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Manual vs. motorized insertion of dental implants – what is more precise in the hands of a novice?

Manuell oder motorisiert – Welche Implantationstechnik erzielt bei Anfängern die größere Präzision?

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Für meine Familie

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1. Abstract

1.1 Summary

Introduction: Accurate positioning of dental implants is essential for clinical success, esthetic outcomes and patient satisfaction. The precision of implant placement, especially in freehand procedures, remains a crucial factor, particularly for novice practitioners.
In this in vitro study, the influence of implant insertion methods - either using a manual ratchet or a surgical motor - and bone quality on the accuracy of dental implant placement was investigated, with regard to angular deviations.

Material and method: A phantom simulating a mandible with an edentulous space spanning both premolars and the first molar was used and synthetic bone blocks representing four types of bone quality (based on the Lekholm and Zarb classification) could be positioned in the edentulous space. Eighty titanium implants were inserted using either a manual ratchet or a surgical motor. All procedures were carried out by a novice clinician. Angular deviations between the final drill axis and final implant position were assessed using two-dimensional radiographs in bucco-lingual and mesio-distal directions. Statistical analysis was based on intraclass correlation coefficients, Shapiro-Wilk tests, Levene's test, ANOVA and Tukey's Honest Differences test with the level of significance set at $\alpha=0.05$.

Results: Mean deviations ranged from 0.86° to 3.79° with a clear trend towards greater deviation in the mesio-distal direction as compared to the bucco-lingual direction. Manual insertion led to significantly lower deviations than motorized insertion ($p=0.001$), particularly in the mesio-distal plane. Bone quality also played a role, with the lowest deviations found in bone quality IV as compared to bone quality I ($p=0.029$).

Discussion: These findings suggest that manual insertion using a ratchet causes less deviations as compared to using a surgical motor for novice practitioners under idealized in vitro conditions. Additionally, lower-density bone may guide the implant more precisely along the predrilled osteotomy. However, this study also highlights the limitations of in vitro models and simplified radiographic methods. Despite these constraints, the study underlines the importance of insertion technique and bone quality in determining implant placement accuracy. Future research should include three-dimensional analyses and clinical validation to further substantiate these findings.

1.2 Zusammenfassung

Einleitung: Die präzise Positionierung von dentalen Implantaten ist entscheidend für den klinischen Erfolg, ästhetische Ergebnisse und die Patientenzufriedenheit. Besonders bei freihändiger, nicht geführter Implantation stellt die Genauigkeit der Implantatinsertion einen kritischen Faktor dar – insbesondere bei begrenzter klinischer Erfahrung. In dieser In-vitro-Studie wurde der Einfluss der Insertionstechnik sowie der Knochenqualität in Bezug auf Winkelabweichungen untersucht. Ziel dieser Studie war es herauszufinden, ob eine signifikante Achsabweichung bei manueller oder motorisierter Implantatinsertion auftreten kann.

Material und Methode: In ein Unterkiefermodell mit zahnlosem Areal regio 44-46 konnten synthetische Knochenblöcke vier verschiedener Qualitäten eingesetzt werden, die die Knochenqualitäten gemäß der Klassifikation nach Lekholm und Zarb repräsentierten. Insgesamt wurden 80 Titanimplantate entweder manuell oder motorisiert in die Blöcke aus Polyurethanschaum inseriert. Die Winkelabweichungen zwischen der finalen Bohrung und der Implantatposition wurden mithilfe zweidimensionaler Röntgenbilder in bukkolingualer und mesiodistaler Richtung gemessen. Die statistische Auswertung erfolgte über Intraklassen-Korrelation, Shapiro-Wilk-Tests, Levene-Test, Varianzanalyse (ANOVA) und Tukey post-hoc Tests. Das Signifikanzniveau wurde bei $\alpha = 0{,}05$ festgelegt.

Ergebnisse: Die mittleren Winkelabweichungen lagen zwischen 0,86° und 3,79°, wobei sich deutlich größere Werte in mesiodistaler Richtung im Vergleich zur bukkolingualen Richtung zeigten. Die manuelle Insertion führte zu signifikant geringeren Abweichungen als die motorisierte Insertion (p=0,001), insbesondere in der mesiodistalen Ebene. Auch die Knochenqualität hatte einen Einfluss: Die geringsten Abweichungen wurden bei Knochenqualität IV festgestellt, im Vergleich zu Knochenqualität I (p=0,029).

Diskussion: Diese Ergebnisse deuten darauf hin, dass die manuelle Insertion mittels Ratsche unter idealisierten In-vitro-Bedingungen bei limitierter klinischer Erfahrung zu geringeren Abweichungen führt als die motorisierte Insertion. Zudem scheint Knochen geringerer Dichte das Implantat präziser entlang der vorgegebenen Osteotomie zu führen. Die Studie weist jedoch auch auf die Einschränkungen von In-vitro-Modellen und vereinfachten röntgenologischen Verfahren hin. Trotz dieser Limitationen unterstreicht sie die Bedeutung der Insertionstechnik und der Knochenqualität für die Präzision der Implantatinsertion. Zukünftige Untersuchungen sollten dreidimensionale Analysen und klinische Validierung umfassen, um diese Ergebnisse weiter zu untermauern.

2. Introduction

2.1 Treatment concept of dental implantology

Dental implantology is of great importance in modern dentistry, as dental implants are increasingly the first choice in cases of tooth loss. Patients can be offered durable and esthetically pleasing solutions that contribute significantly to maintaining their quality of life without harming healthy teeth.
Many implant treatment options for partially or completely edentulous patients can be considered a predictable and reliable treatment concept due to the high success rates of current dental implant systems (Karl & Irastorza-Landa 2017; Jorba-García et al. 2021; Moraschini et al. 2015).
However, the success of implant treatment depends not only on the selection of the implant system, but also to a large extent on the precision of implant positioning and the choice of a suitable surgical protocol, being either bone-specific or implant-specific. Various studies show that deviations from the preoperatively planned implant position are associated with an increased risk of complications, which can result in both functional and esthetic limitations (Jorba-García et al. 2021; Romanos et al. 2019; Gaêta-Araujo et al. 2020).

2.2 Surgical and prosthetic driven implant position planning

Since the exact positioning of a dental implant is an important and decisive factor for successful restoration, optimal function and esthetics, surgical and prosthetic planning must be closely coordinated. Patients increasingly value professional competence and expertise and expect outcomes that fulfill both functional and esthetic demands.
Today, several methods are available for determining the ideal implant position. While conventional two-dimensional radiographs are still used, cone beam computed tomography (CBCT) has become the gold standard for implant planning due to its higher precision and ability to assess anatomical structures in three dimensions (Jacobs et al. 2018; Benavides et al. 2012; Guerrero et al. 2006). When combined with intraoral scanning, CBCT enables prosthetically driven planning by allowing virtual restoration designs to guide the ideal implant positioning and angulation (Jorba-García et al. 2021).
Virtual planning software translates the digital planning and simulation into the clinical procedure contributing to greater accuracy and predictability while reducing the likelihood of intraoperative complications (Wang et al. 2022; Hultin et al. 2012; Pellegrino et al. 2021; Kunzendorf et al. 2021).

Incorrect insertion of an implant, on the other hand, can lead to postoperative complications. From a prosthetic perspective, angulations preventing the proper insertion of abutments or requiring complex, time-consuming and expensive prosthetic corrections, can occur.
Poorly positioned implants can cause soft tissue recession or asymmetrical gingival contours or even buccal bone resorption, resulting in esthetic limitations, particularly in the anterior maxilla. Functionally, implants that are placed too close to neighboring teeth or nerves can lead to discomfort, long-term bone loss or even implant failure (Romanos et al. 2019; Greenstein et al. 2008; Hämmerle and Tarnow 2018; Martin et al. 2014; Buser et al. 2004). Therefore, precise implant position planning is essential to ensure long-term clinical success and patient satisfaction.

