

Article

Retrievability of Fractured Abutment Screws and Damage to Implant–Abutment Connections: An In Vitro Comparative Analysis of Conventional vs. Drilling Techniques

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Abstract: This study aimed to evaluate the retrievability and potential damage to implant–abutment connections caused by fractured abutment screw removal using conventional and drilling techniques. A total of forty abutment screws were randomly inserted into forty dental implants, and then they were fractured and extracted using different removal methods: Group A employed a conventional approach utilizing an exploration probe and an ultrasonic device without irrigation ($n = 10$) (conventional); Group B used the Phibo drilling removal system without irrigation ($n = 10$) (Phibo); Group C utilized the Rhein83[®] drilling removal system without irrigation ($n = 10$) (Rhein83); and Group D implemented the Sanhigia[®] drilling removal system without irrigation ($n = 10$) (Sanhigia). Pre- and postoperative micro-computed tomography (micro-CT) scans were performed on the dental implants, and Standard Tessellation Language (STL) digital files were generated for morphometric analysis to measure the wear volume. ANOVA was used to assess the volumetric differences (mm^3) and percentage ratios of the internal thread volumes of the implant–abutment connections before and after the procedures. Results: This study found no statistically significant differences in the volumetric and percentage ratios of internal threads among the implant groups (Phibo, Rhein83, Sanhigia, and conventional). However, the success rate for retrieving fractured abutment screws was higher (90%) with the drilling systems compared to the conventional technique (50%). These results suggest that drilling systems are more effective for the retrieval of damaged screws. Although drilling techniques without irrigation demonstrated higher removal efficiency compared to the conventional method, both approaches resulted in similar wear volumes at the implant–abutment connections when used to extract fractured screws.

Keywords: abutment screw; dental implants; dental prostheses; fractured; implant-supported prostheses; screw retain



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1. Background

Dental implants with implant-supported prostheses represent an effective and reliable treatment option for replacing natural teeth [1]. Advances in surgical techniques and implant components have significantly improved success rates, achieving over 90% for up to eight years [2]. However, despite these advancements, mechanical failures and biological complications continue to affect peri-implant soft tissues, presenting ongoing challenges in dental implantology [3,4].

Mechanical complications associated with dental implants often include the loosening and fracture of prosthetic or abutment screws, as well as wear and fracture of the prosthesis or other system components [5]. Mechanical complications in dental implants often arise from excessive occlusal forces, material fatigue, or improper prosthetic design. These

factors can lead to screw loosening, fractures, and wear of implant components. Additionally, inadequate maintenance or poor alignment of the implant–abutment connection may exacerbate these issues [6]. Although the occurrence of abutment screw fractures is relatively low, ranging from 0.5% to 8%, they are more frequently observed in fixed partial dentures compared to fixed complex prostheses. The extraction of fractured screw fragments remains a significant challenge in clinical practice, primarily depending on the degree of screw fracture and its engagement with the implant threads [2–5].

In instances where extraction proves difficult or could potentially harm the internal threads of the implant, the options typically include either leaving the fragment in place or opting for implant removal, both of which carry considerable risks, high morbidity, and uncertain prognosis [6–10].

Moreover, removal techniques can generate heat due to the high thermal diffusivity of metals, which can adversely affect the bone–implant interface and compromise osseointegration. Fractured screw fragments can be extracted using conventional or drilling techniques. Agustin-Panadero et al. reported that conventional methods, through the use of an explorer and an ultrasound device, showed a success rate of 73.3%, while the mechanical technique achieved a success rate of 96.7% by precisely drilling into and extracting the fragment. Both techniques have a similar impact on implant–abutment connection integrity [7].

This study aimed to analyze and compare the retrievability of fractured abutment screws and damage to the implant–abutment connections using conventional and drilling techniques. The null hypothesis (H_0) posits that there is no difference in the retrievability and connection damage between the conventional and drilling techniques for fractured abutment screws.

2. Methods

2.1. Study Design

Forty abutment screws (PXAS, BioHorizons, Birmingham, AL, USA) were randomly assigned to forty dental implants (dimensions: 4.6×12 mm: TLX4612, BioHorizons, Birmingham, AL, USA) using the Epidat v.4.1 software (Galicia, Spain). The screws were intentionally fractured within the conical internal hex connection of the dental implants. The implants with the fractured abutment screws (PGHYBN, BioHorizons, Birmingham, AL, USA) were then randomly allocated into one of four removal technique groups using the Epidat 4.1 software. Group A underwent a conventional removal method using an exploration probe and an ultrasonic device without irrigation (ProUltra[®], Dentsply Maillefer[®], Ballaigues, Switzerland) ($n = 10$) (conventional). Group B used the Phibo drilling removal system without irrigation (Phibo, Barcelona, Spain) ($n = 10$) (Phibo). Group C employed the Rhein83[®] drilling system without irrigation (Broken Screw Extractor Kit, Rhein83[®], Bologna, Italy) ($n = 10$) (Rhein83), and Group D applied the Sanhigia[®] drilling removal system without irrigation (FSRK-01; Sanhigia[®], Saragossa, Spain) ($n = 10$) (Sanhigia).

