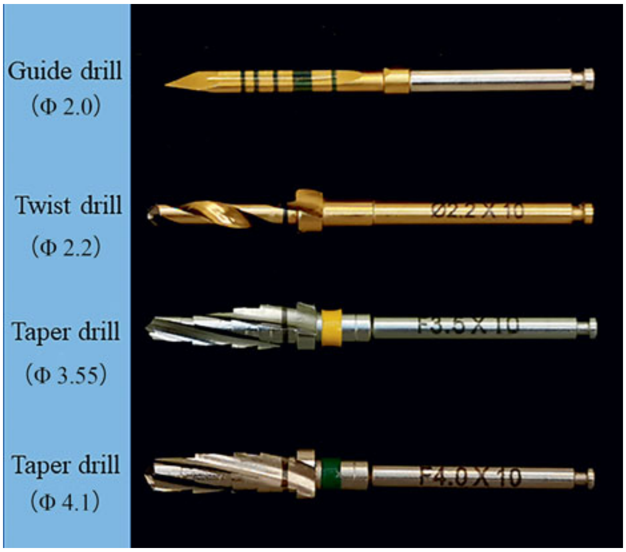

Fig 1 The drills used in the experiment.

cause thermal damage to the bone.[9-11] Additionally, it has no impact on osseointegration or bone loss around implants.[1,12-14] Eliminating the need for irrigation with saline can improve the operator's field of vision and avoid washing away cells, proteins and other soluble substances that play an important role in bone regeneration.[15,16] This process can preserve the autogenous bone graft and maximally restores its osteogenic ability, which is better than conventional drilling with regard to bone regeneration.[16-19] Additionally, the autogenous bone collected during the procedure can be used for bone augmentation to avoid the need for a second surgical site and reduce the use of bone substitutes, thereby also reducing the economic burden on patients. Furthermore, lower drilling speeds can produce greater drilling forces and torques, which can prevent excessive sideways force and minimise the risk of drill bit breakage.[20] Moreover, low-speed drilling without irrigation may provide greater comfort for patients and causes less postoperative pain and inflammation than conventional drilling.[21] These advantages seem to demonstrate that low-speed drilling is superior to other methods.

However, to the best of the present authors' knowledge, there is a lack of evidence regarding the accuracy of implant placement using low-speed drilling. Hence, the aim of this study was to evaluate the accuracy of low-speed drilling and conventional drilling. The secondary aim was to compare the procedure duration and bone chip accumulation.

Materials and methods

The experiments were designed according to a protocol that had been given ethical approval by the Ethics Committee of Shanghai Songjiang District Central Hospital.

Model selection and preparation

Pig ribs obtained from the butcher with a cortical thickness of approximately 2 mm were obtained, and a CBCT scan of each rib was taken before surgery to confirm that an implant (4.2 mm in diameter and 10 mm in length) could be inserted and only penetrated through one layer of cortical bone. The ribs that met the requirements were soaked in sterile normal saline.

DICOM files of the preoperative CBCT scans were imported into the implant planning software (Simplant Pro 17.0, Dentsply Sirona, Charlotte, NC, USA). A group member planned the 3D positions of each intended implant site and changed the implant type to TSIII (4.2 × 10 mm) (Osstem, Seoul, South Korea). The implant templates were manufactured through 3D printing according to the manufacturer's instructions.

Model surgery and deviation detection

All surgical procedures were carried out by a dental postgraduate student (TDL). In order to match the implant models, the surgical procedures were performed using a Taper KIT (Osstem) (Fig 1). The implant sites were located using the implant template and marked with a guide drill at a speed of 800 rpm with irrigation, and the depth of marks was 2.0 mm. Meanwhile, some signposts were placed parallel to the previously planned axis of the implant to indicate the direction (Fig 2). A total of 60 sites were randomly divided into two groups, and different technical conditions (Table 1) were used for each group without a guide template.

The duration of the procedure was recorded for each step. Bone chips generated using low-speed drilling accumulated on the drill surface and near the implantation sites, which could be collected directly; however, the irrigation when using conventional drilling caused difficulty in bone collecting, so bone collection needed to be performed by the surgical assistant.

After the surgery was completed, a postoperative CBCT scan was taken and the data were output as a DICOM file to build the model using Mimics 21. 0 (Materialise, Leuven, Belgium). The virtual preoperative implant positions and the actual postoperative positions were uploaded to Simplant Pro 17.0 and superimposed by manually matching at least three previously made marks.

Table 1 The rotary speed of each drill in model surgery.