2.3 Surgical procedure/ Insertion method

Overall, very few studies (Novsak et al. 2015; Orban et al. 2022; Dal Molin Molinari et al. 2016) are available evaluating the impact of the insertion process of dental implants.
While conventional freehand methods for implant insertion are still commonly used, computer-aided implant surgery (CAIS) has become increasingly established in recent years as a precise method to enhance the accuracy of implant positioning and for transferring preoperative planning into clinical reality (Hultin et al. 2012; D'haese et al. 2017; Panchal et al. 2019).

2.3.1 Static and dynamic computer aided implant surgery (CAIS)

CAIS can be divided in static (sCAIS) and dynamic (dCAIS) systems. Computer-aided implant surgery includes static systems, which use stereolithographic surgical guides being supported by teeth, mucosa, or bone during the preparation and insertion phases (Hämmerle et al. 2009), and dynamic systems which are based on real-time optical tracking and refer to the preoperative 3D plan obtained by CBCT imaging (Jung et al. 2009; Vercruyssen et al. 2014; Block & Emery 2016). Both CAIS systems appear to result in reduced practitioner variability compared to the conventional freehand technique (D'haese et al. 2017; Block & Emery 2016). Static systems can be subdivided into half-guided approaches, where only the pilot osteotomy is guided and subsequent steps are performed freehand, and fully guided approaches, which control both osteotomy and implant insertion. Half-guided techniques are widely used in clinical practice due to advantages such as improved irrigation, easier access in patients with limited mouth opening, and the possibility of manual adjustments during surgery (Ilhan et al. 2021). Although some studies report improved implant positioning compared to freehand surgery (Raabe et al. 2023; Subramani et al. 2022; Taheri et al. 2023; Chen et al. 2022), Orban et al. (2022) found no significant differences in their clinical study.

Fully guided static protocols, as described in literature reviews and in vitro studies, are considered the most accurate option for transferring the planned implant position to the surgical site (Gargallo-Albiol et al. 2020; Raabe et al. 2023). Higher cost, limited intraoral space, and compromised cooling during drilling, potentially requiring intermittent osteotomy to mitigate thermal effects (Kuster et al. 2021; Lamazza et al. 2020, Sekura et al. 2024), constitute the associated disadvantages.

Dynamic CAIS systems offer the benefit of real-time navigation without a surgical guide. While initial systematic reviews showed promising results, these were mainly based on in vitro data (Jung et al. 2009). More recent studies show progress in precision and clinical applicability (Hultin et al. 2012; Panchal et al. 2019), although dynamic systems currently still show greater deviations and therefore higher inaccuracies compared to static navigation (Taheri et al. 2023).

2.3.2 Freehand method

Despite the increasing availability of digital planning tools and guided surgical techniques, the traditional freehand method remains widely used in dental implantology. It is a familiar and flexible approach that does not require additional equipment or a complex planning software. Primarily, this technique relies on the clinician's experience and manual skills.

In the freehand approach, both osteotomy and implant insertion are performed without the aid of surgical guides or even simple laboratory templates - often due to the additional expenses associated with guided surgery, limited intraoral space, or the experience of the surgeon (Li et al. 2023; Wang et al. 2022; Kuster et al. 2021). Depending on the surgeon's preference, implants may be placed using either manual wrenches or surgical motors (Novsak et al. 2015). Manual insertion is often valued for its tactile feedback, while motorized insertion offers a more controlled torque and generally ensures a smoother process.

Nevertheless, the lack of visual or mechanical guidance increases the risk of deviations from the planned position, which in turn may compromise or complicate prosthetic outcomes (Li et al. 2023; Wang et al. 2022; Kuster et al. 2021).

2.4 Bone quality

Alveolar bone quality constitutes an additional key factor influencing treatment success. The varying characteristics of cortical and trabecular bone affect both primary stability and the risk of thermal injury during osteotomy (Lekholm & Zarb 1985; Dal Molin Molinari et al. 2016; Bayarchimeg et al. 2013). In clinical reality, different anatomical situations such as partially or fully edentulous jaws require individual concepts for implant planning and insertion. An essential goal is to avoid damaging vital structures, for example nerves or the maxillary sinus, while simultaneously achieving precise implant placement (Laviv et al. 2023). The macroscopic distinction between cortical and trabecular bone is well known. However, both types vary significantly in their density and composition depending on patient-specific anatomy and their general health status. These variations affect both, the drilling process and heat development within bone. Dal Molin Molinari et al. (2016) have shown that the insertion technique chosen has an influence on temperature development in bone, which in turn may have an impact on bone viability.

Several classification systems have been described in implant dentistry. The most widely used appears to be the classification according to Lekholm & Zarb (1985), in which bone is assessed based on its quality. In this method, bone is subjectively classified into four types based on the ratio of cortical to cancellous bone. Another method for describing bone quality is the classification according to Misch et al. (1990). It is based on the tactile perception during implant site preparation and the Hounsfield unit (HU) for classification, and is used to classify the density and structure of the bone at potential implant sites. Wang et al. (2023) present a more recent method for classifying bone quantity and quality at the implant site. Unlike subjective or purely visual classifications, this system is based on measurable values using CBCT image analysis. They classify cortical and cancellous bone separately and use CBCT for quantitative analysis, providing dentists with a reference basis for grading bone quality prior to implant surgery. However, predicting implant success based solely on bone quality remains unreliable. According to Nicolielo et al. (2020) implant survival appears to be highest in intermediate bone types. In dense cortical regions, deviation from the planned implant position may occur, especially in cases of asymmetrical resistance during the drilling process. This has been observed in an in vitro study with orthodontic mini-implants, in which bone density and implant length influenced implant deviation (Annamalai et al. 2022).

Pre-drilling and expanding the implant site can help minimizing bone damage and at the same time ensure sufficient primary stability (Taing-Watson et al. 2015). Modern implant surgery aims to achieve minimally invasive and accurate results, considering bone structure and the individual anatomy of the patient.

2.5 Experience of the practitioner

According to Wang et al. (2022), dental implant surgery, which used to be a domain of specialists, has become a common approach for novice dental practitioners.

However, there are hardly any studies that evaluate the accuracy of novice versus specialist dentists in implant surgery. In an in vitro study, Wang et al. (2022) investigated the performance of inexperienced versus experienced practitioners in placing dental implants using three approaches (freehand, static guide and dynamic navigation). The parameters in question were the actual implant deviation relative to the planned position, the time required for implant placement and questionnaire-based self-confidence evaluation of practitioners. With the navigation approach, novice practitioners showed accuracy and self-confidence comparable to that of experienced specialists and overall an improved level of accuracy for implant placement with less deviation (Pellegrino et al. 2021; Ilhan et al. 2021; Block et al. 2017; Aydemir & Arısan 2020).

Another study comparing novices versus specialists examined the accuracy of single tooth implantation via a digital registration method (Li et al. 2023). The angular deviations were significantly higher in the student group than in the instructor group for the freehand approach. Nevertheless, the angular deviation of the freehand group was significantly lower after the students gained more experience.

The authors concluded that the experience of the practitioner can be an important component for treatment success (Wang et al. 2022; Li et al. 2023).

2.6 Aim of this in vitro study

The aim of this in vitro study was to investigate the influence of different insertion techniques on the accuracy of implant positioning. Particular attention was paid to the comparison of manual versus motorized insertion of one specific dental implant system performed by a novice practitioner with regard to angular deviations (Subramani et al. 2022; Wang et al. 2022). To address the role of bony structures in dental implantology, the surgical procedure was performed in simulated alveolar bone resembling different qualities.

