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ORIGINAL ARTICLE

Evaluation of accuracy in implant site preparation performed in single- or multi-step drilling procedures

Nadine Marheineke[1] · Uta Scherer[1] · Martin Rücker[2] · Constantin von See[3] · Björn Rahlf[1] · Nils-Claudius Gellrich[1] · Marcus Stoetzer[1]

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Abstract

Objectives Dental implant failure and insufficient osseointegration are proven results of mechanical and thermal damage during the surgery process. We herein performed a comparative study of a less invasive single-step drilling preparation protocol and a conventional multiple drilling sequence. Accuracy of drilling holes was precisely analyzed and the influence of different levels of expertise of the handlers and additional use of drill template guidance was evaluated.

Material and methods Six experimental groups, deployed in an osseous study model, were representing template-guided and freehanded drilling actions in a stepwise drilling procedure in comparison to a single-drill protocol. Each experimental condition was studied by the drilling actions of respectively three persons without surgical knowledge as well as three highly experienced oral surgeons. Drilling actions were performed and diameters were recorded with a precision measuring instrument.

Results Less experienced operators were able to significantly increase the drilling accuracy using a guiding template, especially when multi-step preparations are performed. Improved accuracy without template guidance was observed when experienced operators were executing single-step versus multi-step technique.

Conclusion Single-step drilling protocols have shown to produce more accurate results than multi-step procedures. The outcome of any protocol can be further improved by use of guiding templates. Operator experience can be a contributing factor.

Clinical relevance Single-step preparations are less invasive and are promoting osseointegration. Even highly experienced surgeons are achieving higher levels of accuracy by combining this technique with template guidance. Hereby template guidance enables a reduction of hands-on time and side effects during surgery and lead to a more predictable clinical diameter.

Keywords Implant site preparation · Bone drill · Template-guided drilling · Diameter measurement · Primary stability · Single drill

Introduction

Various experimental studies have shown that an atraumatical surgical procedure during implant site preparation is a determinating factor to achieve functionally correct and stable dental implants [1]. A combination of mechanical and thermal damage during the surgery process can lead to bone necrosis and insufficient osseointegration. These parameters are the main causes for implant failure [2-4].

Conventional preparations of implant sites are produced by using at least three drilling steps, depending on the diameter of the desired implant. In consideration of potentially harmful thermal effects with possible impairment of subsequent osseointegration, the previous doctrines of implant dentistry recommend a protocol of performing small incremental increases of drill holes diameters [2, 4, 5]. The theoretical background of this technique is based on the model that heat and friction generated in bone contact zones during the drilling process is directly correlated to the amount of bone material removed. Accordingly, the quantity of bone chips is correlated to the diameter of the

Nadine Marheineke and Uta Scherer contributed equally

✉ Nadine Marheineke
nadine.marheineke@gmx.de

1 Klinik für Mund-, Kiefer- und Gesichtschirurgie, Medizinische Hochschule Hannover, Carl-Neuberg-Str. 1, 30625 Hannover, Germany

2 Klinik für Mund-, Kiefer- und Gesichtschirurgie, Universität Zürich, Plattenstrasse 11, 8032 Zürich, Switzerland

3 Zentrum CAD/CAM und digitale Technologien, Donau-Universität Krems, Dr.-Karl-Dorrek-Strasse 30,, 3500 Krems, Austria

drill [4]. This traditional approach is not necessarily controversial to findings from other authors.

The accepted opinion is stating that temperature development and its influence on osseointegration is proportional to the time of the bone being exposed to friction forces generated during the drilling activity [6–9]. Multiple studies demonstrate that bone damage caused by heat exposure increases with extended drilling time. While use of a stepwise drilling protocol promises a prolongation of hands-on time and lessens the damaging effect on bone structure [10–12]. Other current findings indicate an excellent success rate of site preparations without thermal trauma, produced by simplified osteotomy using a single-drilling step [13, 14]. Whereas investigations of potential thermal damage, using different preparation protocols, have already been performed, the present study takes a view at the effects on the actual accuracy of the drilling hole.

The accuracy evaluations in the present work were done with special reference to a reduction of drilling steps to just one. The aim was to investigate additional potential inaccuracies caused by simplified protocols. A second approach was to find out, if these alterations could be balanced with help of guided surgery. The use of drilling templates for site preparations is designed to provide greater control and a reduction of risks and failure in implant surgery [15–17]. From the literature, it is known that single-drill techniques are not related to an increase in bone temperature during the surgery [18]. This observation applies to protocols performed with surgical template as well as without its application. Successful implantation in many studies is usually observed by resonance frequency analysis [19] or insertion torques of the implants [20]. Data in this way is collected indirectly after implantation and is not depicting the quality of the drill hole itself. The aim of the present study is to directly investigate the early events of implantation, the drilling procedure.

In the present study, results of a single-step drilling preparation protocol are compared to a multiple drilling sequence. The aim was to contrast different techniques and compare template-guided surgery to free manual preparation. The study separately evaluates these accuracies for different levels of expertise of the handlers, performing the drilling. The dental community witnesses a rapid increase in the number of general practioners involved in implant placement, lessening the quota of specialists. The practioner and his or her level of expertise are crucial factors for the accuracy and the outcome of dental implants [21]. Therefore, the further aim of the study was to add that human factor to the technical and applicatory evaluation. These parameters are making it a combined investigation of the influence of guiding templates on different protocols, as well as levels of expertise of the operators.

Material and methods

Drilling equipment and comparative drilling protocols of implant site preparation

An electric drilling instrument with continuous saline cooling (Elcomed, W&H, Bürmoos, Austria) was used for experimental implant site preparation in the present porcine osseous study. Drilling techniques for preparation of monocortical implant anchorage were carried out according to the surgical protocol suggested by the drill manufacturer (Bego, Bremen, Germany).

