GMR
The Original

A COMPARATIVE STUDY TO ASSESS THE EFFICACY OF DIFFERENT METHODS FOR THE RETRIEVAL OF FRACTURED IMPLANT ABUTMENT SCREW: AN IN VITRO STUDY

Dr. Shitij Srivastava[1], Dr. Akshat Srivastava[2*], Dr. Abhinav Shekhar[3], Dr. Anshuman Chaturvedi[4], Dr. Abhishek Singh[5]

[1]Department of Prosthodontics and Crown & Bridge, Sardar Patel Post Graduate Institute of Dental & Medical Sciences, Lucknow, Uttar Pradesh, India, Email ID: shitijsrivastava@gmail.com
[2*]Department of Prosthodontics and Crown & Bridge, Sardar Patel Post Graduate Institute of Dental & Medical Sciences, Lucknow, Uttar Pradesh, India, Email ID: akshat.srivastava.bds@gmail.com
[3]Department of Prosthodontics and Crown & Bridge, Sardar Patel Post Graduate Institute of Dental & Medical Sciences, Lucknow, Uttar Pradesh, India, Email ID: dentalo3doctor@gmail.com
[4]Department of Prosthodontics and Crown & Bridge, Sardar Patel Post Graduate Institute of Dental & Medical Sciences, Lucknow, Uttar Pradesh, India, Email ID: dranshuman.mds@gmail.com
[5]Department of Prosthodontics and Crown & Bridge, Sardar Patel Post Graduate Institute of Dental & Medical Sciences, Lucknow, Uttar Pradesh, India, Email ID: singhahi0123@gmail.com

ABSTRACT

Introduction: Fractured implant abutment screws represent a significant mechanical complication in implant dentistry and can compromise prosthetic stability, implant longevity, and treatment outcomes. Retrieval of fractured screws is a technically demanding procedure that requires effective removal while preserving implant integrity. Several retrieval techniques have been proposed; however, evidence regarding the most efficient and reliable method remains limited.

Aim: To comparatively assess the efficacy of different methods for retrieval of fractured implant abutment screws in an in vitro setting.

Materials and Methods: A total of 108 implant specimens embedded in acrylic blocks were included in this in vitro experimental study and equally divided into three groups (n=36): Group I—Claw-Type Retrieval Kit, Group II—Reverse Drilling Retrieval Kit, and Group III—Conventional Hand Instrumentation. Fracture morphologies (ASF-1, ASF-2, and ASF-3) were equally distributed among all groups. Outcome variables evaluated included retrieval success rate, number of attempts required, retrieval time, and implant thread integrity following retrieval. Data were statistically analyzed using SPSS version 21.0. Chi-square test, one-way ANOVA, and Tukey post hoc analysis were applied, with $p<0.05$ considered statistically significant.

Results: Overall retrieval success was achieved in 72.2% of specimens. Reverse Drilling and Conventional Instrumentation demonstrated higher retrieval success rates (75%) compared with Claw-Type retrieval (66.7%), although differences were not statistically significant. Reverse Drilling showed significantly greater procedural efficiency with a higher rate of single-attempt retrieval and the shortest mean retrieval time (10.31 ± 3.42 minutes) ($p<0.001$). No significant differences were observed regarding implant thread damage among the groups.

Conclusion: Reverse Drilling demonstrated superior procedural efficiency with fewer retrieval attempts and shorter retrieval time while maintaining implant thread integrity, suggesting that it may represent a reliable and clinically effective technique for fractured implant abutment screw retrieval.

KEYWORDS: Abutment screw fracture; Conventional instrumentation; Dental implantology; Implant complications; Implant thread integrity; Reverse drilling; Retrieval techniques.