3. Materials and methods

3.1 Model of implantation

The selected implantation model simulated a mandibular patient situation with an edentulous gap spanning the region 44-46 (FDI). This edentulous space on the right side of the mandible was the anticipated implant site. The mandibular model was fixed on a base plate (suitable for a phantom head, KaVo, Biberach, Germany) with biresin (Biresin SIKA, Stuttgart, Germany; Fig. 1).

To reuse the model within the test series, the area of the prospective implant site could be provided with an exchangeable bone block. Each bone block was fixed in the model (Annamalai et al. 2022; Putra et al. 2022) during the test procedures using two horizontal screws (Fig. 2) and the mandibular model was positioned in a phantom head (KaVo, Biberach, Germany), equipped with a maxillary model and a face mask.

Each implantation test procedure (implant site preparation and implant insertion) involved the placement of a new bone block.

Figure 1*: Mandibular model with an edentulous space spanning both premolars and first molar on the right side. The model is fixed on a base plate and is shown here without a bone block and screws.*

***Figure 2**: Mandibular model with an inserted bone block fixed with two horizontal screws. The metal pin in the mesio-lingual corner of the bone block was used for orientation purposes of subsequent x-rays.*

3.2 Bone block

Polyurethane foam material was used as bone surrogate material (Solid Rigid polyurethane foam, Sawbones Europe AB, Malmö, Sweden).

The bone blocks were available in four different qualities with varying cortical and trabecular bone thicknesses – with the trabecular bone consisting of a low-density to very low-density portion and the covering cortical layer with varying thicknesses (1-3mm) – mimicking the Lekholm and Zarb classification (Lekholm & Zarb, 1985; Fig. 3, Tab. 1):

Lekholm and Zarb	Cortical Bone	Trabecular Bone
I	3mm 30pcf Solid Foam	12mm 20pcf Cellular Foam
II	2mm 30pcf Solid Foam	13mm 20pcf Cellular Foam
III	1mm 30pcf Solid Foam	14mm 20pcf Cellular Foam
IV	1mm 30pcf Solid Foam	14mm 10pcf Cellular Foam

***Table 1:** Composition of the polyurethane blocks used for simulating different bone qualities.*

The bone blocks were cut using a customized high-precision circular saw (Feinschnitt-Tischkreissäge, Proxxon, Wecker, Luxemburg) to a rectangular shape with a mesio-distal length of 20mm, a bucco-lingual width of 13mm and a height of 15mm to exactly fit the patient model.

A total of 80 bone blocks were utilized in this study resulting from 20 blocks for each of the four different bone qualities equaling a sample size n=10.

In order to have an orientation point, each bone block was provided with a pin hole and corresponding metallic model pin (Amann Girrbach AG, Mäder, Austria) adjacent to the anticipated implant site in the mesio-lingual corner, which was then secured with cyanoacrylate (3M™ Scotch-Weld™, 3M Deutschland GmbH, Neuss, Germany; Fig. 4). The position of the implant site in the center of the bone block (10mm x 65mm) was marked on the bone blocks using a custom-made template.

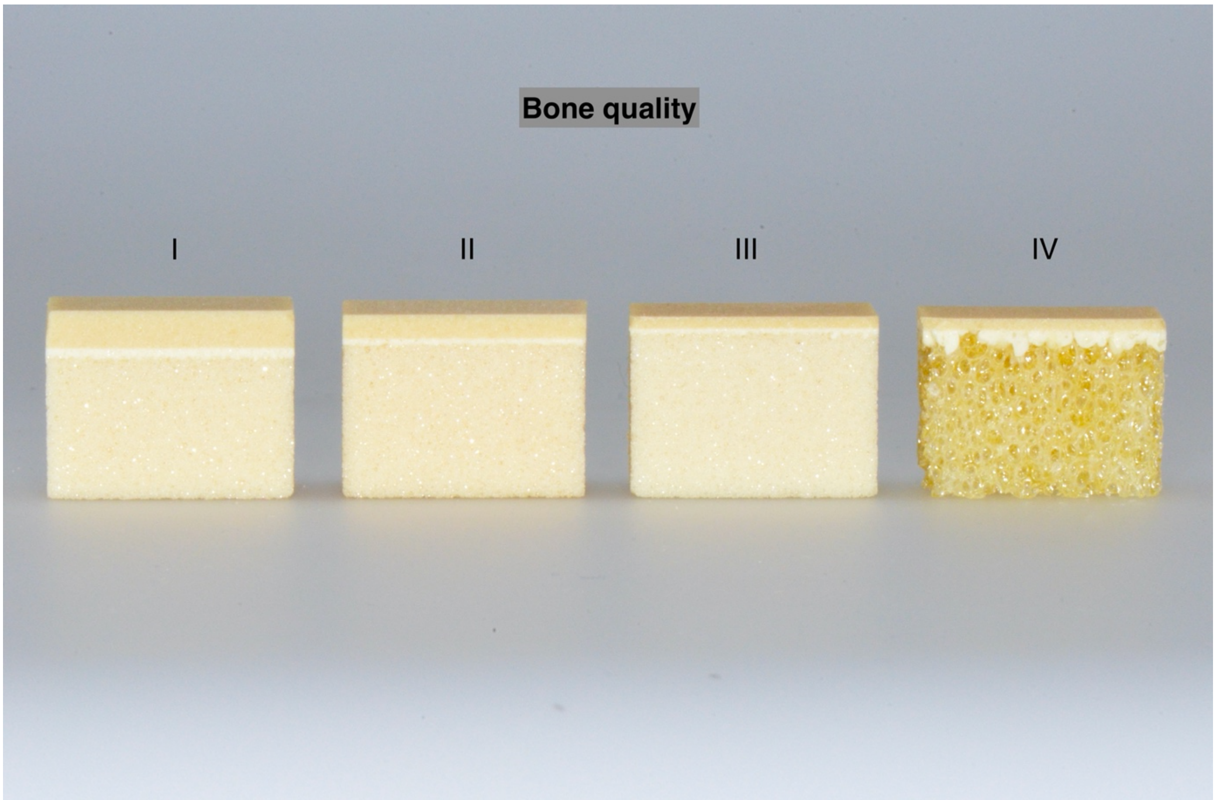

Figure 3: *Polyurethane foam materials used for the simulation of four different bone qualities according to Lekholm and Zarb. The composition of each block is outlined in Table 1.*