In this comparative study, two different types of implant site preparations were performed and compared. First, a single-drill preparation was performed, consisting of a priming puncheon action in order to mark the drill holes placement and allowing guidance of the referring single drill used in this procedure. Hereby, a single drill of 3.25 mm, representing the final size of diameter, was used to complete the preparation. The second preparation technique, named multi-step technique, uses a panel of drills in ascending sizes, starting with a diameter of 1.60 mm and continuing to 2.50, 2.80, and 3.25 mm, producing an incrementally widened drill hole. Both techniques lead to a final drill hole diameter of 3.25 mm, and both were applied to freehanded as well as template-guided drilling operation.

Template-guided drilling was carried out using polyoxymethylene (POM) gauges with embedded guiding sleeves produced with help of computer-aided design and manufacturing (CADCAM), (Datron D5, Darmstadt, Germany). Into these guiding sleeves, spoons with a precise drilling channel could be clamped with a twisting move. This way, a stable positioning was guaranteed. The load-bearing structure of the gauge itself was anchored with screws to the jawbone for maximum resistance against distortion (Fig. 1). Drills were changed after every three drills to avoid possible inaccuracies in diameter due to drill wear.

Experimental osseous model

In order to achieve true-to-life experimental conditions, the drilling actions were carried out in cadaveric porcine mandibles, derived from subjects 3 years of age that underwent second dentition. A total of 72 mandibles were used and grouped. Every jawbone underwent a total of 5 implant site preparations. Eight experimental groups were arranged representing template-guided and freehanded drilling actions, each separated in groups for usage of respectively three persons without surgical knowledge and poor operating experience in mechanical drilling on one side against groups of three highly experienced oral and maxillofacial surgeons on the other. All of these specified experimental configurations were carried out with single-drill preparation as well as multi-step

Fig. 1 Template-guided drilling construction. Guided drilling procedure was carried out using polyoxymethylene (POM) gauges with embedded guiding sleeves. Spoons with a precise drilling channel could be clamped in these guiding sleeves with a twisting move. This way a stable positioning was guaranteed. The load-bearing structure of the POM gauge itself was anchored with screws to the jawbone

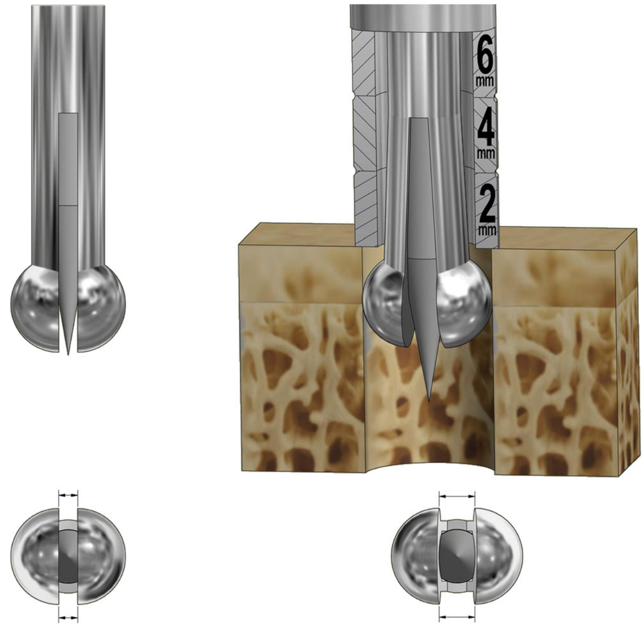

Fig. 2 Measurement principle of the precision instrument for diameter determination (Zentimess, Mahr). The instrument provides high precision measurement of diameter, roundness, and conicity of boreholes by spring-loaded halves of a measuring probe that is splitted by aprotruding pin with a precision-lapped taper. This movement is transferred to an indicating instrument (not shown). (A) Neutral position of the measuring probe after calibration with a diameter ring gauge supplied by the manufacturer (not shown). (B) Expanded measuring probe during application on bone samples at the corresponding 2-, 4-, and 6-mm depths of the drilling hole

preparation. Each of these eight experimental groups comprised three operators. Results were obtained for 150 drilling actions per operator and a 900 drilling actions could be analyzed.

Careful analysis of three-dimensional radiographic examination of the porcine mandible jawbones also provided information about the height and width of the animal bone, degree of corticalization, density of mineralization and possible cancellous bone in the relevant areas. Therefore, jawbones were analyzed in conebeam computer tomography (CBCT) in the Clinic for Cranio-Maxillo-Facial Surgery of the Hanover Medical School (PaX–Zenith 3D, Republic of Korea). Bone quality of the specimen was classified as type D2.

Diameter measurement procedure

Diameter of each drilling hole was recorded with a precision measuring instrument according to the instructions for use (Zentimess, Mahr, Göttingen, Germany) at drill hole depths of 2, 4, and 6 mm. Data were taken in a blinded trial and measurements were taken by an independent person, not involved in the drilling experiments.

Measurement with the Zentimess instrument was taken by measuring probes. The probe design features spring-loaded half-shells that are splitted and expands by a protruding and advancing pin with a precision-lapped taper (Fig. 2). The resulting lateral expansion movement of the half-shells was directly visible on the measuring scale of the Zentimess instrument, graduated in 0.01-mm intervals with a measurement range of ± 0.25 mm and a gauging force of 1 N. Free stroke of the instrument amounts 2.5 mm. The manufacturer quantifies the deviation of linearity of ≤ 2% measuring ranges with 0.47–1.55 mm and ≤ 1% measuring ranges with 1.5–18.6 mm. Reproducability is specified with 1 μm by manual handling.

The deeper the penetration of the expanding pin, the greater the split, and the expansion of the half-shells and the wider the gauged diameter of the measured hole. Comparable measurement depths were gained using distance sleeves on levels of 2, 4, and 6 mm. This means that each drill hole was measured in three levels of depth. Each measuring was taken twice in different orientations. The values of the two corresponding measurements were then averaged.