INTRODUCTION

Dental implants have revolutionized restorative dentistry and are currently regarded as one of the most predictable and successful treatment modalities for replacing missing teeth. Since the pioneering work on osseointegration by Brånemark and co-workers, implant-supported prostheses have demonstrated remarkable clinical success and long-term survival rates ranging from 95–99%.[1,2] The widespread acceptance of implant therapy is attributed to its ability to restore esthetics, function, phonetics, and patient satisfaction while preserving adjacent natural dentition and alveolar bone structure. Despite these advantages, implant-supported prostheses are not free from complications, and biological as well as mechanical failures continue to represent significant challenges in clinical practice.[3,4]

Biological complications associated with dental implants include peri-implant mucositis, peri-implantitis, and progressive bone loss around the implant fixture, whereas mechanical complications comprise ceramic fractures, framework failures, prosthetic screw loosening, and abutment screw fractures.[5] Mechanical complications are particularly important because they directly influence prosthetic stability and treatment longevity. Among these complications, abutment screw loosening

and fracture are considered major causes of implant prosthetic failure and can significantly compromise implant function and patient comfort.[6]

The abutment screw represents a critical component of implant-supported prostheses because it establishes and maintains a stable connection between the implant fixture and the prosthetic superstructure. The preload generated during tightening of the screw ensures intimate contact between the implant and abutment surfaces and contributes to joint stability.[7] Under normal conditions, the screw absorbs and distributes masticatory and occlusal forces effectively; however, repeated cyclic loading and excessive biomechanical stress may lead to reduction in preload and eventual fatigue failure.[8]

Several factors have been identified as contributing to abutment screw fracture. These include improper torque application during prosthesis placement, implant-abutment misfit, parafunctional habits such as bruxism, unfavorable occlusal loading, prosthetic design errors, and manufacturing defects.[9,10] Furthermore, screw loosening frequently precedes screw fracture, allowing repetitive micromovements and increased stress concentration at specific regions of the screw body. Repeated episodes of loading may initiate micro-cracks within the screw structure, which eventually propagate and result in complete fracture.[11]

Abutment screw fractures have been reported to occur in approximately 0.5–8% of implant restorations and represent one of the most technically challenging complications encountered during implant maintenance procedures.[12] The fracture pattern and location play an important role in determining retrieval difficulty and prognosis. To improve understanding and facilitate management, Chowdhary et al. proposed a classification system based on the site of fracture. ASF-1 refers to stripping or fracture of the screw head, ASF-2 involves fracture within the cylindrical screw shank region, and ASF-3 includes fractures occurring in the threaded portion of the screw.[13] Among these, ASF-3 fractures are most frequently observed because maximum bending stresses occur near the first thread region of the screw.[13]

Retrieval of fractured abutment screws presents a significant clinical challenge because the fractured segment frequently remains lodged within the internal implant connection. Removal procedures require careful manipulation to prevent damage to the implant's internal threads and surrounding structures. If retrieval attempts fail or cause excessive thread damage, complete implant removal may become necessary, leading to increased treatment costs, additional surgical intervention, patient discomfort, and prolonged rehabilitation time.[14] Therefore, preservation of the implant body while successfully retrieving the fractured screw fragment is considered essential.

Various retrieval methods have been described in the literature for managing fractured implant abutment screws. Conventional techniques commonly involve the use of explorers, spoon excavators, ultrasonic scaler tips, hemostats, and modified hand instruments.[15] Ultrasonic techniques facilitate screw removal through vibration-induced loosening of the fractured fragment. Mechanical retrieval systems such as reverse drilling kits and claw-type retrieval devices have been developed to improve procedural efficiency and precision. Reverse drilling systems operate by engaging the fractured fragment through counterclockwise rotational movements, while claw-type devices employ specialized mechanical engagement mechanisms to grasp and extract the fragment.

Although numerous techniques are available for fractured screw retrieval, there remains no universally accepted protocol regarding the most efficient and safest method. Existing studies have demonstrated variable success rates depending on implant design, fracture morphology, operator experience, and accessibility of the fractured fragment.[15] Most available evidence consists of isolated case reports and in vitro investigations, resulting in limited evidence-based guidance for clinicians.

Recent advances in implant design, including internal conical connections, platform switching concepts, and microthread configurations, have improved biomechanical behavior and implant survival rates; however, these developments may also influence fracture characteristics and retrieval outcomes. Consequently, continuous assessment of retrieval methods becomes necessary to determine their effectiveness under standardized conditions. Comparative studies evaluating retrieval success rate, procedure time, number of attempts required, and potential damage to implant integrity may contribute valuable evidence for clinical decision-making.