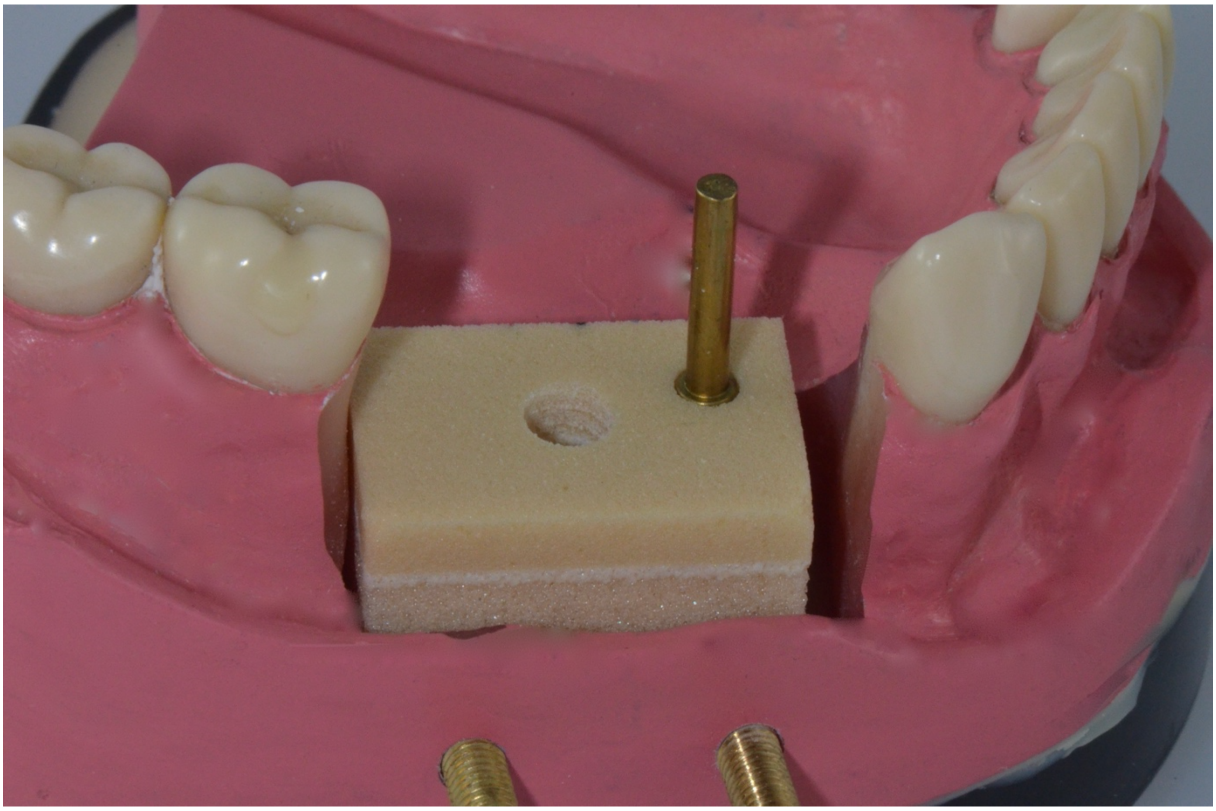

***Figure 4**: Bone block inserted in the mandibular model. The metallic pin is positioned in the mesio-lingual corner of the block adjacent to the implant site prepared in the center of the block.*

3.3 Implantation material and surgical devices

80 tapered implants (Max Implant, Alfa Gate, Kfar Qara, Israel) made of titanium with a diameter of 4.2mm and a length of 11.5mm were used.

The default drill protocol involved five twist drills starting at a diameter of 1.9mm and the final drill having a diameter of a 3.65mm (Alfa Gate, Kfar Qara, Israel; Fig. 5).

A contra-angle handpiece (Expertmatic LUX E15L, KaVo, Biberach, Germany) driven by a surgical motor (KaVo Master Surg, KaVo Dental, Biberach, Germany) was used for implant site preparation (Fig. 5) and implant insertion (Fig.6). The osteotomy sites were prepared based on the values recommended by the manufacturer (Fig. 7). For the manual implant insertion the implant manufacturer's ratchet wrench was used (Fig. 8, Alfa Gate, Kfar Qara, Israel).

***Figure 5**: Contra-angle handpiece with the final twist drill to be used (3.65mm diameter; Alfa Gate, Kfar Qara, Israel).*

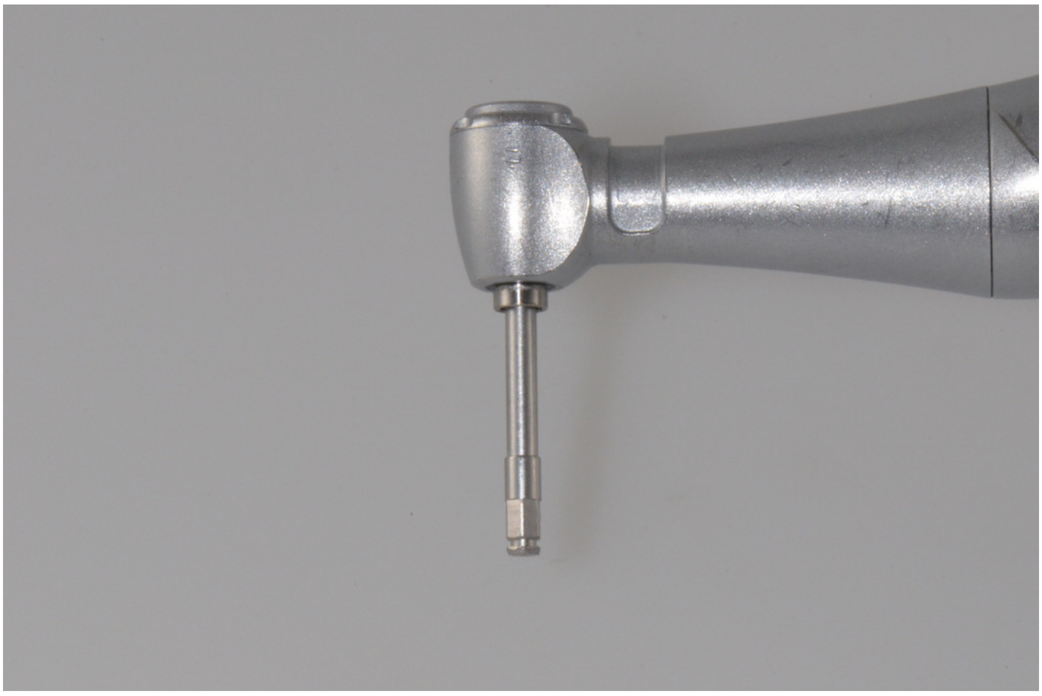

***Figure 6**: Standard platform implant insertion driver (Alfa Gate, Kfar Qara, Israel) mounted in the contra-angle handpiece.*

Figure 5: *Surgical motor with the parameters set for implant insertion.*

Figure 6: *Universal ratchet wrench (Alfa Gate, Kfar Qata, Israel).*

3.4 Implantation protocol and radiography

The first step of the simulated free-handed implant surgery included the bone block being placed in the mandibular model fixed with two horizontal screws. The next step was to mount the model in the phantom head (KaVo, Biberach, Germany). This procedure was followed by the implant protocol adhering to the manufacturer-recommended protocols:

The implant sites were prepared drilling parallel to the tooth 43 (FDI) with the final drill being the bespoke twist drill, until a parallel walled implant site of 3.65mm in diameter and a depth of 12mm was reached (Fig. 9). With the final drill in place, the bone block was removed from the mandibular model for the first set of digital radiographs. The first two X-ray images (Subramani et al. 2022; Annamalai et al. 2022) were taken (60kV, 7mA, 0,5s; Heliodent, Dentsply Sirona, York, PA, USA) with the inserted drill and a custom-made X-ray device (Fig. 10). This X-ray device enabled a reproducible situation: the bone blocks and the X-ray tube could always be positioned and exactly aligned in the same way. The images were taken once in the bucco-lingual direction and once perpendicular in the mesio-distal direction (Verhamme et al. 2013), ensuring that both the drill and the pin were fully visible (Fig. 11).

Afterwards, the twist drill was removed from the bone block which was later screwed back into the mandibular model for implant insertion (Fig. 12).

Implant insertion was performed either by hand using the implant manufacturer's ratchet or by using the surgical motor. The second set of radiographs was then taken in analogy to the X-ray procedure mentioned above with each inserted implant with the implant carrier attached, always making sure that both the inserted implant with the implant carrier and the pin were fully visible. All steps and measures were carried out by one novice clinician.

