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Repositioning accuracy of the implant- and abutment-level prosthetic components used in conventional and digital workflows

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A R T I C L E I N F O

Keywords:
Repositioning accuracy
Misfit
Tightening torque
3D displacement
Implant-abutment connection

A B S T R A C T

Objectives: To evaluate the repositioning accuracy of the implant- and abutment-level impression components (impression abutments and implant scan bodies) and implant abutments (with and without anti-rotational hex index); also, to estimate the tightening torque influence on the positional stability of abutments.
Methods: Seven types of prosthetic components ($n = 7$) [impression pick-up copings (PC), implant scan bodies (ISB), non-hex and hex titanium base implant abutments (TB H and TB NH), multi-unit impression copings (MU PC), multi-unit implant scan bodies (MU ISB), and multi-unit caps (MU C) (Medentika GmbH)] were tested. For repositioning accuracy tests a coordinate measuring machine (CMM) was used. During assembly 15 Ncm torque for all components was applied. After measurement, only hex and non-hex abutments were torqued to 25 Ncm and their coordinates were again recorded to assess torque influence. The procedure was repeated 7 times for each component. Linear and 3D deviations, angulation to the vertical axis, and axial rotation were calculated. The Kruskal-Wallis test was used to compare the measurements between the groups. A post-hoc test (Mann–Whitney U test) was used for pairwise comparison to determine the influence of the torque (α=0.05).
Results: Implant- and abutment-level components used for digital scans showed different positional discrepancies compared to ones used for conventional impressions and ranged from 10 to 37 µm. Hex abutments demonstrated statistically significantly lower 3D deviations (4.4 ± 7.1 µm) compared to non-hex abutments (8.7 ± 6.1 µm). Torque influence was significantly lower for hex abutments than for non-hex abutments.
Conclusions: Repositioning inaccuracies were found in all implant- and abutment-level impression components (impression abutments and implant scan bodies) and all abutments (with and without anti-rotational hex index) tested. Final tightening of the components could cause further positional discrepancies.
Clinical significance: The misfit of the prosthetic components used in conventional and digital workflows stays in the clinically acceptable range. Even when multiple connections and disconnections on the track of the laboratory preparation is needed, it should not have a negative influence for single teeth reconstructions. However, in the complex cases with multiple implants, repetitive repositioning of the prosthetic components may lead to the accumulation of vertical, horizontal and rotational errors leading to the clinical problems with the passive fit of the final framework.

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1. Introduction

Dental implants have been used for several decades as a treatment option for partial and total edentulism. Many studies have shown the long-term treatment success of implant-supported restorations [1,2]. Both clinical and laboratory aspects are very important to achieving lasting implant-supported dental prostheses. The implant positions can be transferred from the clinic to the dental lab in two ways - by conventional impression methods or digital scans.

A misfit of implant-supported restorations can occur because of impression inaccuracies and other errors building up during laboratory and clinical stages. Dental implants after osseointegration are functionally ankylosed, having direct contact with the bone without periodontal ligament support [3]. As a consequence, implants can only move approximately 3–5 μm in the axial direction and 10–50 μm in the lateral direction, while natural teeth show a range of movement of 25–100 μm in the axial direction and 56–108 μm in the lateral direction [3,4]. Unlike natural teeth, dental implants are much less able to compensate for the misfit of the restorations [5]. Therefore, the requirements for the accuracy of implant impression are very high.

The inaccuracies of conventional impression can be caused by impression technique, materials, number of implants, angulation, splinting of impression abutments, and other factors [6,7]. Equally, they can originate from the laboratory work, including implant cast fabrication, modeling, casting or milling, and other procedures resulting in dimensional deviations and the misfit of implant-supported prostheses [8,9].

Digital workflow facilitates interaction with the dental laboratory and eliminates some steps of production, as a result reducing working time and patient discomfort [10–14]. However, the accuracy of digital workflow is affected by different variables, such as scanning pattern, IOS type, characteristics of the implant scan bodies, 3D printing/milling of the implant cast, and prosthesis [10–21].

Many studies have investigated the factors associated with conventional impression methods and digital scanning techniques [15–19]. Most of these studies investigated the effect of impression technique, materials, number and position of implants, type of impression abutments, or implant scan body designs. However, these studies did not investigate the effect of malpositioning of the prosthetic components. Position instability of the different implant system abutments with conical implant-abutment connections can occur even during connection-disconnection of the implant abutment by hand [22]. Further, it was shown that after torque tightening, the vertical displacement of some abutments could exceed 100 μm [23]. Thus, rotation, linear displacement, and angulation changes can occur during the placement and tightening of the prosthetic components that could be of clinical significance. Little is known about the repositioning differences between engaging and non-engaging prosthetic abutments.