Therefore, the present in vitro study was designed to comparatively assess the efficacy of different methods for retrieval of fractured implant abutment screws. By evaluating parameters such as retrieval success, procedural efficiency, and preservation of implant thread integrity, the study aims to identify the most reliable and clinically feasible retrieval approach. The findings are expected to contribute toward establishing evidence-based guidelines and improving treatment outcomes in implant prosthodontics.

MATERIALS AND METHOD

Study Design

The present study was designed as an in vitro experimental comparative study aimed at evaluating and comparing the efficacy of different methods for retrieval of fractured implant abutment screws. The study was conducted in the Department of Prosthodontics and Crown and Bridge at Sardar Patel Postgraduate Institute of Dental and Medical Sciences, Lucknow. The investigation was performed under controlled laboratory conditions to minimize experimental variability and ensure standardization of all procedures. Three different retrieval methods were comparatively evaluated based on their effectiveness in retrieving fractured implant abutment screws. The primary outcome variables assessed included retrieval success rate, retrieval time, number of attempts required for screw retrieval, and integrity of implant internal threads after the retrieval procedure.

Ethical Approval

The study protocol was reviewed and approved by the Research Advisory Council (RAC) and Institutional Ethical Committee (IEC) of Sardar Patel Postgraduate Institute of Dental and Medical Sciences, Lucknow. Ethical approval was

obtained prior to initiation of the study procedures and all research activities were performed according to institutional guidelines.

Sample Size Determination

The sample size was determined using a statistical formula based on previous literature to ensure adequate study power and reliability. Sample size estimation was performed considering a standard deviation of 11.63, effect size of 7.63, and study power of 80%.

The formula used for sample size calculation was:

$n \geq (Z_{\alpha/2}+Z_{\beta})^2 \times 2\sigma^2/E^2$

The calculated sample size was approximately 31 specimens for each retrieval technique. To compensate for potential data loss and to improve statistical validity, an additional 10% was added and rounded to the nearest multiple of three. Therefore, the final sample size consisted of 36 samples per group, resulting in a total of 108 implant specimens.

Sample Distribution

The total sample of 108 implant specimens was equally divided into three study groups according to the retrieval method employed:

Group I: Claw-Type Screw Retrieval Kit (36 samples)
Group II: Reverse Drilling Screw Retrieval Kit (36 samples)
Group III: Conventional Hand Instrumentation Method (36 samples)

Each group included an equal distribution of fracture morphologies to eliminate selection bias and ensure standardization among study groups.

Armamentarium and Materials Used

The study utilized standardized materials and equipment to maintain uniformity throughout the experimental procedures. Dental implants with dimensions of 3.75 × 11.5 mm and **4**.2 × 11.5 mm were used. Surgical implant kits and implant handpieces were employed for implant placement procedures. Cement-retained abutments and fractured abutment screws were used for fracture simulation.

The retrieval instruments included:

a) Reverse Drilling Screw Retrieval Kit
b) Claw-Type Screw Retrieval Kit
c) Spoon excavator
d) DG-16 endodontic explorer
e) Curved mosquito forceps
f) Ultrasonic scaler with tips

Self-cure acrylic resin was used for embedding implants within acrylic blocks.

Sample Preparation

A total of 108 implant specimens were embedded in self-cure acrylic resin blocks simulating edentulous arches. Implant analogs from the same manufacturer were selected to eliminate dimensional and material variations. Two implant dimensions were utilized: 3.75 × 11.5 mm for canine regions and 4.2 × 11.5 mm for molar regions, thereby replicating different clinical situations commonly encountered in implant prosthodontics.

The implants were embedded vertically within acrylic resin blocks using standardized positioning techniques to maintain uniform implant angulation and depth. This standardization ensured consistency during retrieval procedures and eliminated variability due to implant positioning.

Fracture Simulation Procedure

To simulate clinically relevant fractured abutment screws, controlled weakening of abutment screws was performed prior to fracture induction. Screw dimensions were measured using a calibrated digital micrometer to ensure consistency among all specimens.

Grooves were created between the first and second threads of the abutment screws using precision grinding methods. Controlled notches of predetermined morphology were prepared on the upper surfaces of the screws to simulate different fracture configurations.