Figure 7: *Implant site preparation with inserted 12mm twist drill.*

***Figure 8**: Custom-made X-ray device: 1. Set for the bucco-lingual direction, 2. Set for the mesio-distal direction.*

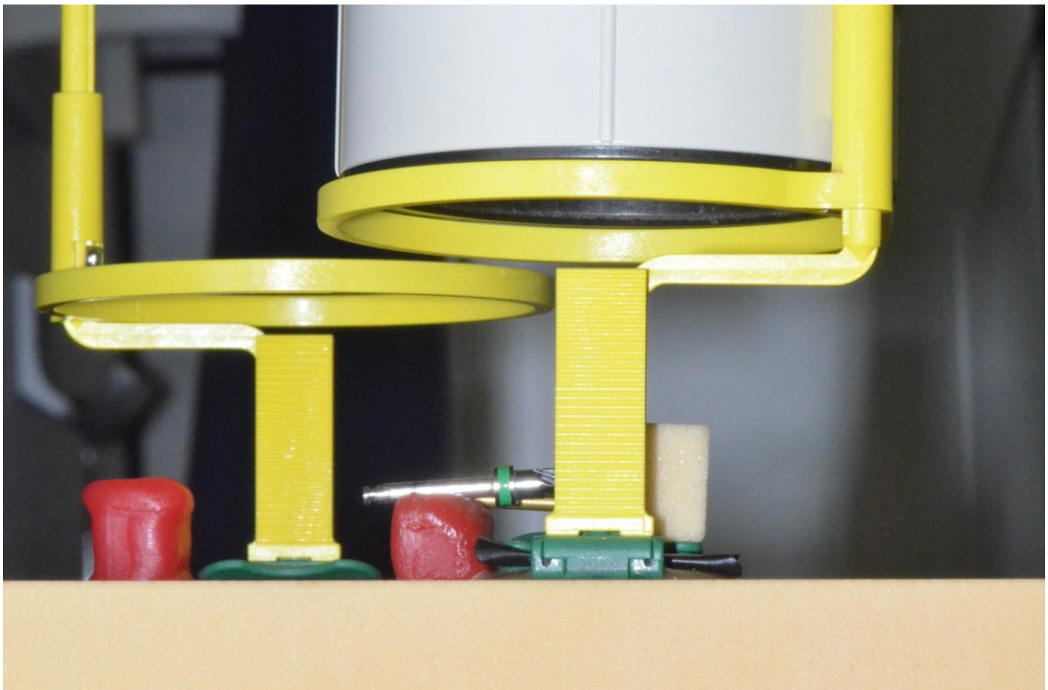

***Figure 9**: Bone block positioned for the X-ray in bucco-lingual direction. The X-ray tube is perfectly aligned with the positioning tool.*

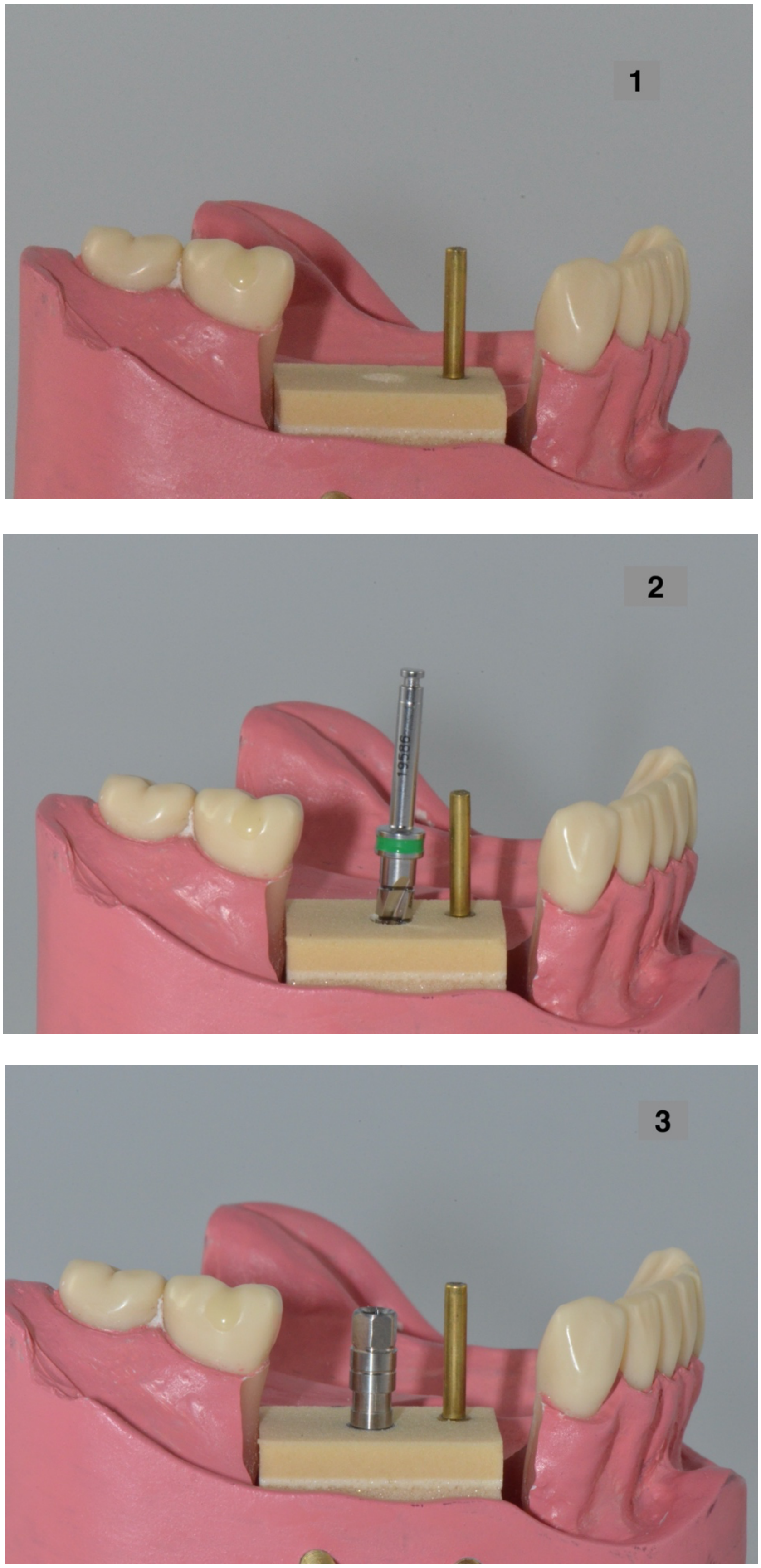

Figure 10*: Mandibular model with inserted bone block in the three stages of the study: 1. Implant site prepared, 2. Drill positioned, 3. Implant inserted*

3.5 Radiographic analysis

A total of four images were available for each bone block: two images in the bucco-lingual direction (implant site preparation and implant insertion) and two in the mesio-distal direction (implant site preparation and implant insertion; Fig. 13).

The angle measurements were carried out by one blinded person using the software ImageJ (U.S. National Institutes of Health, Bethesda, MD, USA). They were repeated twice on separate days.

For the analysis of the radiographs, the long axis of the drill or implant were identified and marked (red line) in the X-ray images. To define the longitudinal axis of the drill, a straight line was drawn through the drill tip and the center of the drill shaft. For the implant, the longitudinal axis was defined by a line drawn along its sagittal axis.

The cortical surface of the bone blocks was as well identified and highlighted (yellow line), so that an angle measurement between the drill or the implant respectively and the cortical surface was possible. Deviation was determined by subtracting the angle measured for the implant from the angle measured for the corresponding drill, with regard to the bucco-lingual and the mesio-distal direction (Wang et al. 2022).

To assess the accuracy of the analysis technique, samples with known angular deviations of 1°, 3° and 5° were created and analyzed.