This study, a randomized controlled experimental trial, took place between April and November 2023 at the Dental Centre of Innovation and Advanced Specialties at Alfonso X El Sabio University (Madrid, Spain). The sample size was determined based on a power effect of 87.2, with a threshold of 80 considered acceptable. To achieve a power effect of at least 80.00% for identifying statistically significant differences, forty abutment screws were included in the study. The bilateral Student's *t*-test, with a 5% significance level, was employed to test the null hypothesis, $H_0: \mu_1 = \mu_2$, for two independent samples.

2.2. Experimental Procedure

Twenty dental implants (4.6×12 mm: TLX4612, BioHorizons, Birmingham, AL, USA) were positioned in nylon tubes using epoxy resin (Exakto-Form[®], Bredent GmbH & Co. KG, Senden, Germany), with a cast key employed to ensure consistent placement according to the ISO 14801 guidelines [11]. Before fracturing the abutment screws (PXAS, BioHorizons, Birmingham, AL, USA) within the conical internal hex implant–abutment connection, micro-computed tomography (micro-CT) scans were conducted using the Super Argus

MicroCT scanner (SEDECAL, Algete, Madrid, Spain) at the Molecular Imaging Laboratory, which is part of the NUCLEUS lab at the University of Salamanca. The scan parameters were set to 45.0 kilovolt peak, 900.0 microamperes, and 720 projections, generating precise Standard Tessellation Language (STL) digital files of the unaltered dental implants (STL1).

Subsequently, the abutment screws (PXAS, BioHorizons, Birmingham, AL, USA) were intentionally fractured within the internal threads of the conical internal hex connection. This was achieved by using a diamond burr (S6881 314 012, Komet Medical, Lemgo, Germany) to sever two-thirds of the abutment screw diameter between the shank and the threads. The screws were then tightened into the dental implants (TLX4612, BioHorizons) with a torque that exceeded the manufacturer's recommended 30 Ncm. After this, the screws were extracted from the dental implants following the assigned removal technique for each case.

2.3. Phibo Drilling Removal System

The abutment screws (PXAS, BioHorizons, Birmingham, AL, USA) randomly assigned to the Phibo drilling removal system without irrigation (Phibo, Barcelona, Spain) were removed using a tungsten carbide bur with an implantology handpiece at 850 revolutions per minute (rpm) using a 20:1 reduction in a clockwise movement without irrigation to perforate the coronal surface of the fractured abutment screw (Figure 1). Afterwards, a stainless-steel pyramid-shaped drill was used with an implantology handpiece at 15 rpm in a 20:1 reduction in counterclockwise movement without irrigation (Figure 1). The drill was placed in the hole created by the previous drill to grab the fragment and remove it by unscrewing it.



Figure 1. Phibo extractor kit, including the centering device to insert the claw reamer bur, the stainless-steel pyramid-shaped drill, the tungsten carbide round bur, and a thread former.

2.4. Rhein83[®] Drilling Removal System

The abutment screws (PXAS, BioHorizons, Birmingham, AL, USA) assigned to the Rhein83[®] drilling removal system (Broken Screw Extractor Kit; Rhein83[®], Bologna, Italy) were extracted by first securing the centering device on the implant connection (Figure 2). A claw reamer bur (680 FA; Rhein83[®]) was then used with an implantology handpiece, operating at 1000–2000 rpm with a 20:1 reduction in counterclockwise rotation (WS-75 LG; W&H, Hawthorne Drive, MI, USA) without irrigation (Figure 2). If any part of the fractured abutment screw remained in the implant, a special reverse-cut bur was utilized at 500–600 rpm, also with a 20:1 reduction in the counterclockwise motion and without irrigation.



Figure 2. Rhein83® extractor kit, including the centering devices to insert the claw reamer bur and the reverse-cut bur.

2.5. Sanhigia® Drilling Removal System

The abutment screws (PXAS, BioHorizons, Birmingham, AL, USA) allocated to the Sanhigia® drilling removal system (FSRK-01; Sanhigia®, Saragossa, Spain) were extracted by first placing and securing the guide (TSV 3.7/4.7; Sanhigia®, Saragossa, Spain) over the implant–abutment connection. A drill was then used with an implantology handpiece at a speed of 1200–2000 rpm, with a 20:1 reduction in the clockwise direction and without irrigation, to perforate the coronal portion of the fractured screw (Figure 3). In the final step, a second drill was employed with an implantology handpiece at 50–80 rpm, with a 20:1 reduction in the counterclockwise motion and without irrigation, to fully extract the fractured screw (Figure 3).



Figure 3. Sanhigia® extractor kit with the first drill, the second drill, and the guide used for affixing the dental implant connection for the second drill.

2.6. Conventional Technique with Exploration Probe and Ultrasonic Appliance

The abutment screws (PXAS, BioHorizons, Birmingham, AL, USA) randomly assigned to the conventional study group were removed using the conventional technique with an exploration probe and an ultrasonic tip (Start-X3, Dentsply SIRONA, Ballaigues, Switzerland) placed in an ultrasonic appliance (ProUltra®, Dentsply Maillefer®, Ballaigues, Switzerland). The exploration probe with counterclockwise circular movements and the ultrasonic tip were used to tap the center of the broken fragment with 30 VA power and 50 Hz frequency; no irrigation was used (Figure 4).