Drilling protocol	Guide drilling (φ2.00)	Twist drill (φ 2.20)	Taper drill (φ3.55)	Taper drill (φ4.10)
Low-speed	800 rpm	50 rpm	50 rpm	50 rpm
Conventional	800 rpm	800 rpm	800 rpm	800 rpm

The planned and actual implant positions were represented by the neck centre point and root centre point in spatial coordinates, and each point was measured three times. Lateral neck deviations, lateral apex deviations and vertical apex deviations were calculated according to the distance formula ($d = |a*b|/|a|$), and angular deviations (Fig 3) were calculated according to the vectorial angle formula ($\cos\theta = a*b/(|a|*|b|)$), and other mathematical methods were used to decrease the measurement error.

Histomorphometric and quantitative analysis of bone chips

After preparation, the bone chips generated in the two groups were collected individually and fixed in 4% paraformaldehyde for 2 days. Following serial dehydration with graded ethanol, the samples were dried using a critical point drier. An electronic balance was employed to measure the dry weight of the samples.

The histomorphometric analysis of bone chips was performed using a sieving method and a scanning electron microscope (SEM). The 30 sites of bone chips collected by low-speed drilling were merged and then screened using sieves with diameters of 200, 400 and 600 µm. The bone chips in both groups were divided into three subgroups: bone chips with sizes of 200 to 400, 400 to 600 and > 600 µm. Almost no chips passed through the 200-mm diameter sieve. The overall weight and the dry weight of each part were measured and recorded. The bone chips gathered using conventional drilling were analysed in the same way.

In the following days, the samples were sputter-coated and analysed microscopically using an SEM (HITACHI, Tokyo, Japan) to determine size variations. The SEM images at ×30 for each group were analysed using ImageJ software (National Institutes of Health, Bethesda, MD, USA). To be defined as “chips”, the observed bone particles had to display clear boundaries. Thirty chips from each group were chosen and the projection area and Feret diameter were measured to indicate their size.

Since it was difficult to collect chips when using conventional drilling, a trephine drill (ChengDuPeiYang, Sichuan, China) with an inner diameter of 3 mm and an outer diameter of 4 mm and which had the same depth of preparation was used for the control group for comparison with low-speed drilling (Fig 4). The dry weight of bone blocks generated using a trephine drill were also measured using electronic balance.

Fig 2 The signpost in the rib that served as an indication of nearby implantation sites.

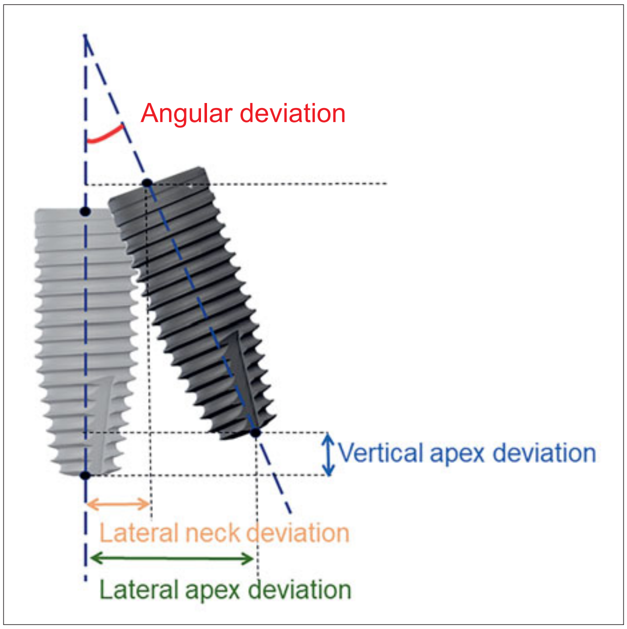

Fig 3 Illustration depicting the method of deviation measurement.

Fig 4 The trephine bur used in the experiment.

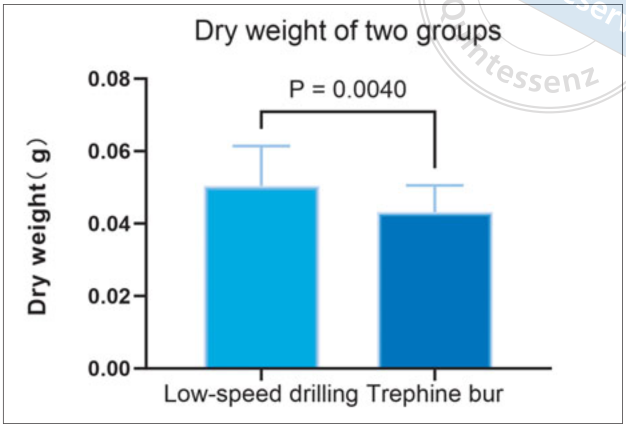

Fig 5 Bar charts representing the dry weight of two technologies.