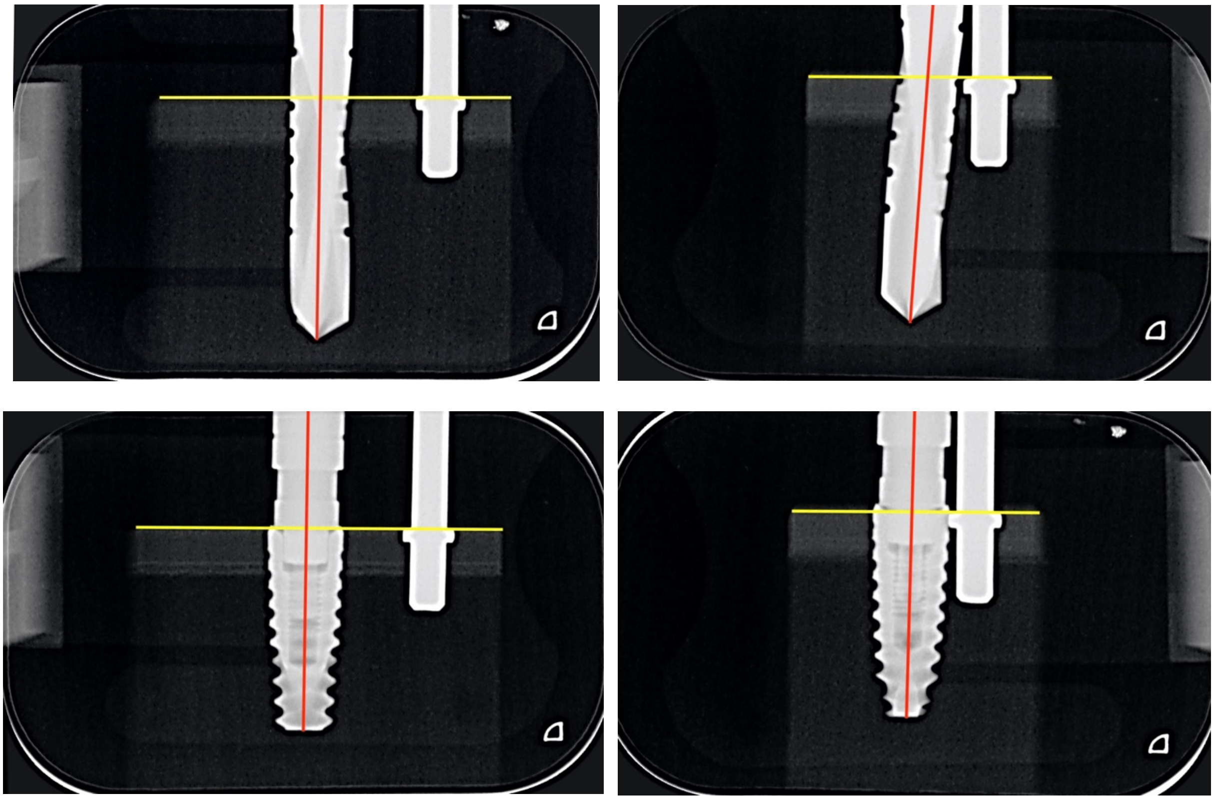

***Figure 11**: First and second set of Radiographs in the bucco-lingual direction on the left side (drill in the left upper picture, implant in the left lower picture) and in the mesio-distal direction on the right side (drill in the right upper picture, implant in the right lower picture). The long axis of the drill and implant is marked red, the cortical surface is marked yellow.*

3.6 Statistical analysis

The deviation was determined by the subtraction of the angles measured for the drill and implant. Statistical analysis was based on mean values being calculated on the basis of the three measurements performed. Intraclass correlation coefficients (ICC) were calculated to assess the reliability of the three measurement series (McGraw & Wong 1996; Shrout & Fleiss 1979).

Comparative statistical analysis used two-way analysis of variance and post-hoc Tukey mean comparisons following to Shapiro-Wilk tests for normality of the measurement distribution and the homogeneity of variance (Levene test).

The level of significance was set at $\alpha=0.05$ for all comparisons performed.

4. Results

4.1 Radiography

Three measurement series of the total of 80 specimens were carried out as described previously.

4.2 Overview of all measurements

The calculated mean values and standard deviations for all measurements are shown in Figure 14, providing an overview of the distribution of the deviations determined in this study.
The intraclass correlation coefficients (Table 2) were used to evaluate the consistency between the three different measurement series, indicating a good level of consensus between the three series.
Shapiro-Wilk tests were performed to check the normality of distribution of the measured values with only three exceptions: Bone Quality I - Motor Insertion - Bucco-lingual p=0.048; Bone Quality II - Motor Insertion - Mesio-distal p=0.039; Bone Quality III - Hand Insertion - Bucco-lingual p=0.0123 demonstrated in table 3.
Levene's test revealed a p-value of 0.062 indicating homogeneity of variances. Due to the balanced design of the experiment with equal sample sizes, ANOVA could be considered as being robust against the minor violations of its prerequisites.

4.3 Direction of measurement (bucco-lingual vs. mesio-distal)

The mean deviations ranged from 0.86° (bone quality III – motor insertion – bucco-lingual) to 3.79° (bone quality III – motor insertion – mesio-distal), revealing that the direction of measurement had a significant influence on the deviations.
The clearly greater deviations occurred – regardless of bone quality – in the mesio-distal direction compared to the bucco-lingual direction.
The analyses of variance in the bucco-lingual direction showed no significant differences (Table 4), while such significant differences were observed in the mesio-distal direction, which were considerably influenced by the bone quality (p=0.028) and the insertion method (p=0.001) (Table 5a).

4.4 Bone quality

Following comparisons between the groups were carried out using Tukey's Honest Differences test (Table 5b). The results showed a significant difference between bone quality I and IV (p=0.029), with smaller deviations observed in bone quality IV.

4.5 Insertion method

In addition, significant differences were also identified using Tukey's Honest Differences test (Table 5b) between the two insertion methods (p=0.001), with manual implant insertion leading to lower deviations.