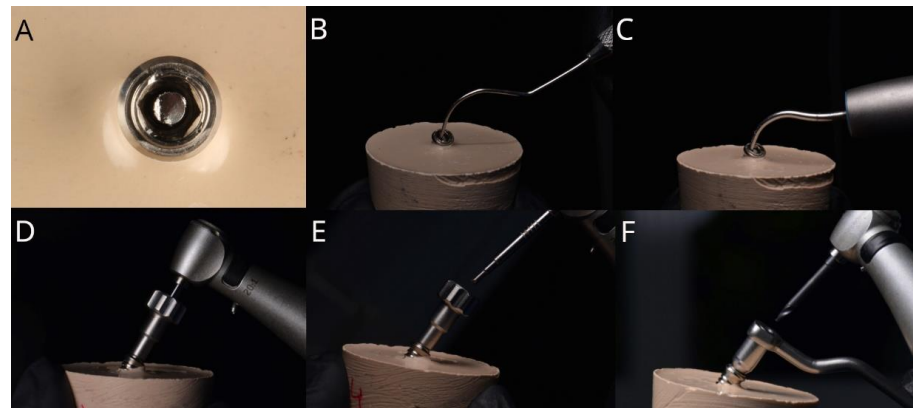


Figure 4. (A) Dental implant embedded into the epoxy resin material with an intentionally fractured abutment screw; (B) exploration probe; (C) ultrasonic tip; and (D) Phibo, (E) Rhein83®, and (F) Sanhigia® extractor kits used for the removal of the fractured abutment screw.

2.7. Measurement Procedure

After the abutment screws were removed (PGHYBN, BioHorizons, Birmingham, AL, USA), or after 5 min had passed, a postoperative micro-CT scan (Super Argus MicroCT, SEDECAL, Algete, Madrid, Spain) (STL2) was taken under the aforementioned exposure parameters. Next, the STL1 and STL2 digital files were imported into the reverse engineering morphometric software (3D Geomagic Capture Wrap v.2024, 3D Systems®, Rock Hill, SC, USA), and the best-fit algorithm was used to align the digital STL files. The differences in volume between the STL1 and STL2 digital files were then analyzed to assess the wear volume. The tolerance between the alignment of the digital files was set at $\pm 10 \mu\text{m}$ and the spectrum at $\pm 100 \mu\text{m}$. A maximum of 5 min of working time was allowed for recording the removal of the abutment screws from the dental implants. A unique operator with over 10 years of experience in prosthetic dentistry performed the various techniques for removing the abutment screws (P.M.-A.), and the measurement procedures were performed by another operator (A.Z.-M.), who was calibrated and blinded to the randomization process of the samples and who had performed the same digital measurement procedure in a previous study [8].

The wear on the internal threads of the conical internal hex implant–abutment connection ($4.6 \times 12 \text{ mm}$, TLX4612 BioHorizons, Birmingham, AL, USA) was analyzed by comparing the pre- and postoperative STL digital files after aligning the STL1 and STL2 digital files and calculating the volumetric differences (mm^3) of the conventional technique (Figure 5B and video 1, <https://youtu.be/eR76VAanLt0> (“(accessed on 23 September 2024)”) and the Phibo (Figure 5C and video 2, (https://youtu.be/Bgb2wMQHF_E “(accessed on 23 September 2024)”), Rhein83 (Figure 5D and video 3, (<https://youtu.be/Ra61jd8cNYs>, (“(accessed on 23 September 2024)”), and Sanhigia (Figure 5E and video 4, <https://youtu.be/va9fL47p-HE>, (“(accessed on 23 September 2024)”) drilling removal systems.



Figure 5. (A) Procedure for aligning pre- and postoperative digital files and isolating the wear volume (red) of the damaged conical internal hex implant–abutment connection internal threads after removing the fractured abutment screws; (B) conventional technique with an exploration probe and an ultrasonic appliance; (C) Phibo drilling removal system without irrigation; (D) Rhein83® drilling removal system without irrigation; and (E) Sanhigia® drilling removal system without irrigation.

2.8. Statistical Tests

Tables were created with summary statistics for each of the response variables according to the group, including number of observations, mean, median, standard deviation, and minimum and maximum values. These statistics were presented graphically using box diagrams.

Normality tests were performed using the Shapiro–Wilk test. For variables with a normal distribution, the comparison of means between groups was performed using an analysis of variance (ANOVA); if statistically significant differences between the groups were detected, 2-by-2 comparisons were performed, and the *p*-values were adjusted using the Tukey method to correct for type I errors. For variables with a non-normal distribution, the comparison between groups was performed using a non-parametric analysis (Kruskal–Wallis test); if statistically significant differences between the groups were detected, 2-by-2 comparisons were performed, and the *p*-values were adjusted using the Bonferroni method.

The statistical analysis was performed with the SAS v9.4 software, SAS Institute Inc., Cary, NC, USA. Statistical decisions were made taking the value of 0.05 as the significance level.

3. Results

Table 1 and Figure 6 display the means and SD values for the postoperative volumetric differences (mm³) of the internal threads at the conical internal hex implant–abutment connection among the study groups.

Table 1. Descriptive statistics of the volumetric differences (mm³) of internal threads at the conical internal hex implant–abutment connection.

Study Group	<i>n</i>	Mean	SD	Minimum	Maximum
Conventional	10	47.14 ^a	0.44	46.60	47.73
Phibo	10	47.18 ^a	0.49	46.37	47.82
Rhein83	10	46.80 ^a	0.77	45.89	47.79
Sanhigia	10	46.74 ^a	1.04	45.17	48.07

^a Different superscripts signify statistically significant differences between groups (*p* < 0.05).