Corresponding impression abutments and implant scan bodies can be used with different implant systems. Some studies reported that the repositioning accuracy of implant scan bodies, when connected to implants, was 39 μm (±58 μm) [24]. Therefore, it is essential to define the repositioning accuracy of both impression components and abutments that are used with specific implant systems and to determine the effect of torque tightening. This can considerably affect the accuracy of conventional and digital workflow and exceed the accuracy levels of intraoral scanners and CAD/CAM devices. The research evaluating and comparing the repositioning accuracy of impression components and abutments used in conventional and digital workflows is currently lacking.

The misfit of 10 μm to 150 μm are considered clinically acceptable in the literature [23,24,25]. At the same time, the gap size between the abutment and implant hypothetically is desired to be smaller than any periodontally harmful bacteria (< 2 μm) [26]. However, it was found that crestal bone stability is more affected by the micro-movements of the implant-abutment connected rather than the gap size alone [27]. Numerous definitions of “passive fit” can be found [4,26-30]. The maximum possible passive fit of the implant-supported restorations should be achieved as implants are immobile due to the absence of the periodontal ligament [31]. Inaccuracies can also cause potential occlusal and interproximal contact problems that increase the need for chairside or laboratory adjustments and cause esthetic and functional problems. Failure to provide a sufficient passive-fit and appropriate occlusal contacts can lead to various complications after occlusal loading: fracture of the prosthesis, abutment screw loosening or fracture, or even implant fracture [31,32]. However, a retrospective study with a mean observation period of 19 years (range 12 to 32 years) found that the effect of misfit up to 230 μm could have limited long-term clinical results [33].

For a single crown fabrication usually, internal connection abutments with an anti-rotational element are used, and for a fixed partial denture – implant abutments without anti-rotational elements are commonly recommended. Multi-unit abutments and corresponding impression abutments, implant scan bodies, and caps are widely used for the full-arch cases [34].The aim of this in vitro study was to evaluate the repositioning accuracy of the implant- and abutment-level impression components (implant impression abutments and implant scan bodies) and implant abutments (with and without hex index) and to estimate the tightening torque influence on the positional stability of the implant-level prosthetic abutments. The null hypothesis was that the repositioning accuracy of the implant- and abutment-level impression components and abutments used for digital and conventional workflow do not differ significantly and that the tightening torque has no effect on this.

2. Materials and methods

Machined steel block ($h = 14$ mm, $w = 30$ mm, $l = 180$ mm, Ra=0.33 μm, Rz=2.25 μm) was used in coordinate measurements as a reference part. On the upper surface of the block, 7 holes (diameter of 5 mm) were drilled perpendicular to the top surface with a 25 mm distance between them. Seven Microcone (D 4,0 L 11,0) implants (Medentika GmbH, Hügelsheim, Germany) were fixed in the prepared holes of the steel block perpendicularly to the surface with acrylic resin material (Pattern Resin, LS; GC, Tokyo, Japan). Implants have 10° conical implant-abutment connection with a connection depth of 1,62 mm. Implant- and abutment-level impression and prosthetic components from the same manufacturer (Medentika GmbH) impression pick-up abutment (PC), implant scan body (SB), multi-unit impression abutment (MU PC), multi-unit implant scan body (MU SB), non-hex titanium base (TB NH), hex titanium base (TB H), multi-unit cap (MU C) were evaluated. Pictures, models and materials of each component are presented in Table 1.

To standardize the measurements, steel gauge blocks (Holex 481,070 7; Hoffmann Group, München, Deutschland) were attached to each measured component at exactly same position with acrylic resin material (Pattern Resin LS; GC) using a prefabricated matrix (Fig. 1). A coordinate measuring machine (CMM) (Global Performance; Hexagon Manufacturing Intelligence, North Kingstown Rhode Island, United States) equipped with scanning probe head (LSP-X3; Hexagon Metrology) and a software program (PC-DMIS; Hexagon Metrology S. p. A) were used to measure the position of the prosthetic components. Maximum permissible error (MPE) of the machine according to ISO 10,360–2 standard is MPE(E0)=1.5 + 1.0·L/333.0 μm and MPE(E150)= 1.5 + 1.0·L/333.0 μm. The maximum permissible probing error according to ISO 10,360–5 standard is MPE(PFTU)=1.6 μm and the maximum permissible limit repeatability of the range MPL(R0)=1.4 μm. Measurements were performed in the laboratory environment with a controlled temperature of 21 °C ± 0.5 °C and humidity of 50%. Pre-hit distance 0.7 mm, check distance 13 mm, touch speed 2 mm/*sec* during measurements were used. Measurements of specimens were performed by a mechanical engineer, who did not have any knowledge about implant dentistry. Deviations were measured at the level of 8 mm below

Table 1
Specifications, manufacturer codes, and pictures of the impression and prosthetic components included in the study.