Table 2 Descriptive statistics (means ± standard) and p-values of the deviation.

3D deviation	Low-speed drilling	Conventional drilling	t (Z)	*P* value
Lateral neck deviation	0.594 ± 0.442	0.590 ± 0.319	0.042	0.967
Lateral apex deviation	1.204 ± 0.556	1.087 ± 0.538	0.829	0.410
Vertical apex deviation	0.474 ± 0.291	0.640 ± 0.354	−1.982	0.052
Angular deviation	5.566 ± 1.964	4.871 ± 2.194	1.293	0.201

Table 3 Procedure time data, mean ± SD. All drilling protocols were repeated 15 times.

Drilling protocol	Final diameter (mm)	Mean ± SD(s)
Low-speed	φ2.2	6.721 ± 1.263
	φ3.5	8.776 ± 1.409
	φ4.0	5.029 ± 1.193
	Total time	20.526 ± 3.009
Conventional	φ2.2	4.153 ± 0.621
	φ3.5	3.692 ± 0.578
	φ4.0	2.865 ± 0.430
	Total time	10.710 ± 1.155

Statistical analyses

Statistical analyses were performed using IBM SPSS 25 (IBM, Armonk, NY, USA). The normality of the data was assessed using histograms and a Shapiro-Wilk test. All data that were normally distributed were compared using an independent samples *t* test, and the rest were compared using a Mann-Whitney U-test.

Results

Precision of the 3D position

In this study, a total of 60 implant surgery procedures were performed on the models: 30 in the low-speed drilling group and 30 in the conventional drilling group. There were no significant differences between the two groups for any of the four primary outcome variables ($P > 0.05$) (Table 2).

Duration of the procedure

The results of the analysis of the duration of the procedure are presented in Table 3. The total duration in the low-speed drilling group was 20.526 ± 3.009 seconds (95% confidence interval [CI] −19.402 to 21.649), whereas that in the conventional drilling group was 10.710 ± 1.155 seconds (95% CI −10.279 to 11.141), which was significantly different ($P < 0.001$).

Accumulation of bone chips

Despite having an assistant to help with bone collection in the conventional drilling group, the collection tended to be less efficient. The dry weight of bone chips was far less than that in the low-speed drilling group. Due to the difficulty in collecting bone chips generated during conventional drilling, a trephine drill was selected for the control group for further evaluation of the bone collecting ability of low-speed drilling. There was a significant difference in the dry weight of the bone chips between the control group (0.0431 ± 0.0074 g, 95% CI −0.0407 to 0.0460) and the low-speed drilling group (0.0504 ± 0.0109 g, 95% CI −0.0463 to 0.0545) ($P = 0.004$). The weight of the chips was greater in the low-speed drilling group (Fig 5).