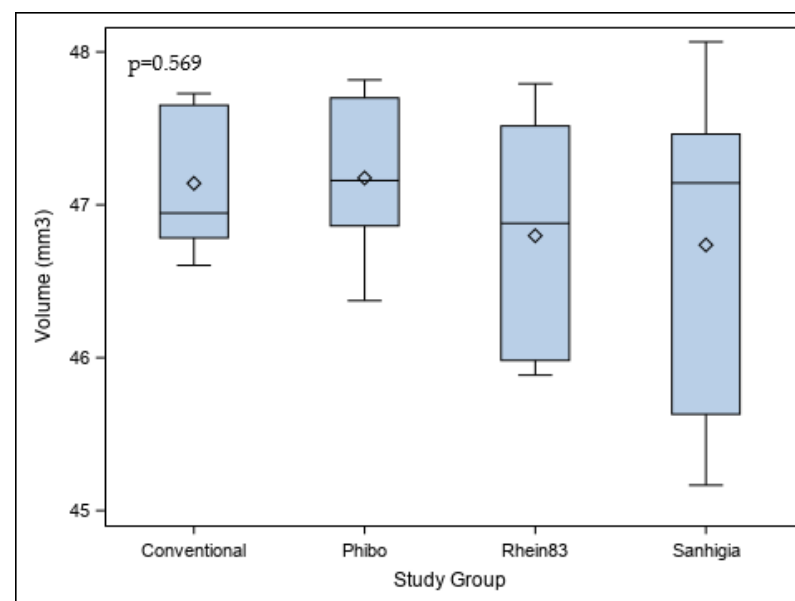


Figure 6. Box plot of the postoperative volumetric differences (mm³) of the internal threads at the conical internal hex implant–abutment connection among the conventional, Phibo, Rhein83, and Sanhigia study groups. The median value is represented by the horizontal line in each box. The *p*-value corresponds to the comparison between the means (ANOVA).

The ANOVA results did not show statistically significant differences ($p = 0.569$) in the postoperative volumetric differences of the internal threads at the conical internal hex implant–abutment connection between the conventional, Phibo, Rhein83, and Sanhigia study groups (Figure 6).

Table 2 and Figure 7 display the means and SD values for the volumetric differences (mm^3) between the pre- and postoperative volumes of the internal threads at the conical internal hex implant–abutment connection among the study groups.

Table 2. Descriptive statistics of the volumetric differences (mm^3) between the pre- and postoperative volumes of the internal threads at the conical internal hex implant–abutment connection.

Study Group	<i>n</i>	Mean	SD	Minimum	Maximum
Conventional	10	0.97 ^a	0.44	0.62	1.75
Phibo	10	1.19 ^a	0.49	0.39	1.84
Rhein83	10	0.97 ^a	0.72	0.00	1.81
Sanhigia	10	0.92 ^a	0.79	0.00	2.08

^a Different superscripts signify statistically significant differences between groups ($p < 0.05$).

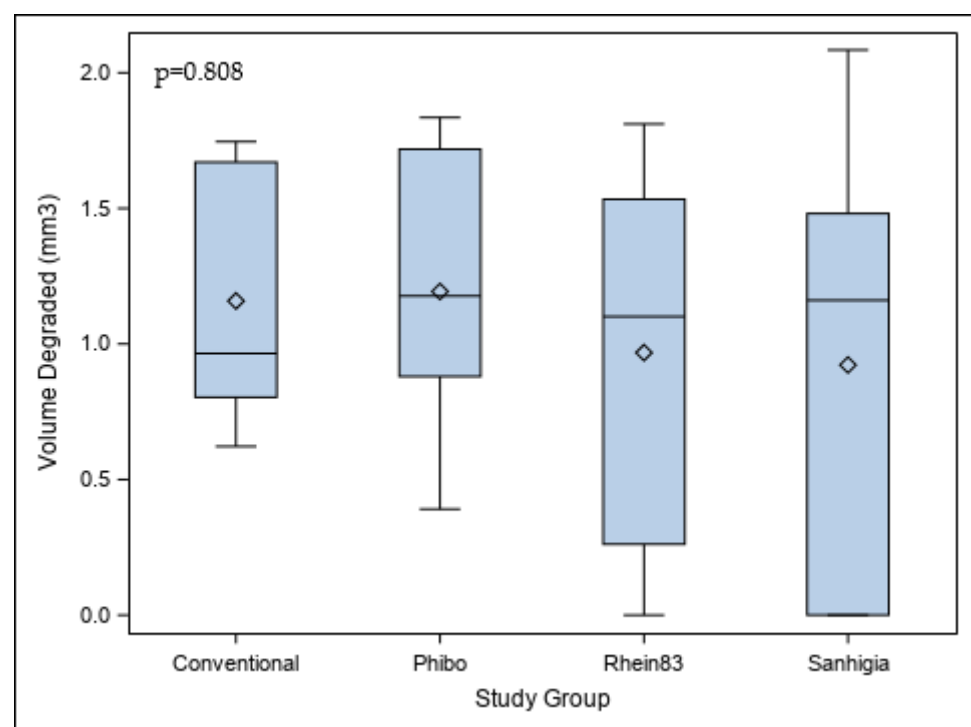


Figure 7. Box plot of the volumetric differences (mm^3) between the pre- and postoperative volumes of the internal threads at the conical internal hex implant–abutment connection among the conventional, Phibo, Rhein83, and Sanhigia study groups. The median value is represented by the horizontal line in each box. The p -value corresponds to the comparison between the means (ANOVA).