	Components tested		Material	Recommended torque	Hex index
Impression components	Pick-up copings (PC) # 2–04–01		Titanium Grade 5CF	15 Ncm	+
	Scanbodies (SB) # 2–09–10		Titanium specially coated	15 Ncm	+
	Multi-unit Pick-up copings (MU PC) # 0–31–04		Titanium Grade 5CF	15 Ncm	–
	Multi-unit Scanbodies (MU SB) # 0–31–01		Titanium specially coated	15 Ncm	–
Prosthetic components	Non-Hex Ti bases (TB NH 15/25) # 2–09–15		Titanium Grade 5CF	25 Ncm	–
	Hex Ti bases (TB H 15/25) # 2–09–12		Titanium Grade 5CF	25 Ncm	+
	Multi-unit caps 15Ncm (MU C) # 0–31–06		Titanium Grade 5CF	15 Ncm	–

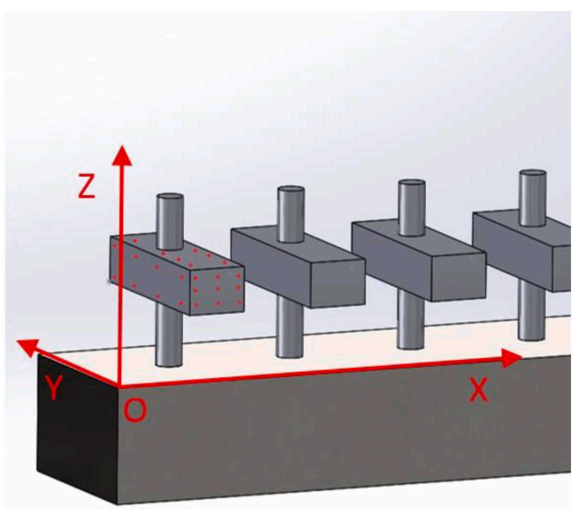

Fig. 1. Graphical representation of the steel block with an embedded dental implant and connected prosthetic component with attached gauge block. Red dots indicate the CMM measurement points.

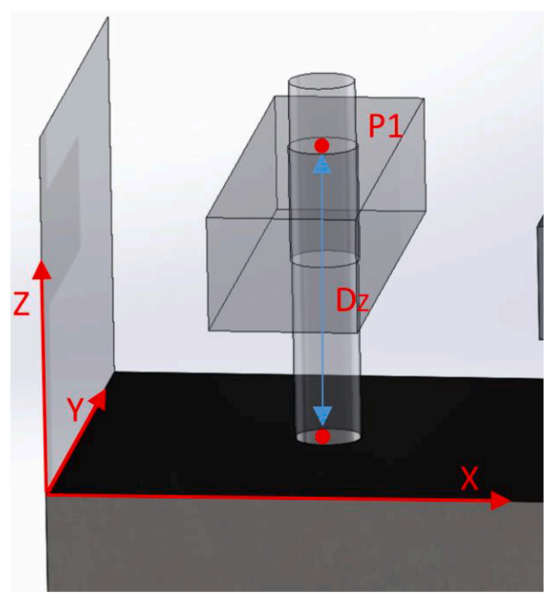

Fig. 2. All linear deviations were measured 8 mm below the top surface of the gauge block (Dz distance) in order to represent deviations at the implant prosthetic platform level.

the top of the steel gauge block, to represent deviations at the level of implant-abutment connection (Fig. 2).

Seven prosthetic components with an attached gauge block (test body) were screw-tightened (15 Ncm torque for all impression and prosthetic components was applied using the torque wrench) to the implants embedded in the steel block (reference part, Fig. 3) and positioned in the CMM. As the TB NH group had no anti-rotational element, the hard laboratory duplication silicon matrix (Elite Double 32, Zhermack, Badia Polesine, Italy) was fabricated using the TB H group. Hard silicon matrix ensured same positions of the steel gauge blocks in TB NH group as in remaining groups. Then, the coordinates of the components were recorded. In case of hex and non-hex titanium bases, they were next torqued to the final torque of 25 Ncm as recommended by the manufacturer and their coordinates were recorded again. The difference between the coordinate measurements after 15 and 25 Ncm torques was used to estimate the torque influence on the positional stability of TB NH and TB H. After the measurements, each component was disconnected from the implant and re-connected seven times and CMM measurements were repeated.