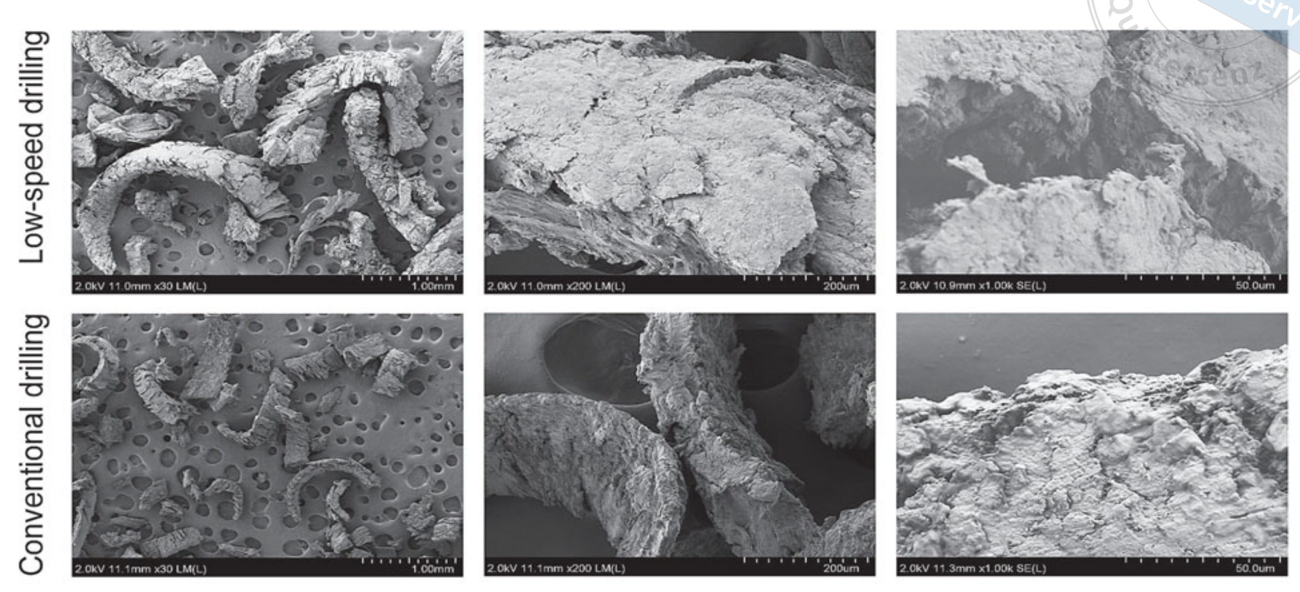

Fig 6 SEM analysis of bone particles harvested by two techniques. The bone particles produced by low-speed drilling were larger than the particles produced by conventional drilling.

Table 4 Characterisation of the average projection area and Feret diameter of bone chips.

Drilling protocol	Area (mm^2, mean ± SD)	Feret diameter (mm, mean ± SD)	Z	*P* value
Low-speed	0.780 ± 0.247	0.154 ± 0.142	−6.446	< 0.001
Conventional	1.769 ± 0.256	0.677 ± 0.313	−6.594	< 0.001

Size of bone chips

SEM analysis of the samples produced by conventional drilling revealed square and rectangular chips. The low-speed drilling samples displayed larger, rectangular chips (Fig 6). The bone chips produced by low-speed drilling were larger than those produced by conventional drilling ($P \leq 0.001$) (Table 4). The large bone chips accounted for a large proportion of the low-speed drilling group, with the percentage of bone chips > 600, 400 to 600, and 200 to 400 µm being 39.1%, 41.2% and 19.7%, respectively. The percentages for the conventional group at > 600, 400 to 600 and < 200 µm were 48.2%, 23.4% and 28.4%, respectively.

Discussion

To confirm whether low-speed drilling without irrigation was safe, the temperature change during drilling was measured using a digital infrared camera and thermocouple.[9-11,22] After ensuring that low-speed drilling did not cause thermal damage, the researchers conducted animal experiments and found that there were no significant differences in crestal bone loss (CBL) or bone–implant contact (BIC) between implants placed via low-speed drilling and those placed via conventional drilling.[1,23] Furthermore, Pellicer-Chover et al[12] and Tabassum et al[13] used low-speed drilling in clinical trials and found no apparent difference in bone loss around the implants between low-speed drilling and conventional drilling after a 12-month follow-up. Low-speed drilling was applied to prepare the sockets for autogenous tooth transplantation, and after a 7-year follow-up, the transplanted teeth remained stable.[24] Low-speed drilling also may provide improved primary stability and cause less postoperative pain and inflammation.[23,25] It appears that low-speed drilling has no impact on the long-term success rate of implants.

To the best of the authors' knowledge, this is the first study evaluating the accuracy of implant preparation using low-speed drilling. In this study, four primary outcome variables were chosen to compare the accuracy between two methods. However, no improvements in accuracy were observed when low-speed drilling was used for preparation compared to conventional drilling, which was inconsistent with the findings of other studies.[26] There are several likely reasons for this discrepancy. First, bone chips that accumulate near implantation sites can interfere with the observa-

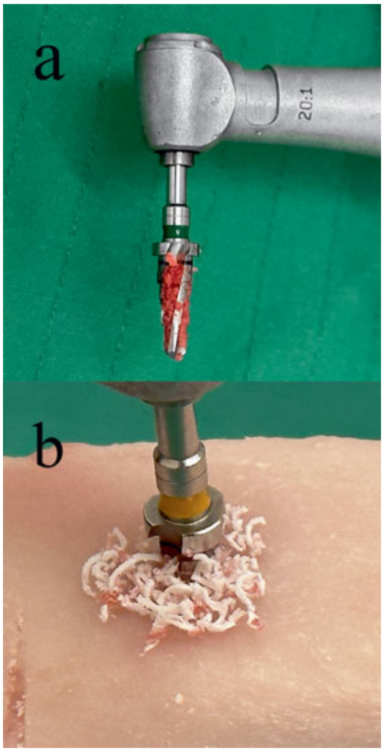

Fig 7 Bone particles accumulate on the drill's surface **(a)** or near the implantation sites **(b)**.