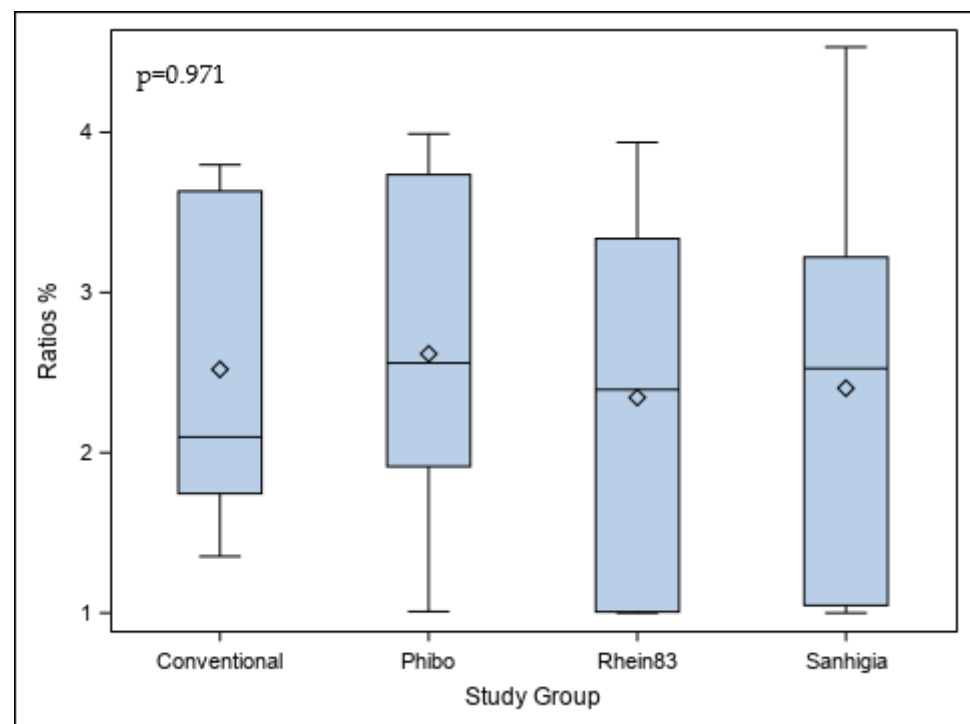
The ANOVA results did not show statistically significant differences ($p = 0.808$) in the pre- and postoperative volumes of the internal threads at the conical internal hex implant–abutment connection between the conventional, Phibo, Rhein83, and Sanhigia study groups (Figure 7).

Table 3 and Figure 8 display the means and SD values for the volumetric ratio (%) between the pre- and postoperative volumes of the internal threads at the conical internal hex implant–abutment connection among the study groups.

Table 3. Descriptive statistics of the volumetric ratio (%) between the pre- and postoperative volumes of the internal threads at the conical internal hex implant–abutment connection.

Study Group	<i>n</i>	Mean	SD	Minimum	Maximum
Conventional	10	2.52 ^a	0.95	1.35	3.80
Phibo	10	2.62 ^a	1.02	1.01	3.99
Rhein83	10	2.34 ^a	1.23	1.00	3.94
Sanhigia	10	2.40 ^a	1.26	1.00	4.53

^a Different superscripts signify statistically significant differences between groups ($p < 0.05$).

**Figure 8.** Box plot of the volumetric ratio (%) between the pre- and postoperative volumes of the internal threads at the conical internal hex implant–abutment connection among the conventional, Phibo, Rhein83, and Sanhigia study groups. The median value is represented by the horizontal line in each box. The p -value corresponds to the comparison between the means (ANOVA).

The ANOVA results did not show statistically significant differences ($p = 0.971$) in the volumetric ratio (%) between the pre- and postoperative volumes of the internal threads at the conical internal hex implant–abutment connection between the conventional, Phibo, Rhein83, and Sanhigia study groups (Figure 8).

Additionally, the success rate for retrieval of the fractured abutment screws from the conical internal hex implant–abutment connection was analyzed. The results showed that 90% of the fractured abutment screws were successfully removed using the Phibo, Rhein83, and Sanhigia drilling removal systems, whereas 50% of the fractured abutment screws were successfully removed using the conventional technique with an exploration probe and an ultrasonic appliance.

4. Discussion

The results of the present study reject the null hypothesis (H_0) that there is no difference in the retrievability and damage to the implant–abutment connection of fractured abutment screws between the conventional and drilling techniques. While various techniques were employed, no statistically significant differences were found among them. However, the non-irrigation drilling techniques with the Phibo, Rhein83, and Sanhigia drilling systems demonstrated a higher retrieval success rate of 90% for fractured screws, compared to only

50% for the conventional technique. This raises questions about the practical efficacy of less invasive approaches.