An automated program for the measurement of each test body position was created and used during each measurement. On the bigger XY and YZ surfaces of the test body, 8 evenly distributed points were measured respectively. However, the XZ surface were smaller than XY an YZ it was decided to add one more additional point in the middle of the smaller XZ surface and to use 9 points to ensure the reliability and

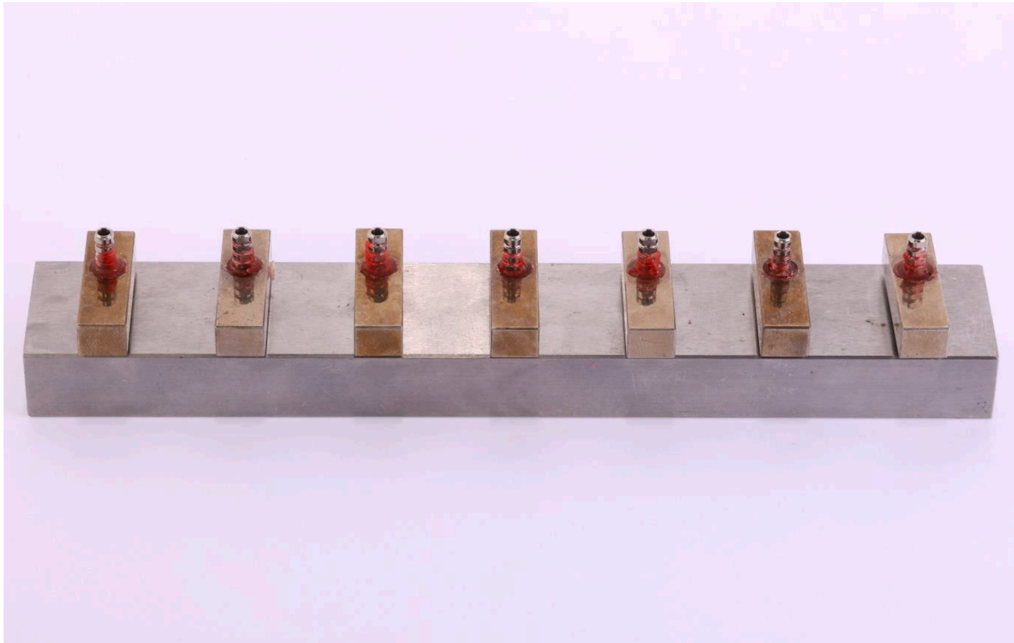

Fig. 3. The model with the embedded implants and the attached steel gauge blocks.

repeatability of measurements.

These points were used in order to create planes in the measured surfaces which could be used for the representation of test body position in the coordinate system. With the position of the hole in the test body known, created XZ and YZ planes were parallelly moved to the hole center point and the axis of the implant component was determined. The intersection of the axis with the XY plane of the test body allows the creation of point P1 which will be used for the evaluation of the component's position in the coordinate system. Linear deviations (in X, Y, Z axes, and 3D space), angulation to the Z axis, and axial rotation of the component were calculated.

The sample size calculation was done using software G*Power 3.1 (Heinrich, Heine University of Dusseldorf; Dusseldorf, Germany) with following parameters: size of effect 0.25, statistical power 0.8, and significance level 0.05. Statistical analysis of the displacements was performed using SPSS statistics 21.0 (IBM; Armonk, New York). As means and standard deviations of the absolute differences were skewed, they were summarized as medians and quartiles. The Kruskal-Wallis test was used to analyze if there were statistical differences between impression components and also abutment components torqued with 15 Ncm. A post hoc test (Mann–Whitney U test) was used for pairwise comparison to determine statistical differences (α=0.05). α was adjusted by using a Bonferroni correction for impression components ($0.05/6 = 0.0083$) and for abutment components torqued with 15 Ncm ($0.05/3 = 0.0167$).

3. Results

The results of the positional accuracy of the components evaluated in the study are presented in Table 2 and Figs. 4–7-6. Statistically significant differences were found between the groups ($P<0.05$).

3.1. Linear deviations

The 3D displacement (the net result of deviations in the X, Y, and Z axes) median value of the implant impression abutments (36.5 μm) was the highest among the impression components (SB - 16.1 μm; MU PC - 15.8 μm; MU SB - 10.4 μm). PC group results were statistically significantly different from MU PC and MU SB groups. The dimensional position of SB components varied the most (Fig. 4), which was extensively influenced by the angular deviation of SB (Fig. 5).