The fracture patterns were classified according to Chowdhary et al. into:

ASF-1: Fracture involving stripping or deformation of the screw head
ASF-2: Fracture occurring within the screw shank region
ASF-3: Fracture involving the threaded region of the screw

After preparation of the notches, screws were tightened using a calibrated torque meter until fracture occurred. The torque value at the point of fracture was recorded for all samples.

Figure 1: Implants embedded in acrylic model

Retrieval Procedure

Group I: Claw-Type Screw Retrieval Technique

The claw-type retrieval kit consisted of a screw remover, abutment hex remover, screw tap repair instrument, fixture remover, and cover screw remover. Retrieval procedures were performed according to manufacturer recommendations. The claw mechanism was engaged with the fractured screw fragment and counter-rotational force was applied carefully to facilitate screw retrieval while minimizing damage to implant threads **(figure 1)**.

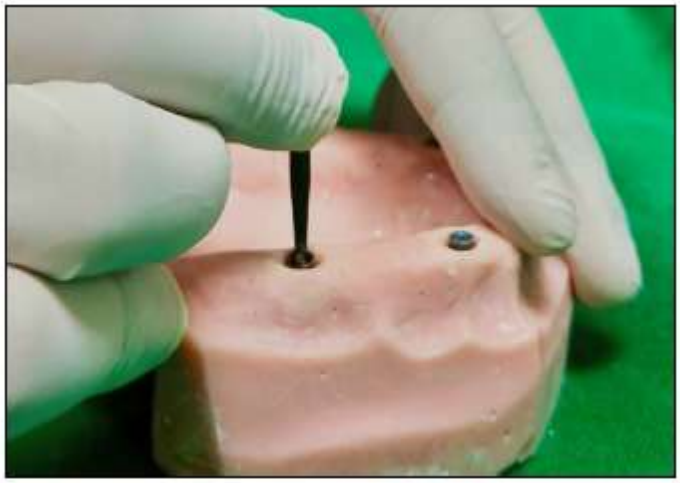

Figure 2: Retrieval through Claw type instrument

Group II: Reverse Drilling Screw Retrieval Technique

The reverse drilling retrieval kit included a reverse drill, retrieval instrument, screw remover, and rescue drill guides. The reverse drill was operated in a counterclockwise direction to create engagement within the fractured screw fragment. Following drilling, the retrieval instrument was inserted into the prepared site and reverse rotational movements were applied until complete removal of the fractured fragment was achieved **(figure 2)**.

Figure 3: Retrieval through reverse drilling kit

Group III: Conventional Hand Instrumentation Technique
The conventional retrieval method involved the use of commonly available dental instruments including spoon excavators, DG-16 endodontic explorers, curved mosquito forceps, and ultrasonic scaler tips. The fractured screw fragment was carefully manipulated using these instruments to create rotational movement and facilitate retrieval **(figure 3)**.

Figure 4: Retrieval through conventional instrument [Ultrasonic Scaler tip]

Evaluation Criteria
The efficacy of retrieval methods was assessed based on predetermined outcome parameters. Retrieval was considered successful if the fractured screw fragment was completely removed within 15 minutes without causing damage to implant internal threads.
The following variables were recorded: success or failure of retrieval procedure, number of attempts required for retrieval, total time required for retrieval, implant thread integrity following retrieval, fracture morphology type and implant location and dimensions

Assessment of Implant Thread Integrity
Following completion of retrieval procedures, implant thread integrity was assessed using impression coping seating tests. Impression copings were hand-tightened within the implant body and evaluated for seating resistance.
Subsequently, a new stock abutment was torqued to 25 Ncm to determine internal thread condition. Resistance during tightening or incomplete seating was considered indicative of thread damage. Specimens showing thread damage were discarded and replaced to maintain study consistency.

Data Collection Procedure
All observations were systematically recorded in a structured data collection sheet. Retrieval time was measured using a digital stopwatch from initiation of retrieval until complete screw removal or procedural failure. Data collected included fracture morphology, retrieval outcome, retrieval time, number of attempts, and implant thread status.