Statistics

A software package (SPSS 11.0 Inc. Chicago, IL, USA) was used for the statistical analysis. Mean values and standard deviations were calculated for each group. Data was found not normally distributed (Kolmogorov-Smirnov-Test), so that Wilcoxon analysis was performed to compare the level of significance within and between the groups.

Results

For experimental in vitro evaluation of accuracy of drill holes diameters, drilling for 360 implant sites preparations has been performed and subsequent precise measuring has been taken. Due to the different protocols which are either done in multi-step or a single-drilling procedure, 360 implants sites represent 900 drilling actions in total. Measurement of diameters of drill holes produced by a 3.25-mm surgical drill bit provided data within the limits of 3.10 and 3.67 mm. As result from elastic property of natural bone tissue, many measured values were showing a smaller diameter of the drill hole than the deployed drilling instrument with a dimension of 3.25 mm [22, 23]. Previous published data already showed the impact of expertise level on precision and accuracy concerning the diameter of preparations [21]. In the present work, these results were replicated and the advantage of template-guided drilling used by low or high-level skilled operators was reconfirmed (Figs. 3, 4, 5). Operators with low level of experience in dental implantation were producing drill holes with higher degree of variations in diameter by means of higher standard deviations in measurement depth of 2, 4, and 6 mm. Experienced operators produce significantly differing drilling hole diameters ($p \leq 0.001$) over less experienced operators when using the multi-step technique, as shown in Fig. 3 [21].

Less experienced operators were able to significantly increase the accuracy of the diameter through using a guiding template significantly ($p \leq 0.001$), (Fig. 4). Multi-step preparations strongly benefit from template guidance when performed by individuals with low training status.

On the contrary, the beneficial effect of template guidance in hands of experienced operators is significant, but much less pronounced. Professional oral surgeons were not producing significant superior accuracies of drill holes diameters over less experienced operators, when templates were used. Manual multi-step preparation is showing higher values of accuracy with mathematical significant evidence, as shown in Fig. 5.

When the freehand technique combined with multi-step drilling was used, unexperienced operators were not able to

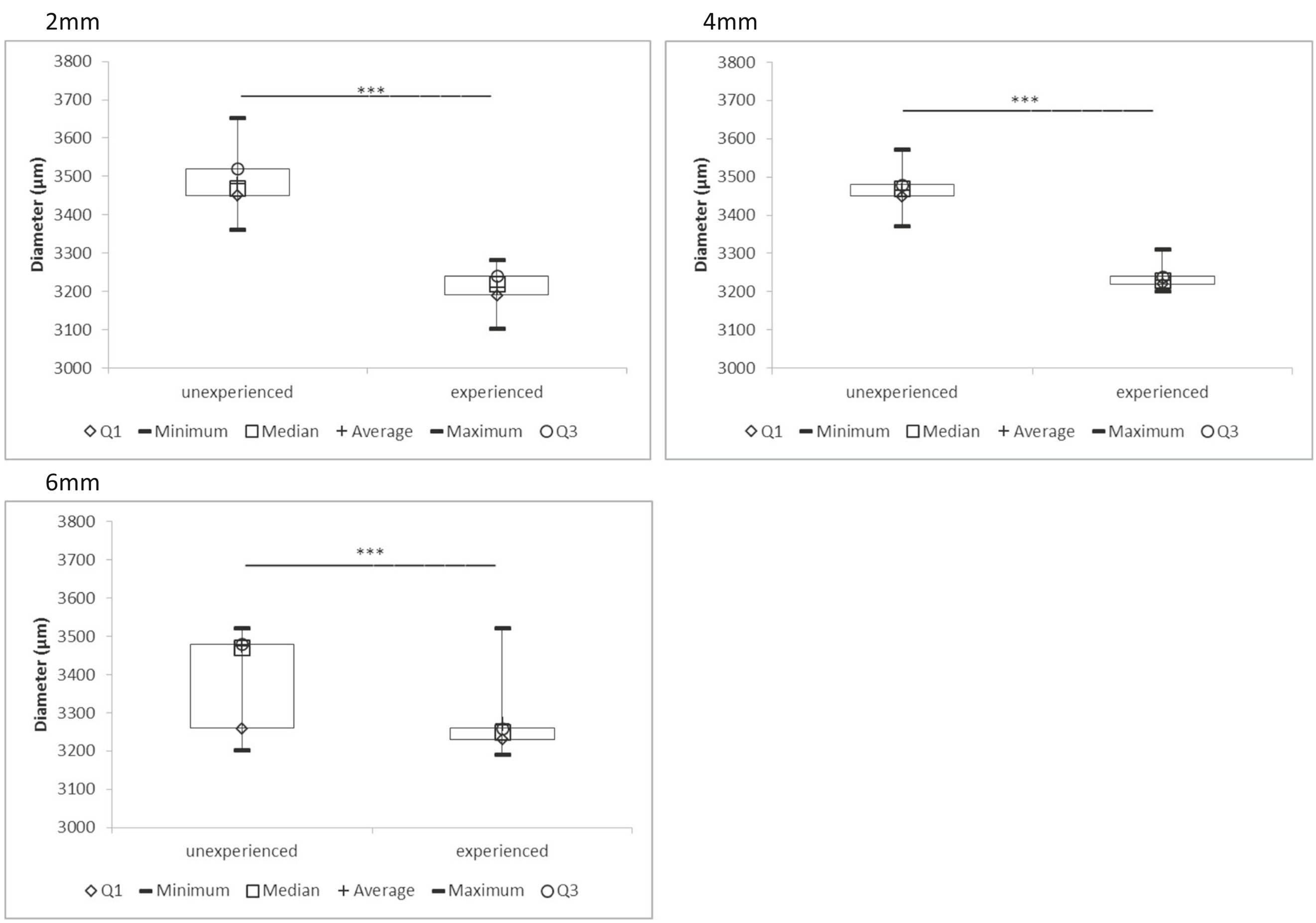

Fig. 3 Multi-step preparation technique without template guidance performed by experimentators with different levels of expertise. Diameter measurement of the internal radius of drill holes in porcine mandibles performed with a 3.25-mm gauge drill according to instructions of manufacturer (Bego, Bremen, Germany). Plottings show Averages, Medians, Minima and Maxima, and Q1 and Q3, as well as significances. The drilling actions of experienced and unexperienced operators were compared. Results of measurement in drill holes in depth of 2 mm (a), in depth of 4 mm (b) and, in depth of 6 mm (c) are illustrated. Level of significance is marked with asterisks: $** = p \leq 0.01$, $*** = p \leq 0.001$