tion of length marks and affect depth control during preparation (Fig 7). Second, the inadequate cutting capability requires operators to apply additional axial force, which increases the risk of the drill slipping and affecting direction. Third, a reduction in rotation speed may affect drill stability. The basic theory behind the design of the tri-spade drill was the inherent stability and self-centring of a tripod.[27] However, as the rotation speed decreases, the chip escape rate and stability decrease accordingly. This could also explain why the operator experienced sideways forces while drilling. Nevertheless, most of these reasons were speculative and largely related to the design of the drills. Further investigation is required to determine whether drills designed specifically for low-speed drilling can improve accuracy during implant bed preparation.

Other differences between low-speed drilling and conventional drilling were also compared in this study. From the perspective of process time, the procedure time of low-speed drilling is approximately 1.9 times that of conventional drilling, which is similar to the finding of Calvo-Guirado et al.[1] The procedure time may be related to bone density and the design of the drill, both of which need further study. Although this approach prolongs the operation time, it provided greater comfort for patients because they did not experience a drowning sensation.[21]

During preparation by low-speed drilling, bone chips accumulate near the implantation sites and on the drill surface (Fig 7), which are heavier than the chips harvested by a trephine bur. Moreover, irrigation during conventional drilling makes it difficult to collect bone debris and leads to bone loss. Therefore, compared to the other two technologies, the slow-speed technique not only provides advantages in bone harvesting but also may avoid a second surgical site when facing small and medium-sized bone defects.

When examining samples under a microscope, Ozcan et al[25] discovered that conventional drilling causes more damage to cancellous bone than low-speed drilling, resulting in bleeding and bone marrow disruption, but there were no significant differences in the morphology of the cortical bone cutting surfaces. As yet, no research has been conducted into whether the method could influence the generation of bone chips. Scholars found that the bone chips harvested by low-speed drilling had better osteogenic potential than conventional drilling, ultrasonic osteotomy and other bone harvesting technologies.[16,17] The size of bone chips is important for osteogenic activity. A clinical study showed that large bovine-derived bone chips (1 to 2 mm) generated a 1.4 times higher volume in sinus augmentation than smaller granules (0.25 to 1 mm).[28] The area and Feret diameter measured in SEM images show that the size of bone chips harvested by low-speed drilling were significantly larger. According to the results of the screening method, 80.3% of the chips collected in the low-speed drilling group and 71.6% of the chips collected in the conventional drilling group were > 400 µm in length, but the proportion that was > 600 µm in length was larger when using conventional drilling. However, according to the result of the SEM method, the Feret diameter of low-speed drilling was much larger than 600 µm. The difference between the two methods was probably due to the fact that the result of the screening method was influenced by the oblong shape of bone chips. Although the volume of the chips was larger, they can pass through small diameter voids because of their slender shape. Therefore, the result of the SEM analysis was extremely serious. In general, low-speed drilling also made it possible to harvest more large bone chips, which may improve bone regeneration and repair.

Finally, this in vitro study is not free of limitations. A major limitation was that the drills used were not designed for low-speed drilling, which could obscure the superiority of this technology. In addition, dead pig ribs can be used to simulate human anatomy, but pig ribs are weaker than the human mandible, which may affect the results despite the thickness of the cortical bone being homogeneous. Furthermore, all procedures were performed by one experienced operator. Different results might be found by other investigators according to their level of experience.

Conclusion

According to the results of this study and its limitations, low-speed drilling has no influence on the accuracy of implant nest preparation, which may be increased by changing the drill design. Compared to conventional drilling, it offers advantages in terms of bone harvesting, as more and larger bone chips can be collected and osteogenic ability can be maximally restored. It can also reduce the consumption of bone substitutes to alleviate the economic burden on patients. Thus, the authors believe that low-speed drilling has the potential to be an alternative to current methods, and the characteristics of the drill should be further studied to develop a design that suits this technology and expands its advantages.

Conflicts of interest

The authors declare no conflicts of interest related to this study.

Author contribution

Dr Teng Da LIU contributed to the conceptualisation, methodology, project administration and manuscript draft; Drs Jing Jing CHEN and Shu Ya LI contributed to the software data analysis; Dr Shu Hong WANG contributed to the methodology, supervision of the study and revision of the manuscript.

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