The scientific literature has yet to establish an efficient and predictable protocol for the removal of fractured abutment screw fragments from within dental implants. Current studies on managing these fractures are limited, and no scientific evidence is currently available to guide clinicians in choosing the most effective or manageable technique [7,10]. Additionally, there is no documentation on the volumetric impact at the implant–abutment interface following fractured screw removal. Ideally, an effective extraction of a fractured screw within an implant should avoid damage to the internal threading to prevent adverse outcomes, such as implant removal [12,13]. If the internal threading remains intact, only a new screw would be necessary, allowing the reuse of both the implant and the prosthesis.

A previous study emphasized the importance of avoiding damage to the implant connection and access channel during fractured screw removal, particularly with internal connection implants [9]. Additionally, fractured screw removal is crucial to maintaining implant functionality [14]. Moreover, it has been highlighted that abutment screw fractures could increase the gap at the implant–abutment interface, leading to peri-implantitis development [15]. This underscores the clinical importance of removing fractured abutment screws. However, maintaining the integrity of an implant’s internal thread is challenging, with damage rates of 9.8% reported, which sometimes prevents subsequent prosthetic placement. In addition, an internal thread damage rate of 13.33% has been reported [7,10].

These drilling techniques have emerged in response to the mechanical complications associated with implants, such as screw fractures. Potential mechanical complications include loosening, screw fractures, wear, prosthesis fractures, and damage to other system components [6]. Despite numerous clinical and in vitro studies, the exact causes of these complications remain unclear and may stem from improper prosthesis fitting [16]. Notably, experienced clinicians have been reported to tighten screws at 30–50% less than necessary [17]. The torque applied to the implant prosthetic screw is crucial for achieving the ideal load at the screw joint and preventing loosening [3,5,18]. Undetected loosening is a primary cause of screw fractures, with potential contributing factors including bruxism, unfavorable superstructure design, overload, rehabilitation malfunction, inadequate abutment seating, occlusal interferences, and manufacturing errors [1,3,6].

Screw loosening can occur when the forces acting to separate the screw joint, such as off-axis occlusal loads, exceed the forces holding the abutment and implant together. Additionally, screw fractures can arise from superstructure misalignment, overload, or malfunction [5]. Research has indicated that screw fractures are often associated with the external hexagon prosthetic connection [19], while implant systems equipped with anti-rotational features, such as an internal hex, tend to exhibit improved strength [19,20]. These systems, along with those where the abutment is deeply integrated into the implant body, have shown lower rates of complications [21]. Consequently, implant manufacturers have begun designing more robust internal connections to reduce the risk of loosening and subsequent screw fractures [19].

Various techniques for extracting fractured screw fragments have been developed, each dependent on the initial condition of the fragment [20]. Conventional, conservative methods are often recommended as the first line of treatment. For instance, a dental explorer can be rotated counterclockwise to recover the remaining screw fragments, as suggested by previous studies [22]. Other effective techniques include the use of an ultrasonic tip, which has a reported success rate of 73.3% [7], cotton swabs [23], and Er-YAG lasers [24]. In cases where conservative methods fail, more invasive techniques, such as specialized rescue instruments designed by different implant manufacturers, may be employed. One such example is the IMZ TwinPlus Repair Set K 3.3 (Dentsply Friadent, Mannheim, Germany) [2,21]. This method typically involves drilling the fragment to ensure retention before unscrewing it, as described by other researchers [25]. However, this procedure can be complicated and time-consuming for routine clinical use, as it risks damaging the threads within the implant [21,25].

Previous research suggested the use of two burs: the first is a serrated #557 bur, which is used counterclockwise when the fragment is deep, and the second is a #33 ½ bur, which is used clockwise when the fragment is coronal for complete fragment extraction to avoid implant damage [26].

The use of these techniques can not only damage the implant but also compromise osseointegration, altering the implant–bone interface due to heat production [27,28].

Overheating of osseous tissues can lead to irreversible damage. When bone is subjected to temperatures of around 47 °C for 1 min, this sometimes causes lesions in adipose cells and inconsistent tissue damage [29].

In cases of failure to remove the fractured screw fragment, other less invasive methods have been proposed to save the implant and avoid explantation. In addition, a previous study introduced a custom metal abutment into the implant, repositioning the implant-supported rehabilitation [30]. One study used shorter abutment screws as a replacement without prior removal of the remaining broken screw fragment [31], and another also used a shorter second screw to fix the implant-supported prosthesis, attaching it to the remaining fractured fragment without prior extraction [32].

Despite the use of these methods for fragment extraction, irreversible damage to implants can occur [25]. One study recommended that clinicians must be especially careful to avoid damaging the dental–implant connection, in addition to the implant access channel, when extracting the fractured screw [27].

This study shows that the use of the conventional and drilling techniques for the extraction of fractured abutment screws did not result in statistically significant differences in the morphometric wear volume of the implant–abutment connection ($p = 0.569$), or the wear volume ($p = 0.808$) or ratio ($p = 0.971$) of the internal hexagonal threads at the implant–abutment connection.

An accurate morphometric analysis (tolerance at $\pm 10 \mu\text{m}$) of the wear volume of the dental conical internal hex implant–abutment connection after fractured abutment screw extraction validates this measurement procedure, which can be used in future studies to analyze volumetric changes. However, the accuracy of this measurement procedure is dependent on the resolution of the compared STL digital files; it is, therefore, prudent to use digital files with a high tessellation density, such as those obtained with micro-CT. In any case, further studies are needed to establish the clinical relevance of implant–abutment damage and heat generation and their effect on dental implant prognosis.