Hex abutments demonstrated significantly lower 3D deviations (4.4 μm) compared to non-hex ones (8.7 μm) and multi-unit caps (9 μm). When 25 Ncm torque was applied, hex abutments (6 μm) also had smaller dimensional deviations than non-hex ones (11.5 μm). Torque influence on 3D deviations was statistically significantly lower for hex abutments (11.8 μm) than for non-hex abutments (13.3 μm).

For all types of impression components, the lowest displacements were in the vertical (Z) axis (PC - 3.4 μm; SB - 1.7 μm; MU PC - 0.6 μm; MU SB - 0.8 μm) (Fig. 6). Implant-level impression components had

Table 2
The measurements (median values and interquartile ranges) of positional accuracy of the prosthetic components tested.

Components tested	X [μm]		Y [μm]		Z [μm]		3D [μm]		Angle to Z axis [°]		Rotation [°]	
	Median	IQR	Median	IQR	Median	IQR	Median	IQR	Median	IQR	Median	IQR
Pick-up copings (PC)	33.50	7.40	11.20	9.70	3.40	4.50	36.50	8.10	0.03	0.06	0.15	0.32
Scanbodies (SB)	4.00	5.10	7.60	40.00	1.70	2.40	16.10	37.70	0.06	0.24	0.41	0.49
Multi-unit Pick-up copings (MU PC)	13.60	11.60	6.40	10.00	0.60	0.70	15.80	10.70	0.01	0.01	–	–
Multi-unit Scanbodies (MU SB)	5.10	7.60	6.60	10.00	0.80	2.20	10.40	13.80	0.01	0.01	–	–
Ti base Non-Hex 15Ncm (TB NH 15)	1.70	3.70	2.60	4.50	7.60	6.20	8.70	6.10	0.02	0.02	–	–
Ti base Hex 15Ncm (TB H 15	1.20	4.20	1.90	6.00	1.90	3.00	4.40	7.10	0.03	0.03	0.10	0.21
Multi-Unit Caps 15 Ncm (MU C)	2.80	4.30	7.10	10.20	0.60	0.70	9.00	11.10	0.01	0.01	–	–
Ti base Non-Hex 25Ncm (TB NH 25)	5.10	6.40	4.70	5.20	5.20	7.10	11.50	8.50	0.02	0.03	–	–
Ti base Non-Hex 15Ncm (TB NH 15	1.80	3.10	2.70	6.30	2.90	3.30	6.00	8.90	0.02	0.03	0.22	0.55
Ti base Non-Hex Torque Influence	2.70	3.40	4.20	4.50	10.90	5.60	13.30	5.00	0.02	0.02	–	–
Ti base Non-Hex Torque Influence	1.20	1.30	1.60	1.30	11.50	3.40	11.80	3.50	0.01	0.01	–	–

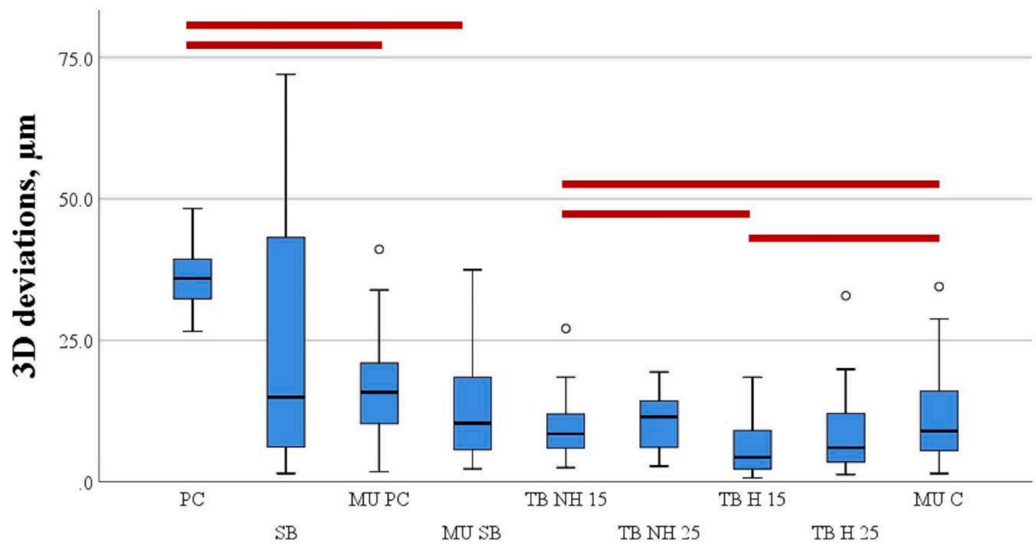

Fig. 4. Positional 3D deviations of tested components with statistically significant differences ($p<0.05$) between the groups marked with lines. (PC - Pick-up copings; SB - Scanbodies; MU PC - Multi-unit pick-up copings; MU SB - Multi-unit scanbodies; TB NH - Ti base non-hex, TB H - Ti base hex, MU C - Multi-unit caps.).