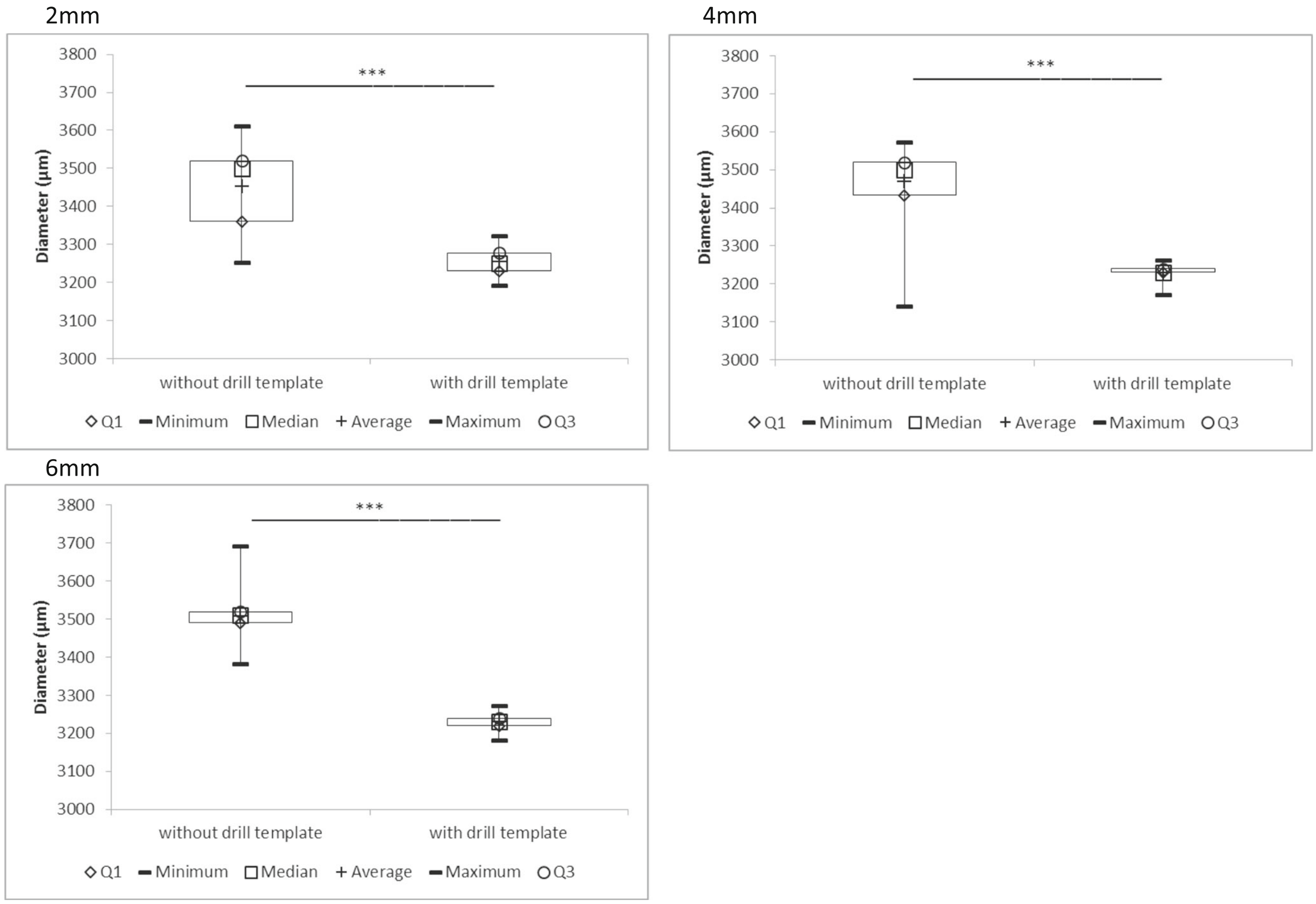

Fig. 4 Unexperienced operators are able to enhance drilling accuracy by usage of template guidance by multi-step technique. Diameter measurement of the internal radius of drill holes in porcine mandibles performed with a 3.25-mm gauge drill according to instructions of manufacturer (Bego, Bremen, Germany). Plottings show Averages, Medians, Minima and Maxima, and Q1 and Q3, as well as significances of drill holes diameter measurement. Drill holes were prepared by unexperienced operators using multi-step technique. These drilling actions were compared with regard to support of template guidance. Results of measurement in drill holes in depth of 2 mm (a), in depth of 4 mm (b), and in depth of 6 mm (c) are illustrated. Level of significance is marked with asterisks: $** = p \leq 0.01$, $*** = p \leq 0.001$

produce significantly improved drill holes accuracies over the freehand single-step technique Fig. 6.

Statistical evaluation of the effect of the simplified single-drill technique in combination with manual handling shows mean values of drill hole diameters between 3.213 and 3.271 mm in depth of measurement between 2 and 6 mm. The significant difference ($p \leq 0.001$) in comparison to the standard drill protocol with mean values between 3.255 and 3.289 mm of drill holes diameter becomes apparent. Experienced operators using the single-step technique achieved a significantly increased accuracy over their multi-step results (Fig. 7).

Experienced operators were able to improve their already very exact guided preparation results by using the single-step technique (Fig. 8).