5. Limitations of the Study

This study presents several limitations that should be considered when interpreting the results. First, the *in vitro* nature of this study limits the generalizability of the findings to real clinical scenarios. While *in vitro* models allow for controlled variable manipulation and a focused examination of specific aspects such as retrievability and damage to implant–abutment connections, *in vivo* conditions may introduce additional factors, such as biological variability and the dynamics of the surrounding tissue, which could influence the observed results.

Furthermore, although heat generation during drilling procedures was considered in this study, this is a critical factor that warrants a more in-depth analysis. In clinical settings, heat generation can impact both the integrity of the implant and the connection, as well as the success of retrieving fractured screws. In this study, a standardized protocol was applied to minimize heat during the drilling process; however, it is acknowledged that this topic should be explored in greater detail in future research.

6. Conclusions

Despite the limitations of this study, the results suggest that non-irrigated drilling techniques have a greater extraction capability compared to conventional removal techniques. However, it is important to note that both conventional and drilling techniques produce

a similar wear volume in the implant–abutment connection when extracting fractured abutment screws.

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References

- Mizumoto, R.M.; Jamjoom, F.Z.; Yilmaz, B. A risk-based decision-making tree for managing fractured abutment and prosthetic screws: A systematic review. *J. Prosthet. Dent.* **2018**, *119*, 552–559. [[CrossRef](#)] [[PubMed](#)]
- Sprenger, A.; Gutaszkas, K.; Filippi, A.; Rosentritt, M.; Kühl, S. Stability of Implant-Abutment Connection After Using the Rescue Kit: An In Vitro Study. *Int. J. Oral. Maxillofac. Implants* **2018**, *33*, 1305–1311. [[CrossRef](#)] [[PubMed](#)]
- Ferreira, M.B.D.; Delben, J.A.D.; Barão, V.A.R.D.; Faverani, L.P.D.; Dos Santos, P.H.D.; Assunção, W.G.D. Evaluation of torque maintenance of abutment and cylinder screws with Morse taper implants. *J. Craniofac. Surg.* **2012**, *23*, e631–e634. [[CrossRef](#)] [[PubMed](#)]
- Jung, R.E.; Pjetursson, B.E.; Glauser, R.; Zembic, A.; Zwahlen, M.; Lang, N.P. A systematic review of the 5-year survival and complication rates of implant-supported single crowns. *Clin. Oral. Implants Res.* **2008**, *19*, 119–130. [[CrossRef](#)] [[PubMed](#)]
- Arias, S.R.; Rueggeberg, F.A.; Mettenburg, D.; Sharawy, M.; Looney, S.; Elsayed, R.; Elsalanty, M.E. Heat generation during removal of an abutment screw fragment from dental implants. *J. Prosthet. Dent.* **2018**, *119*, 620–625. [[CrossRef](#)]
- Nayana, P.; Nayak, S.S.; Chatterjee, A.; Sivaraman, K.; Srikanth, G.; Singh, C. Retrieval of Fractured Implant Abutment Screws: A Narrative Review. *J. Int. Soc. Prev. Community Dent.* **2022**, *12*, 287–294. [[CrossRef](#)]
- Agustín-Panadero, R.; Baixauli-López, M.; Gómez-Polo, M.; Cabanes-Gumbau, G.; Senent-Vicente, G.; Roig-Vanaclocha, A. In vitro comparison of the efficacy of two fractured implant-prosthesis screw extraction methods: Conventional versus mechanical. *J. Prosthet. Dent.* **2020**, *124*, 720–726. [[CrossRef](#)]
- Pérez, M.B.; Zubizarreta-Macho, Á.; Sánchez, J.B.; Rodríguez, J.H.; Pérez-Barquero, J.A.; Deglow, E.R.; Montero, S.H. Removal capability, implant-abutment connection damage and thermal effect using ultrasonic and drilling techniques for the extraction of fractured abutment screws: An in vitro study. *BMC Oral Health* **2022**, *22*, 603. [[CrossRef](#)]
- Carneiro, T.d.A.P.N.; Prudente, M.S.; e Pessoa, R.S.; Mendonça, G.; das Neves, F.D. A conservative approach to retrieve a fractured abutment screw—Case report. *J. Prosthodont. Res.* **2016**, *60*, 138–142. [[CrossRef](#)]
- Agustín-Panadero, R.; Labaig-Rueda, C.; Castillo-Rodríguez, B.; Ferreira, A.; Solá-Ruiz, M. In Vitro Evaluation of Three Methods for the Retrieval of Fractured Screw Fragments from Dental Implants. *Int. J. Oral Maxillofac. Implants* **2017**, *32*, e119–e124. [[CrossRef](#)]
- ISO 14801:2016; Dentistry. Implants. Dynamic Loading Test for Endosseous Dental Implants. ISO: Geneva, Switzerland, 2016.
- Vanl, B.; Özkan, Y.; Kulak-Özkan, Y. Retrospective analysis of prosthetic complications of implant-supported fixed partial dentures after an observation period of 5 to 10 years. *Int. J. Oral Maxillofac. Implants* **2013**, *28*, 300–304. [[CrossRef](#)] [[PubMed](#)]
- Papaspyridakos, P.; Chen, C.J.; Chuang, S.K.; Weber, H.P.; Gallucci, G.O. A systematic review of biologic and technical complications with fixed implant rehabilitations for edentulous patients. *Int. J. Oral Maxillofac. Implants* **2012**, *27*, 102–110. [[PubMed](#)]
- Quek, C.E.; Tan, K.B.C.; Nicholls, J.I. Load fatigue performance of a single-tooth implant abutment system: Effect of diameter. *Int. J. Oral Maxillofac. Implants* **2006**, *21*, 929–936. [[PubMed](#)]
- Tsuruta, K.; Ayukawa, Y.; Matsuzaki, T.; Kihara, M.; Koyano, K. The influence of implant-abutment connection on the screw loosening and microleakage. *Int. J. Implant Dent.* **2018**, *4*, 11. [[CrossRef](#)]
- Lee, J.-H.; Cha, H.-S. Screw loosening and changes in removal torque relative to abutment screw length in a dental implant with external abutment connection after oblique cyclic loading. *J. Adv. Prosthodont.* **2018**, *10*, 415–421. [[CrossRef](#)]
- Schwarz, M.S. Mechanical complications of dental implants. *Clin. Oral. Implants Res.* **2000**, *11* (Suppl. 1), 156–158. [[CrossRef](#)]
- Siamos, G.; Winkler, S.; Boberick, K.G. Relationship between implant preload and screw loosening on implant-supported prostheses. *J. Oral Implantol.* **2002**, *28*, 67–73. [[CrossRef](#)]
- Kitagawa, T.; Tanimoto, Y.; Odaki, M.; Nemoto, K.; Aida, M. Influence of implant/abutment joint designs on abutment screw loosening in a dental implant system. *J. Biomed. Mater. Res. B Appl. Biomater.* **2005**, *75*, 457–463. [[CrossRef](#)]