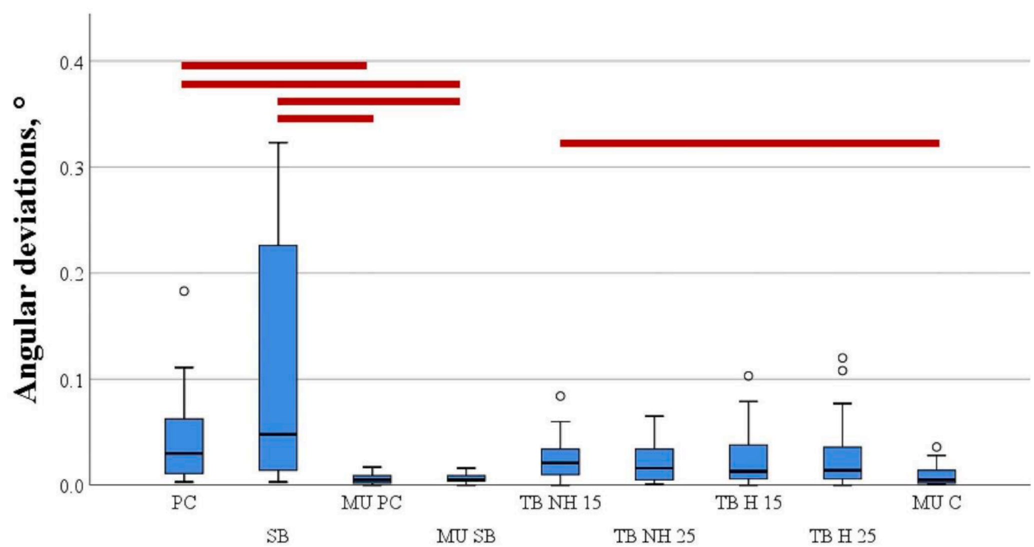

Fig. 5. Angular deviations of tested components with respect to the Z (vertical) axis with statistically significant differences ($p<0.05$) between the groups marked with lines. (PC - Pick-up copings; SB - Scanbodies; MU PC - Multi-unit pick-up copings; MU SB - Multi-unit scanbodies; TB NH - Ti base non-hex; TB H - Ti base hex; MU C - Multi-unit caps.).

statistically significantly higher vertical deviations than abutment-level impression components. However, no significant difference was found between SB and MU SB groups.

The statistically significant differences were found between all abutment components when 15 Ncm torque was applied (TB NH 15 - 7.6 µm; TB H 15 - 1.9 µm; MU C - 0.6 µm). With a torque of 25 Ncm, TB NH (5.2 µm) had a significantly higher vertical deviation than TB H (2.9 µm). Tightening to the final torque values did not significantly influence vertical discrepancies for TB NH (10.5 µm) compared to TB H (11.5 µm).

Deviations in X and Y axes represented displacement of components in the horizontal plane. Which for the impression components were larger (1.7 µm to 33.5 µm) and smaller for the abutments(1.2 µm to 7.1 µm).

3.2. Rotation

The rotation deviation could only be accurately measured between hex components that had anti-rotational elements. PC (0.15°) rotated less than SB (0.41°) and this difference was of statistical significance. (Fig. 7)

Higher torque applied to hex abutments increased the rotation angle from 0.10° to 0.22°

3.3. Angular deviation to vertical axis

SB (0.06°) had the highest angular deviation to Z axis among all impression components (PC - 0.03°; MU PC - 0.01°; MU SB - 0.01°). Implant-level impression components had statistically significantly higher angular deviations than abutment-level impression components.

TB NH 15 (0.02°) showed a significantly higher angular deviation to the Z axis than MU C (0.01°), while TB H (0.01°) did not differ significantly. Torque increase influenced angular discrepancies in TB NH (0.02°) and TB H (0.01°) groups.