One central and general observation in the present study was that deviations are increasing with the depth of the drilling hole, regardless of technique or level of experience Figs. 1, 2, 3, 4, 5.

Discussion

Conditions beneficial for a desired primary stability of implants have been widely discussed and are known to be dependent on several factors: material, surface, diameter, and shape of the dental implant itself as well as practical factors during the surgery [24–27]. Correct use and insertion of the dental implant are obligatory for successful surgery.

The precise site preparation of the drilling hole and choice of corresponding drilling tools and implant systems is very essential as well [21, 28]. Optimal osseointegration requires optimal implant-bone contact, especially since this process it is not yet fully understood and since drilling debris has influences on initial osseointegration [29–33]. Previous studies demonstrate that micromovement of the implant above 150 μm leads to encapsulation by fibrous tissue. It also results in resorption of bone and inhibition of sufficient growth of osteoblasts. Disabled osteoblasts accounts for reduced wound

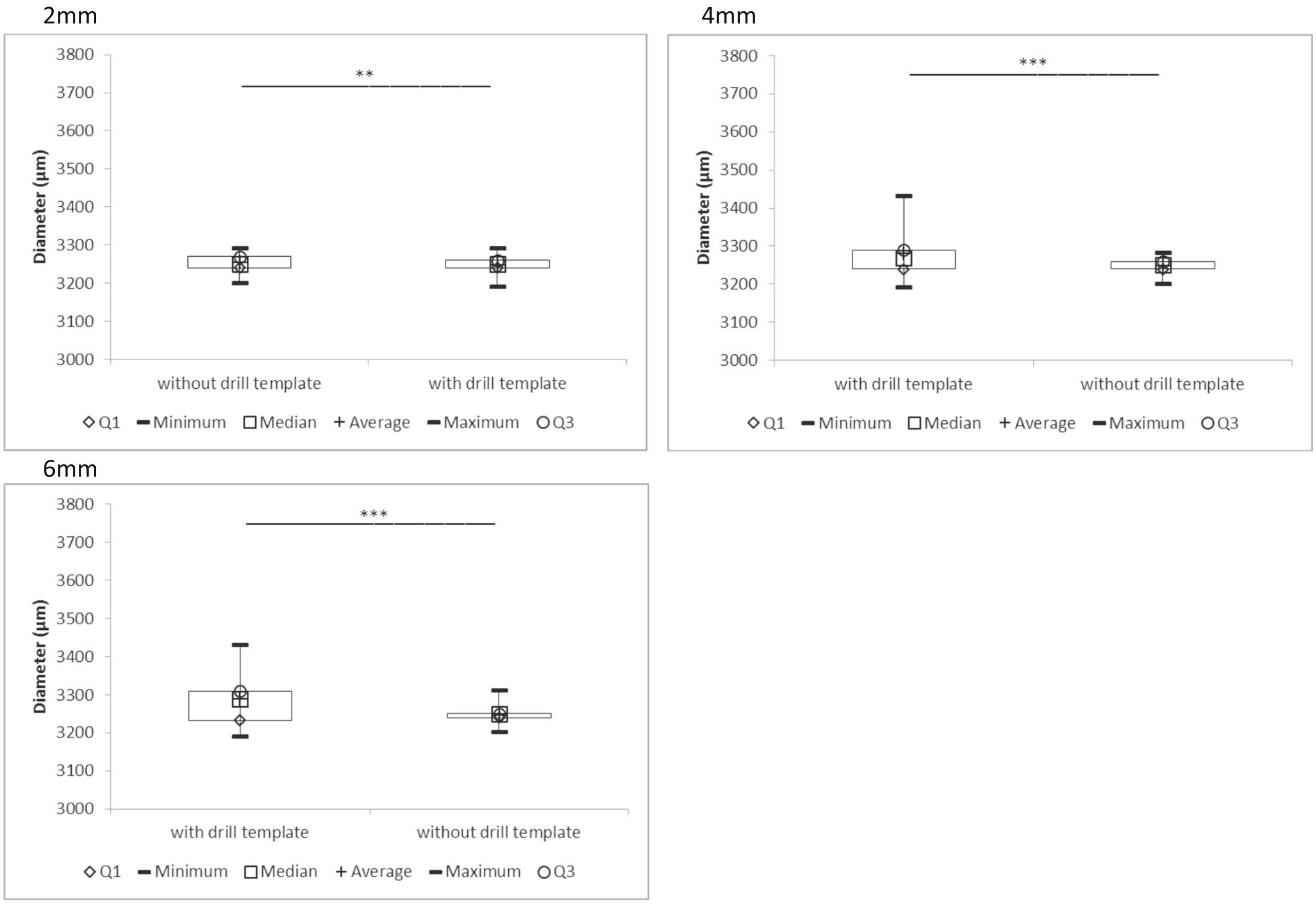

Fig. 5 Beneficial effects of template guidance in hands of experienced operators. Diameter measurement of the internal radius of drill holes in porcine mandibles performed with a 3.25-mm gauge drill according to instructions of manufacturer (Bego, Bremen, Germany). Plottings show Averages, Medians, Minima and Maxima, and Q1 and Q3, as well as significances of drill holes diameter measurement. Drill holes were prepared by experienced operators by multi-step technique. These drilling actions were compared with regard to support of template guidance. Results of measurement in drill holes in depth of 2 mm (a), in depth of 4 mm (b), and in depth of 6 mm (c) are illustrated. Level of significance is marked with asterisks: ** = $p \leq 0.01$, *** = $p \leq 0.001$

healing [34, 35]. Several studies suggest that a possible explanation for the greater stability is the use of undersized caliber drills for preparation. Here, the implant is subsequently being press fitted into the site. This press-fit theory emphasizes, that accuracy again is a fundamental resource needed to achieve primary stability and successful outcome of dental implantation [36–39]. Prolonged tissue exposure is also known to have a negative effect on postoperative course due to the increased release of pro-inflammatory cytokines and amplified inflammatory response [40]. In order to achieve less hands-on-time in dental implant surgery and to improve on accuracy, a simplified drilling protocol was pursued. Therefore, a protocol with guided support, achieving less micromovement, was set up. Previous studies have reported that simplifications of the traditional gradual expansion result in bone apposition to implants that is comparable with traditional techniques [41, 42]. Several publications suggested, that reducing the number of drill steps is not compromising clinical results [13, 14, 43]. Limiting the duration of surgical intervention is argued to be not only causing more patient satisfactory but also to be leading to better healing [44].