20. Huang, Y.; Wang, J. Mechanism of and factors associated with the loosening of the implant abutment screw: A review. *J. Esthet. Restor. Dent.* **2019**, *31*, 338–345. [[CrossRef](#)]
21. Nergiz, I.; Schmage, P.; Shahin, R. Removal of a fractured implant abutment screw: A clinical report. *J. Prosthet. Dent.* **2004**, *91*, 513–517. [[CrossRef](#)]
22. Lee, M.-S.; Chiang, C.-P.; Tseng, W.-Y.; Ho, C.-L.J. Rapid retrieval of fractured implant abutment screws with a custom-made screwdriver. *J. Dent. Sci.* **2023**, *18*, 1952–1955. [[CrossRef](#)] [[PubMed](#)]
23. Barbosa, J.M.; Ascenso, J.; Hirata, R.; Caramês, J. The cotton driver: An alternative technique for removing fractured screw fragments. *J. Prosthet. Dent.* **2014**, *112*, 1601–1602. [[CrossRef](#)] [[PubMed](#)]
24. Gupta, H.; Singh, A.; Priyadarshi, S.; Yusuf, S.M.; Srivastava, S. Various Treatment Modalities for Retrieval of Broken Abutment Screw in Implant Prosthodontics. *Int. J. Clin. Implant Dent. DVD* **2015**, *1*, 60–65. [[CrossRef](#)]
25. Yoon, J.; Lee, H.; Kim, M. Safe Removal of a Broken Abutment Screw with Customized Drill Guide and Rotary Instrument: A Clinical Report. *J. Prosthodont.* **2016**, *25*, 170–173. [[CrossRef](#)]
26. Flanagan, D. Management of a Fractured Implant Abutment Screw. *J. Oral Implantol.* **2016**, *42*, 508–511. [[CrossRef](#)]
27. Ormianer, Z.; Lewinstein, I.; Moses, O. Heat generation in 1-piece implants during abutment preparations with high-speed cutting instruments. *Implant Dent.* **2013**, *22*, 60–65. [[CrossRef](#)]
28. Cordioli, G.; Majzoub, Z. Heat generation during implant site preparation: An in vitro study. *Int. J. Oral Maxillofac. Implants* **1997**, *12*, 186–193.
29. Eriksson, R.A.; Albrektsson, T.; Magnusson, B. Assessment of bone viability after heat trauma. A histological, histochemical and vital microscopic study in the rabbit. *Scand. J. Plast. Reconstr. Surg.* **1984**, *18*, 261–268. [[CrossRef](#)]
30. Canpolat, C.; Özkurt-Kayahan, Z.; Kazazoğlu, E. Management of a fractured implant abutment screw: A clinical report. *J. Prosthodont.* **2014**, *23*, 402–405. [[CrossRef](#)]
31. Kim, B.-J.; Yeo, I.-S.; Lee, J.-H.; Kim, S.-K.; Heo, S.-J.; Koak, J.-Y. The effect of screw length on fracture load and abutment strain in dental implants with external abutment connections. *Int. J. Oral Maxillofac. Implants* **2012**, *27*, 820–823.
32. Yi, Y.; Heo, S.-J.; Koak, J.-Y.; Kim, S.-K. Alternative approach to salvaging an implant with a fractured screw fragment: A clinical report. *J. Prosthet. Dent.* **2021**, *125*, 18–21. [[CrossRef](#)] [[PubMed](#)]

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