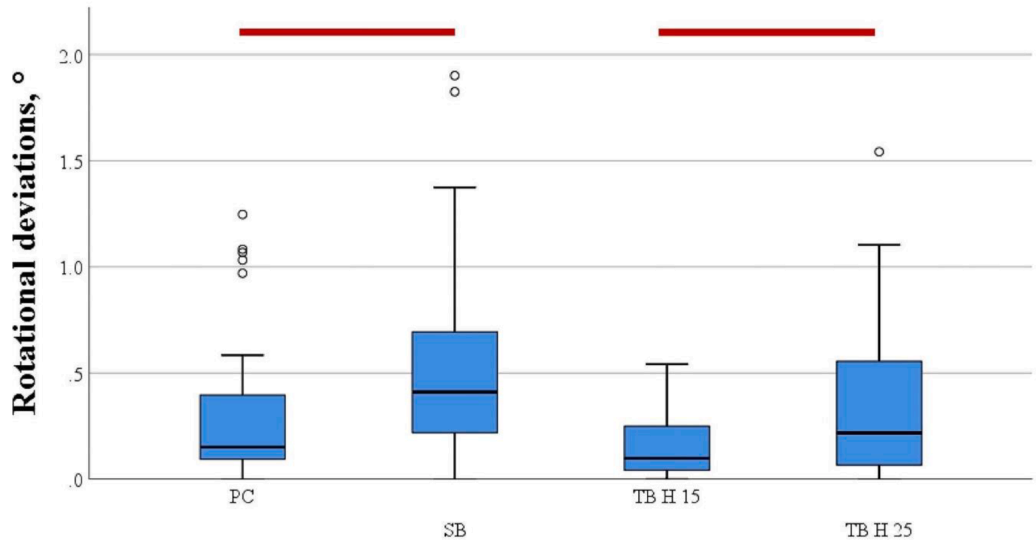

Fig. 6. Positional deviations of tested components in vertical axis with statistically significant differences ($p<0.05$) between the groups marked with lines. (PC - Pick-up copings; SB - Scanbodies; MU PC - Multi-unit pick-up copings; MU SB - Multi-unit scanbodies; TB NH - Ti base non-hex; TB H - Ti base hex; MU C - Multi-unit caps.).

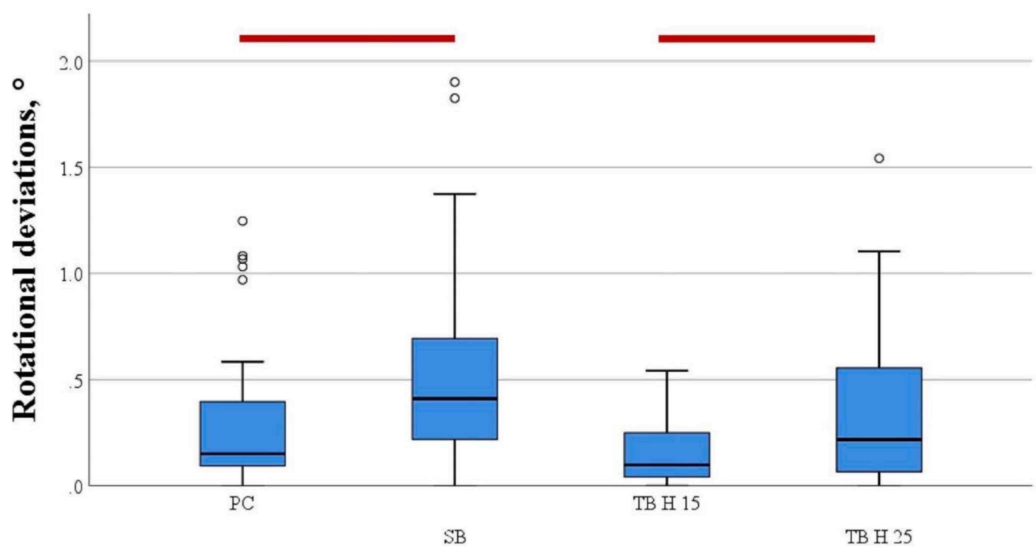

Fig. 7. Rotational deviations of tested components with statistically significant differences ($p<0.05$) between the groups marked with lines. (PC - Pick-up copings; SB - Scanbodies; TB H - Ti base hex).

4. Discussion

The results of this study have demonstrated that repeated manual disassembly and reassembly of the implant prosthetic components results in positional deviations. As statistically significant differences were found, the null hypothesis was rejected.

However, the measured differences were found to be statistically significant, their levels (10 to 37 μm) are in range of clinical acceptance (10–150 μm) [23–25]. Nevertheless, as it looks to have no clinical significance in single implant reconstructions, the accumulation of discrepancies may occur when complex multi-implant reconstruction is prepared. Considering full arch restoration with 6 or 8 implants and maximum error accumulation originating from impression components and abutments can predispose the misfit of the prosthesis and inaccurate proximal contacts [3–5,31,32,35]. Also, it can increase the risk of peri-mucositis or peri-implantitis [36].