Many implant manufacturers do provide alternative and simplified preparation protocols. These protocols have been reviewed with regard to duration of the bone formation process and success in osseointegration [42, 44]. Defective or delayed bone formation is more related to wider implant diameters due to prolonged healing time. These findings were observed in conservative drilling protocols as well as simplified procedures [41, 45]. Literature also provides indications, that incremental preparation of bone potentially results in an interference during the drilling steps caused by bone debris transportation [46]. Additionally, data is available from a study that compared a multi-stepped drill protocol to a single-stage implant site preparation. Here, analysis of thermal influences during the drilling process was performed and outcome of primary stability was evaluated by resonance

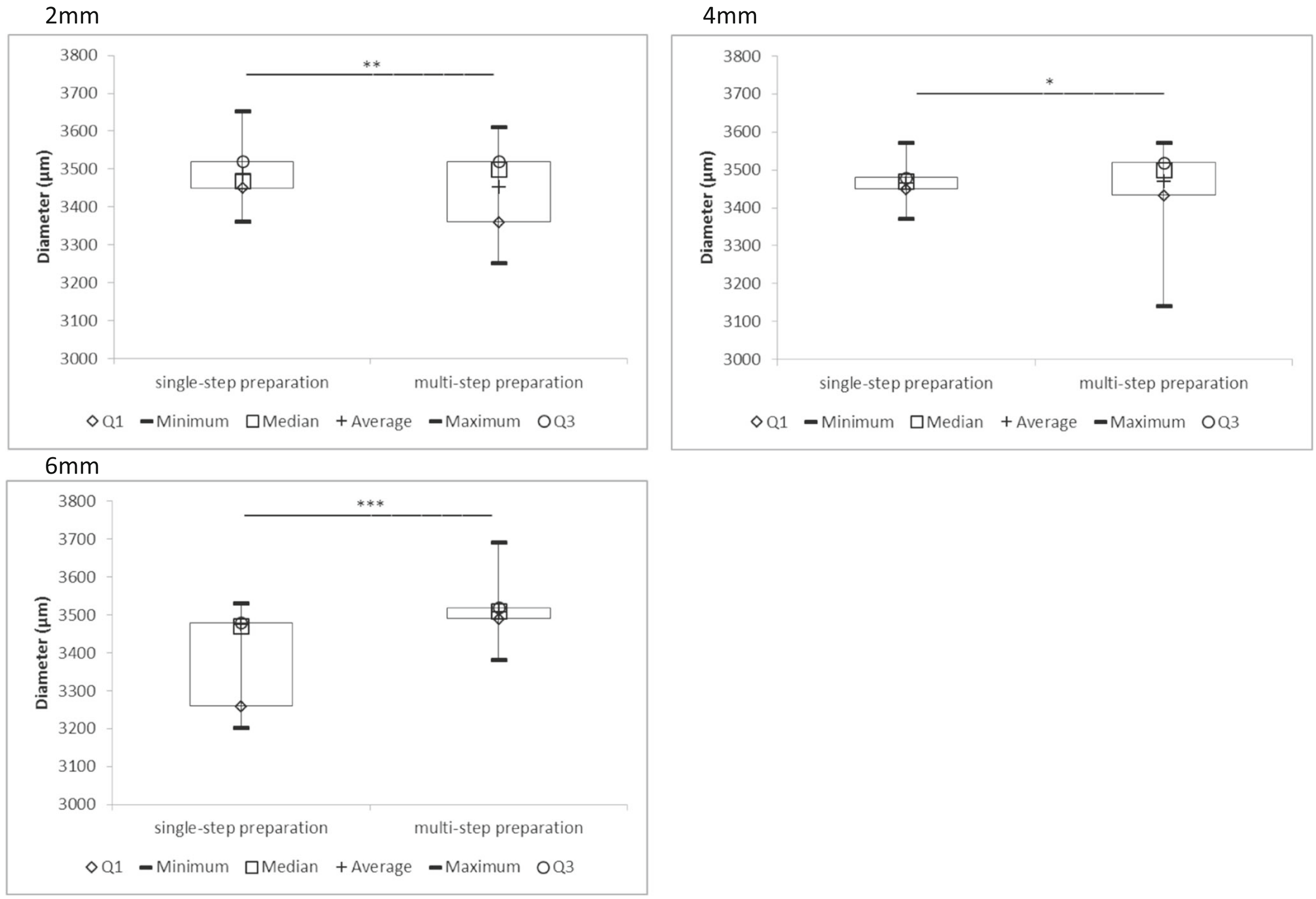

Fig. 6 Level of accuracy remains equal between single- and multi-step technique by not template-guided preparation performed by persons with low level of expertise. Diameter measurement of the internal radius of drill holes in porcine mandibles performed with a 3.25-mm gauge drill according to instructions of manufacturer (Bego, Bremen, Germany). Plottings show Averages, Medians, Minima and Maxima, and Q1 and Q3, as well as significances of drill holes diameter measurement. Drill holes were prepared by unexperienced operators by multi-step and single-step technique without template guidance. Results of measurement in drill holes in depth of 2 mm (a), in depth of 4 mm (b), and in depth of 6 mm (c) are illustrated. Level of significance is marked with asterisks: ** = $p \leq 0.01$, *** = $p \leq 0.001$

frequencies analysis. In contrast to the present study, these experiments were performed in artificial bone samples. Results showed that implant stability was higher when single-staged drilling technique was used, compared to incremental drilling protocol. The authors see a possible explanation for the greater stability in the press-fit theory. Additionally, reduced site preparation time and thus lesser bone tissue damage were emphasized as advantages of the single-step technique [47]. In the present study, the aspect of beneficial reductions in preparation time, when using a single-stage protocol, was incorporated into an analysis of alternative drilling procedures. These analytical aspects were supplemented with measurement of precision of the produced drill holes.