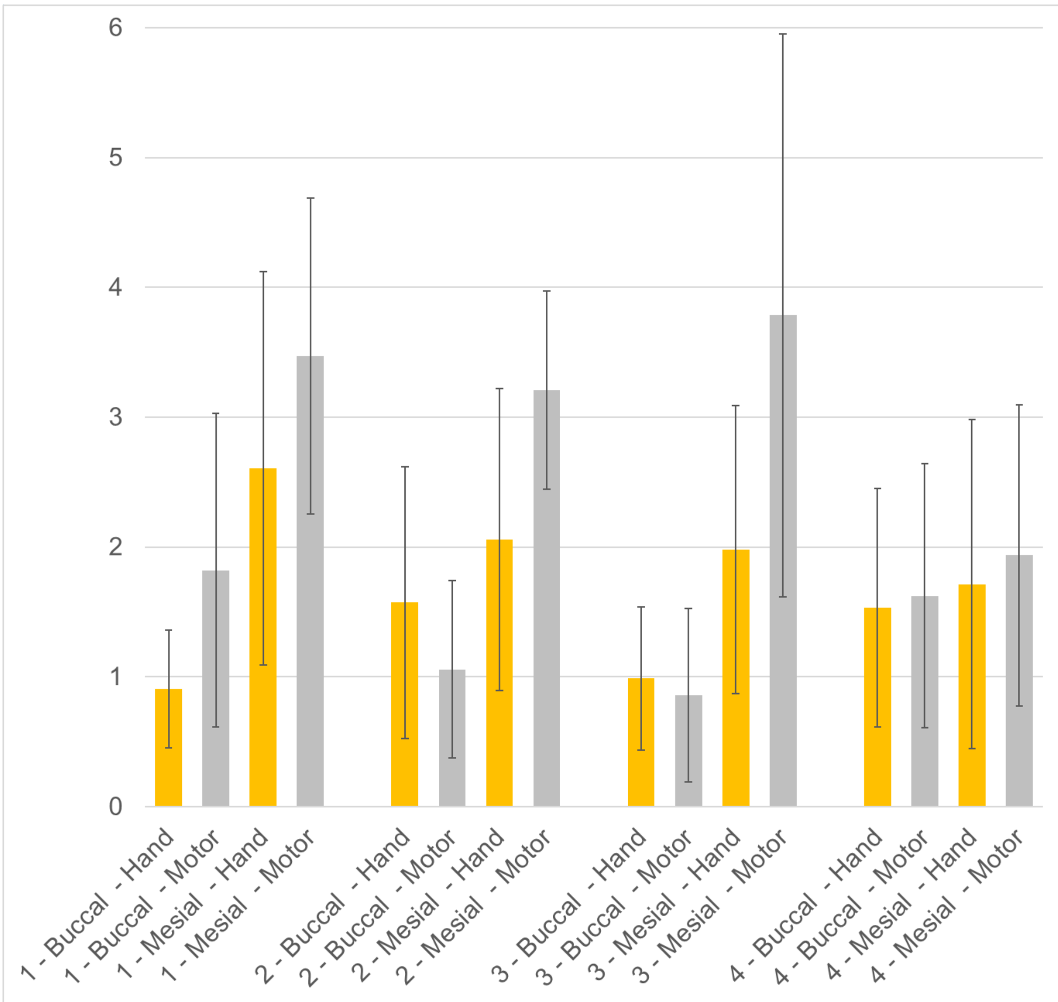

Figure 14: *Mean values and standard deviations determined for the four different groups.*

	buccal	mesial
Drill	0.803	0.880
Implant	0.793	0.900
ICC Interpretation < 0.50: poor 0.50 - 0.75: moderate 0.75 - 0.90: good > 0.90: excellent		

***Table 2**: Intraclass correlation coefficients (ICC) for the evaluation of the consistency between the three different measurement series in this study.*

Bone quality	Buccal		Mesial	
	Hand	Motor	Hand	Motor
I	0.484	**0.048**	0.371	0.099
II	0.270	0.312	0.928	**0.039**
III	**0.012**	0.214	0.787	0.251
IV	0.724	0.257	0.078	0.086

***Table 3**: Results of Shapiro-Wilk tests to examine the normal distribution of measurement values. Significant differences (p<0.05) are written in bold.*

	Sum of squares	Degrees of freedom	F-value	p-value
Bone quality	4.5	3	2.04	0.116
Insertion method	0.2	1	0.23	0.635
Bone quality : Insertion method	5.5	3	2.48	0.068
Residuals	52.7	72		

***Table 4**: Results of the analyses of variance (ANOVA) based on measurements made in the bucco-lingual direction. Significant values are written in bold.*

	Sum of squares	Degrees of freedom	F-value	p-value
Bone quality	17.5	3	3.19	**0.028**
Insertion method	20.4	1	11.19	**0.001**
Bone quality : Insertion method	6.5	3	1.18	0.322
Residuals	131.2	72		

Table 5a*: Results of the analyses of variance (ANOVA) based on measurements made in the mesio-distal direction. Significant values are written in bold.*

	Difference	Lower	Upper	adjusted p-value
Bone qualities				
II vs.I	-0.404	-1.527	0.719	0.780
III vs. I	-0.156	-1.279	0.967	0.983
IV vs. I	-1.213	-2.336	-0.090	**0.029**
III vs. II	0.248	-0.875	1.371	0.938
IV vs. II	-0.809	-1.932	0.314	0.239
IV vs. III	-1.057	-2.180	0.066	0.072
Hand vs. Motor	1.01	0.408	1.611	**0.001**

Table 5b*: Results of Tukey multiple comparisons of means. Significant values are written in bold.*

5. Discussion

The creation of an osteotomy that corresponds exactly to the previous planning is often the primary goal in implant surgery, whereas the insertion of the implant is rarely seen as critical and it is assumed that the implant will follow the predrilled path. It is also presumed that manual insertion provides greater tactile feedback and enables more precise adjustment, especially of the vertical implant position, while motorized insertion avoids the moving lever arm seen when using the ratchet.

So far only one clinical study with several co-factors (Orban et al. 2022) was found comparing manual and motorized implant insertion. The aim of this in vitro study was to evaluate the potential effect of the two most common implant insertion methods on implant angulation.

5.1 Discussion of material and method

5.1.1 Model of implantation and bone block

The present study was designed as a strictly standardized in vitro investigation to analyze the differences between manual and motorized implant insertion under controlled conditions.

Synthetic polyurethane foam has been widely used as bone surrogate in several biomechanical tests, as this material exhibits a similar cell structure and consistent biomechanical characteristics to human bone structure (Comuzzi et al. 2023). The use of standardized polyurethane bone blocks with four defined bone qualities according to the classification of Lekholm & Zarb (1985) took into account different anatomical conditions to ensure an approximation to clinical reality. However, it does not reproduce all the biomechanical and biological attributes of living bone such as blood supply, elasticity and microarchitecture.

3D printed dental models have proven their high accuracy and reproducibility in dental education (Zhang et al. 2019; Emir & Ayyildiz 2020). However, their use requires upfront investment and technical expertise, including specialized equipment, trained personnel and post-processing steps (Dawood et al. 2015). Advances in 3D printing techniques and materials are likely to enable the production of more cost-effective and realistic simulation models (Richter et al. 2022).

Animal models such as minipig mandibles (Grobecker-Karl et al. 2019), porcine cadavers (Scherer et al. 2015), and sheep tibiae (Karl et al. 2013) are commonly used in current research.

Human cadavers are also utilized as implantation models to investigate effects of implant macrodesign and diameter on primary stability (Akkocaoglu et al. 2005; Turkyilmaz et al. 2009). In vivo implant placement remains a central focus of recent systematic reviews (Tang et al. 2019; Michelinakis et al. 2021; Gkioka & Rausch-Fan 2024).

5.1.2 Position of implant insertion

Another aspect of standardization was the restriction to only one specific implant position with simulated ideally healed implant sites, which allowed the implantation accuracy to be tested under the best possible conditions. This facilitated the interpretation of the results with regard to the influence of the insertion method. Cohort-specific co-factors such as the implant region influencing implant placement accuracy (Taheri et al. 2023) or the timing of implant placement were not applicable. Chen et al. (2022) showed, that implants placed at post-extraction sockets resulted in more deviations than those from delayed placement. According to Raabe et al. (2023) significantly higher implant position accuracy was also found at healed sites compared to extraction sockets.

Such co-variables should be considered in further studies.

5.1.3 Surgical procedure (freehand vs. CAIS)

The decision to use a freehand implantation procedure in this study should be mentioned. In contrast to current clinical approaches, which increasingly rely on fully-guided implantation protocol, the freehand procedure being performed by a novice implantologist can be seen as a worst case scenario with respect to precision. Studies have confirmed the superiority of guided implant placement over freehand implant placement (Hämmerle et al. 2015). In guided procedures, drill guides define the axis not only during the osteotomy, but also - in the case of fully guided implant placement - during insertion, which has been found to lead to fewer complications (Jorba-García et al. 2021) and potentially leading to less deviation.

Excluding surgical guides allowed the study to focus exclusively on how the insertion method – manual or motorized – affected implant deviation.

5.1.4 Experience of the practitioner

Since all implantations were performed by one single practitioner, the influence of inter-individual variability could be excluded.