In the present study, implant-level scan bodies showed smaller 3D positional discrepancies (16.1 μm) compared to impression abutments (36.5 μm). Similar results were observed on the abutment level 15.8 μm to 10.4 μm respectively. Implant-level abutments (1.9- 7.6 μm) had higher vertical repositioning errors than multi-unit caps (0.6 μm).

The implant system used in this study has a conical implant-abutment connection with a cone angle of 10° (with a connection depth of 1,62 mm). It is known that positional discrepancies of the abutments are possible in systems with conical implant-abutment interfaces [22,23,36,37]. Theoretically, implant abutments with a smaller cone angle could have better stability in the horizontal plane, while vertical deviations can increase. The same, flat connection between multi-unit abutment and appropriate pick-up may provide higher accuracy [37]. Other similar studies compared a specific type of prosthetic component from different implant systems [3–5,24,38]. However, in the current study, the positional stability of all prosthetic components used during the whole workflow from impression to prosthesis delivery was analyzed. All components tested had repositioning discrepancies, which could lead to error accumulation of up to 50 μm considering median values. However, considering the maximum deviations, it could reach

100 μm and above. It could be assumed that with a more complex prosthetic procedure that involves multiple connections and disconnections of the prosthetic components, larger discrepancies could occur only due to the repositioning errors.

A significant difference between impression abutments (0.15°) and implant scan bodies (0.41°) was found regarding rotational stability. A clearance fit is mandatory to allow effortless connection and disconnection of the components. It must enable a full seating of the connecting parts but, at the same time, could compromise positional stability [39]. Although impression abutments and implant scan bodies have the same geometric structure, the rotational freedom of the implant scan body was found to be larger.

Material differences between impression abutments and implant scan bodies could also be a factor leading to different positional stability. However, all analyzed components were made of Titanium Grade V. The implant scan bodies selected are additionally covered with a special anti-reflective coating to achieve better scanning accuracy. This coating extended onto the connection surface and could lead to a tighter fit compared to uncoated impression abutments. However, when this coating wears out, edges of anti-rotational elements also smoothen out, and this can be the source of higher rotational deviations of implant scan bodies when they are used multiple times.

The rotational discrepancy of hex abutments (0.10° under 15 Ncm) increased when higher torque was applied (0.22° under 25 Ncm). Although the 0.12° difference was statistically significant, the clinical relevance could be limited. Jemt et al. showed that misfitting superstructures did not jeopardize implant osseointegration when different torque levels (15 to 25 Ncm) were applied [40].

Angulation deviations of implant components were on par with the values found in another study [39]. These deviations were small with all types of implant abutments, however, they were higher for the impression components (0.03–0.06°) and did not exceed the clinically acceptable 0.4° threshold that was reported in previous studies [41].

There were several limitations of this study. Firstly, when an implant prosthetic component did not have an anti-rotational element, a positioning matrix was used to confirm the position of the component to be tested. The matrix could create a less reproducible rotational position of the gauge block; however, the rotational deviations were not measured in these cases. Moreover, the 8 mm distance from the top of the gauge block was used for measurements. This could complicate the comparison of the results with other studies, which used different measuring techniques. Lastly, the results are specific only to the implant system used in this research and cannot be applied to the third-party components or the situations when the component is fixed to the implant analog. Then, further studies are needed to investigate this phenomenon with other implant systems having different degree of conical connections as well as other kinds of implant-abutment interface and components manufactured in different materials [42–43]. After laboratory tests clinical studies should be perform to check how specific clinical conditions may affect this phenomenon.

5. Conclusions

Positional deviations were found with all implant prosthetic components evaluated in this study. Implant to component connection type may have an influence on the inaccuracy of the connection especially when torque of assembly increases. However angular and rotational deviations were found to be low and of limited significance. 3D linear deviations accumulating from the usage of impression components and abutments, can reach up to 100 μm when maximum deviations are considered and especially when multi-implant reconstruction is performed what may lead to clinical problems.

CRediT authorship contribution statement

Vygandas Rutkūnas: Conceptualization, Methodology, Writing – review & editing. **Vytautas Bilius:** . **Julius Dirsė:** Writing – original draft, Investigation. **Marta Revilla-León:** Writing – original draft, Validation. **Marius Rimašauskas:** Investigation. **Łukasz Zadrożny:** Writing – review & editing, Validation, Funding acquisition. **Rita Trumpaitė-Vanagienė:** Writing – review & editing, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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