Our data was obtained from experiments using natural bone and provides rather life-like (true-to-life) conditions. In the present study, it was possible to confirm the published results, performed in artificial material. Our results indicated higher accuracy of implant preparations generated by single-step drill protocols, which might result in an increased primary stability. Due to characteristic structural inhomogeinities in natural bone, the in vitro specimens provide almost ideal physical properties. Clinical conditions may show less precise results for the single-drill sites due to movement of the guides or potential restriction of access during surgery. But we expect the relations of our findings to stay valid. That may be supported by clinical studies [15, 48]. Our results significantly indicated that a reduction of the number of drilling steps leads to a reduction of potential sources of errors.

The multi-step procedure, providing the more complex workflow, was showing an increase of discrepancies in the diameter of the implant site preparation. Other factors for harmful heat production during preparation than the pure time, should be kept in mind. Especially, when simplified drilling protocols are more susceptible to interference of worn out instruments. Several studies show that temperature increases when life span of drills is exhausted after multiple usage [49, 50]. Evaluation of cutting capacity, instrument sharpness, and

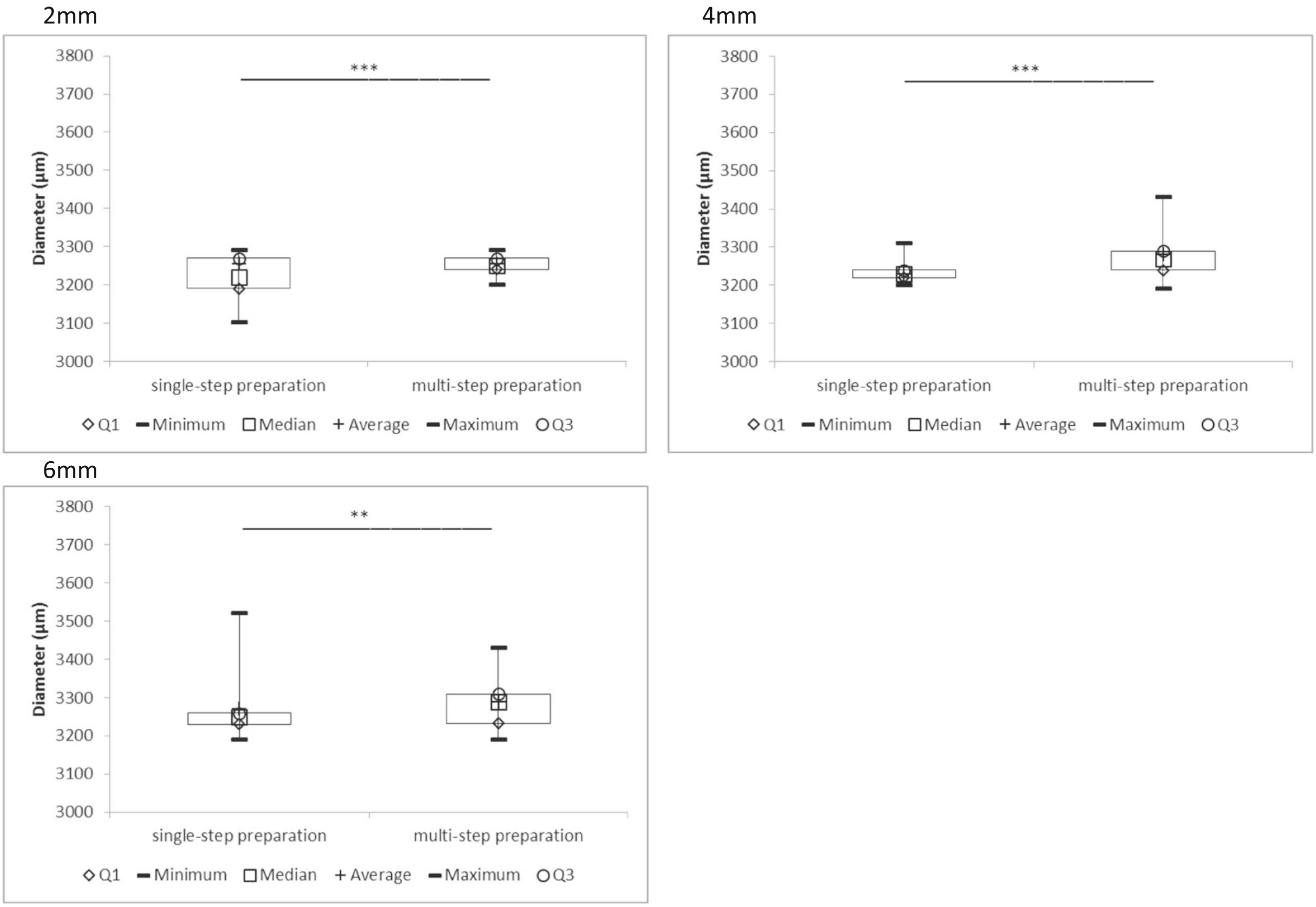

Fig. 7 Improved accuracy was observed when experienced operators were executing singe-step technique without help of template guidance. Diameter measurement of the internal radius of drill holes in porcine mandibles performed with a 3.25-mm gauge drill according to instructions of manufacturer (Bego, Bremen, Germany). Plottings show Averages, Medians, Minima and Maxima, and Q1 and Q3, as well as significances of drill holes diameter measurement. Drill holes were prepared by experienced operators by multi-step versus single-step technique. These drilling actions were compared without support of template guidance. Results of measurement in drill holes in depth of 2 mm (a), in depth of 4 mm (b), and in depth of 6 mm (c) are illustrated. Level of significance is marked with asterisks: ** = $p \leq 0.01$, *** = $p \leq 0.001$