A common thought is that a more experienced operator is able to place implants more accurately (Cushen & Turkyilmaz 2013). Rungcharassaeng et al. (2015) showed, that the vertical deviation of the implants placed by inexperienced operators was greater than by the experienced operators, although not significant.

For those cases, Wang et al. (2022) and Li et al. (2023) showed that navigation systems equalize the performance of experienced vs novice practitioners as compared to freehand implant surgery. Under clinical conditions, dynamic computer assisted surgery systems allow for more accurate implant placement in comparison with the conventional freehand method, regardless of the surgeon's experience (Jorba-García et al. 2018). Orban et al. (2022) emphasize this by stating that a major advantage of the guided approach is that surgical skills do not have a major influence, and go even further claiming that the surgeon's experience does not have a significant effect on the outcome.

5.1.5 Radiographic analysis

Only a very simplistic analyzing technique based on intraoral radiographs has been used here as described in a previous study (Annamalai et al. 2022). However, this is also associated with potential measurement inaccuracies. The study addressed this problem by carrying out three rounds of evaluation. This allowed for checking the reproducibility of the measurements and demonstrated a good level of reproducibility.

3D scanning and matching (Raabe et al. 2023; Song et al. 2023; Verhamme et al. 2013) would have been a more contemporary and less operator-dependant alternative. Intraoral scanning has proven to be a reliable, radiation-free method for accurately determining three-dimensional implant positions, particularly in clinical practice (Stoetzer et al. 2014).

A deliberate decision was made not to record vertical deviations but instead implants were inserted flush with the bone surface. In clinical studies, the deviation in the insertion depth is often evaluated critically, as even minor vertical drilling errors could lead to trauma of vital anatomical structures.

Possible major complications being sensory damage involving the peripheral branches of the trigeminal nerve (e.g. the inferior alveolar nerve, the mental nerve, the lingual nerve), leading to transient or permanent sensation loss or neuropathic pain (Laviv et al. 2023).

In line with Wang et al. (2022) and Verhamme et al. (2013), only angular deviations in the bucco-lingual and mesio-distal planes were measured, as these are considered most critical from a prosthetic perspective – especially with regard to long-term treatment success.

5.2 Discussion of the results

5.2.1 Influence of the insertion method

Initially, no significant difference in precision in the bucco-lingual direction was found between manual and motorized insertion. Both methods achieved comparable accuracies in this dimension.

In contrast, there was a clear advantage of manual insertion in the mesio-distal direction with significantly lower axial deviations occurring when the implants were inserted manually as compared to motorized insertion.

In both directions, the deviations were on average within a range that can be considered acceptable in the context of freehanded implantations. Valente et al. (2009) found in a clinical study comparing the three-dimensional positions of planned and placed implants a maximum deviation of 8°. The values determined in the current study are therefore quite realistic in view of the in vitro setup used (Bover-Ramos et al. 2018).

A recent clinical study by Orban et al. (2022), which evaluated a half-guided surgical protocol, described mean angulation errors of approximately 4° and horizontal deviations of 1.06 - 1.28mm - with no significant differences between motorized and manual insertion. However, in that study all parameters measured (coronal deviation, apical deviation and angular deviation) showed a trend towards higher values with motorized insertion compared to manual insertion (Orban et al. 2022). The results herein match the results of the present study. The differences are minimal and unlikely to affect the clinical outcome of the prosthetic restoration, as both methods produced only minor positional and angular deviations.

5.2.2 Influence of the bone quality

The effect of bone quality was relatively small and reached statistical significance only in the comparison between the two extremes of bone classes I and IV. A lower bone quality, with only a thin cortical layer and sparse trabeculae in cancellous bone (bone class IV) led to lower deviation. Implants in compromised alveolar bone followed the predrilled path precisely, whereas greater deviations occured in dense bone with thick cortical and trabecular structures. In an in vitro study with orthodontic mini-implants, Annamalai et al. (2023) investigated the deflection from the planned drilling path as a dependence of bone density and implant length. Their results showed that both bone quality and implant length had a significant influence on the deviation with denser bone material seemingly reducing deviation, while longer mini-implants showed greater deviation.

Cristache et al. (2017) showed, that differences in accuracy were noticed when analyzing implants inserted in maxilla and mandible. For the mandible, significant lower angular deviations (p=0.03) were found compared to the maxilla, with maximum angular deviations in the mandible of 3.9° and in the maxilla of 4.22°. This also indicates an influence of bone quality on the accuracy of implant placement.

5.3 Limitations of the study

5.3.1 Materials and methods

<u>In-vitro-setting</u>

The implantation model and the synthetic bone blocks were used to simulate a clinical situation.

Clinical factors such as the patient's individual anatomy, blood flow, tissue resistance, reduced bone volume, and the implant site can lead to different outcomes. In vivo, existing restorations, misaligned teeth, limited mouth opening, soft tissue conditions, as well as blood and saliva can make implant insertion more difficult.

Although the use of standardized synthetic bone blocks with four different bone qualities offered a methodological advantage by generalizing the implant site, their material characteristics only approximate those of human cortical and trabecular bone. As a result, clinical applicability is limited, and the findings should be interpreted as an idealized scenario.

Implant parameters

Only one implant size and type was tested at a single position. In clinical reality, however, there is a variety of implants, differing in diameter, length and design. In particular, implant length has been mentioned in the literature (Annamalai et al. 2022; Cristache et al. 2017; D'haese et al. 2012) as a contributing factor for deviations.

5.3.2 Surgical procedure (Freehand vs. CAIS)

Deliberately omitting navigated aids was justified by research logic, but does not reflect the state of the art in implantology. In current clinical routine, drilling templates (statically guided) or dynamic navigation systems are increasingly being used, especially in complex cases, in order to increase accuracy (Hämmerle et al. 2015).

5.3.3 Analysis method and evaluation objectivity

Despite being repeated three times in order to minimize bias, the use of two-dimensional X-ray measurements is limited in terms of accuracy and objectivity. While the repeated measurements have shown a high degree of reproducibility, fully automated three-dimensional data collection would have offered greater precision, capturing nearly all components of accuracy (Pessoa et al. 2022; Raabe et al. 2023; Song et al. 2023; Verhamme et al. 2013; Stoetzer et al. 2014). The lack of a digital comparison of the implant position (using CBCT or 3D scan) therefore represents a methodological limitation. Small deviations may have gone undetected and the two-dimensional method provides no information about vertical discrepancies.

In summary, the aforementioned limitations create the framework within which the results of this study should be interpreted.

This study forms a component for understanding the topic of “manual vs. motorized” and should be supplemented by further studies, ideally with clinical validation.

5.4 Conclusion

Angular deviations were greater in the mesio-distal than in the bucco-lingual direction.
Smaller deviations were obtained in particular for bone quality IV and the manual insertion method, while dense bone caused a larger deviation in implant positioning.
Statistical tests confirmed that these differences were significant and not random (Tukey's Honest Differences test).
In conclusion, the study shows that both the bone quality and the insertion method have a significant influence on the deviations in the measured values and thus on the precision of the implant insertion.
When performing the insertion of a dental implant, clinicians should bear in mind that the insertion process itself can lead to axial deviations if the implant does not exactly follow the direction of the osteotomy.
Manual implant insertion as a novice practitioner appears to be less critical in terms of possible axial deviations, resulting in a higher degree of precision.

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7. Publications

Publication
Schulz A, Grobecker-Karl T, Karl M (2025):
Maschinelle versus manuelle Insertion dentaler Implantate.
Implantologie, accepted

Poster presentation
Schulz A, Grobecker-Karl T, Karl M:
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9. Curriculum Vitae

Aus datenschutzrechtlichen Gründen wird der Lebenslauf in der elektronischen Fassung der Dissertation nicht veröffentlicht.