potential corrosion is required in context of shortened drilling procedures with less incremental steps [44]. Another disadvantage of short drilling protocols is the severely limited chance for operators to correct any noticed errors during the preparation procedure. Therefore, the single-step protocol method is advised only for clinicians with high experience. Generally, these data strongly recommended the use of surgical guides, especially in simplified protocols [44]. Multi-step drilling technique carries the option of detecting and adjusting the axis of misaligned implant sites in early stages. A reduction of the number of incremental steps down to a single-drilling phase also demands a steeper learning curve, even for experienced surgeons [14, 43]. These statements are concordant to our experimental results indicating higher degree of accuracy produced by operators with high expertise level. We see in the application of surgical guidance a beneficial technical aspect to achieve improvement of accuracy and primary stability.

Accuracy of freehand implantation may be sufficient in many clinical situations, if presurgical planning is performed accurately [51, 52]. But several studies indicate that the accuracy of axis and implant position is significantly more precise by usage of surgical guides than with the manual method. Surgical guidance also reduces the risk of damage to adjacent structures [53, 54]. Guided techniques lead to improved survival and success over freehand techniques, especially in type III and IV bone and provide potential of immediate restoration [55–57]. Our results demonstrate the beneficial effect of drill guidance in both drilling techniques with view to the drill holes diameters. Enhanced time and expenses required for fabrication of individual surgical guides has to be taken into account. However, this investment in time and labor is partially balanced by a reduction of chairside treatment time through implementing the single-drill technique. The improved outcome as a result from higher

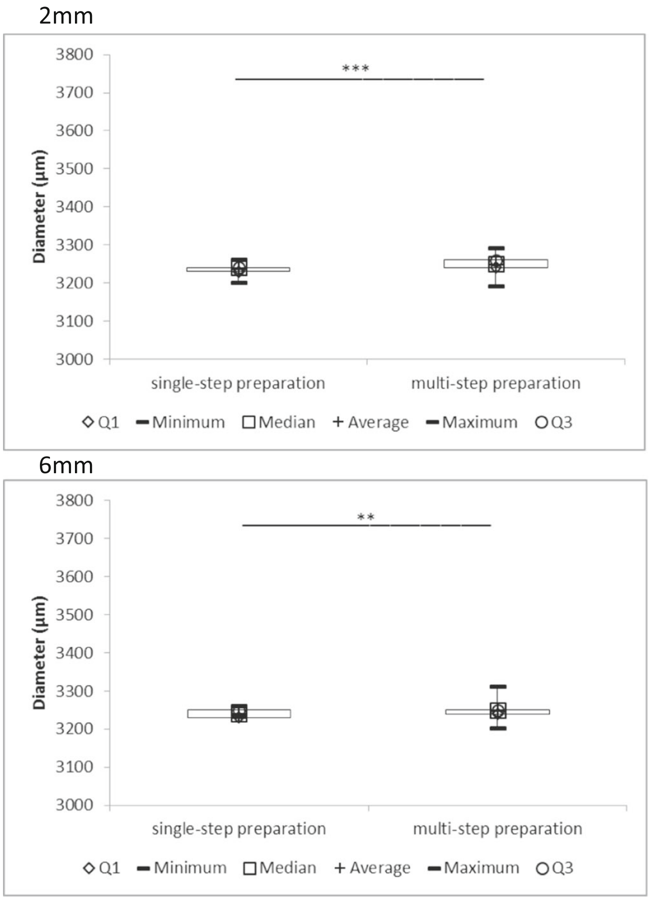

Fig. 8 Additional application of guiding templates can increase accuracy levels of experts using single-step implant site preparation. Diameter measurement of the internal radius of drill holes in porcine mandibles performed with a 3.25-mm gauge drill according to instructions of manufacturer (Bego, Bremen, Germany). Plottings show Averages, Medians, Minima and Maxima, and Q1 and Q3, as well as significances of drill holes diameter measurement. Drill holes were prepared by experienced operators by multi-step technique. These drilling actions were compared with regard to support of template guidance. Results of measurement in drill holes in depth of 2 mm (a), in depth of 4 mm (b), and in depth of 6 mm (c) are illustrated. Level of significance is marked with asterisks: $** = p \le 0.01$, $*** = p \le 0.001$

accuracy, might justify the added time and expense, besides the possibility of simplifying the drilling protocol. Additionally, simplified techniques using a single-drilling step just require a single-drilling guidance. This aspect is advantageous, as the multi-step technique requires multiple guides that have to be changed corresponding to each drill diameter throughout the surgery. The combination of surgical guidance and single-drill technique allows for restorations to be precisely placed and for minimal intra-operative discomfort for the patient.

Results of the present study also confirmed that placement of dental implants with use of templates for guided drilling can be performed with more precision and less risk. This advantage is shown to be regardless of the level of expertise of the practioner. Knowledge and experience of practioners is a key factor in avoiding and managing complications during the surgical procedure. In particular individual anatomy and poor access of the oral cavity especially in the posterior quadrant are challenging. These abilities and clinical conditions will show a strong impact on the clinical outcome in vivo; however, the necessary model environment cannot be simulated in an in vitro study. With multi-step drilling technique, it is possible to adjust the axis of misaligned implant sites. By reducing the number of incremental steps to a single-drilling phase, a learning curve is required even for experienced surgeons [14].The present data clearly indicates these findings and strongly supports the opinion that simplified protocols need assistance of guided drilling.

In conclusion, the present data indicates that simplified drilling protocols, like the single-drill technique, supports accuracy in dental implantation.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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