Statistical Analysis
The collected data were entered into Microsoft Excel and analyzed using Statistical Package for Social Sciences (SPSS) software version 21.0. Descriptive statistics were expressed as mean ± standard deviation and percentages. Inferential statistical analysis was performed using Chi-square test for categorical variables and one-way analysis of variance (ANOVA) for continuous variables. Post hoc comparisons between groups were performed using Tukey's HSD test. Statistical significance was considered at $p < 0.05$

RESULTS
The present in vitro comparative study was conducted in the Department of Prosthodontics and Crown and Bridge, Sardar Patel Postgraduate Institute of Dental and Medical Sciences, Lucknow, to evaluate and compare the efficacy of different techniques for retrieval of fractured implant abutment screws. A total of 108 implant specimens embedded within acrylic dental casts were included in the study and equally allocated into three study groups according to the retrieval method employed.
The primary objective was to determine the success rate of each retrieval method in complete removal of fractured implant abutment screws. Secondary objectives included assessment of retrieval time, number of attempts required, and integrity of implant threads following retrieval procedures.
A total of 108 implant specimens were included in the present in vitro study and were equally distributed among the three retrieval technique groups. Each group consisted of 36 specimens (33.3%), with Group I undergoing retrieval using the Claw-Type Retrieval Kit, Group II using the Reverse Drilling Retrieval Kit, and Group III using Conventional Hand Instrumentation. The equal allocation of specimens ensured uniformity and minimized selection bias among study groups.

With respect to fracture morphology, all groups demonstrated an identical distribution pattern. Each retrieval group consisted of 12 specimens (33.3%) with ASF-1, 12 specimens (33.3%) with ASF-2, and 12 specimens (33.3%) with ASF-3 fracture patterns. Statistical analysis demonstrated no significant difference in fracture morphology distribution among the study groups (p = 1.000), indicating adequate standardization and comparability.

Similarly, equal representation of implant location was maintained across the groups. In each study group, 18 implants (50%) were placed in the maxillary arch, while the remaining 18 implants (50%) were located in the mandibular arch. No statistically significant difference in arch distribution was observed among the groups (p = 1.000), confirming homogeneous sample allocation prior to retrieval procedures.

This standardized baseline distribution ensured that any differences observed in retrieval outcomes could be attributed primarily to the retrieval techniques rather than variations in fracture morphology or implant location.

Among the 108 retrieval procedures performed, successful retrieval was achieved in **78 specimens (72.2%)**, while **30 specimens (27.8%)** showed retrieval failure. Group II (Reverse Drilling) and Group III (Conventional instrumentation) demonstrated the highest retrieval success rates (**75% each**) compared to Group I (Claw-Type technique) (**66.7%**). However, the differences were not statistically significant (p=0.660) **(table 1)**.

The number of attempts required for successful retrieval showed statistically significant differences among groups (p=0.001). Reverse drilling technique exhibited the greatest efficiency, with **75% of specimens successfully retrieved in a single attempt**. By contrast, the majority of specimens in Group I and Group III required multiple attempts. The absence of third-attempt retrievals in Group II further indicates superior procedural effectiveness **(table 2)**.

Most retrieval procedures (**72.2%**) were completed within 15 minutes. Group II and Group III demonstrated greater efficiency, with **75% of procedures completed within the stipulated time**, compared with **66.7%** for Group I. However, these differences were not statistically significant **(table 3)**.

No implant thread damage was observed in **78 specimens (72.2%)**, indicating preservation of implant integrity following retrieval procedures. Although thread damage occurred more frequently in the Claw-Type group (33.3%) than in the Reverse Drilling and Conventional groups (25%), the difference was not statistically significant **(table 4)**.

The mean retrieval time differed significantly among the three techniques (p<0.001). Reverse drilling required the least retrieval time (10.31 ± 3.42 minutes), followed by conventional instrumentation (13.72 ± 3.93 minutes) and claw-type retrieval (14.67 ± 3.68 minutes) **(table 5)**.

The findings of the present study indicate that Reverse Drilling and Conventional instrumentation techniques demonstrated superior retrieval success rates and greater efficiency compared with the Claw-Type retrieval method**.** Reverse drilling particularly required significantly less retrieval time and fewer attempts while preserving implant thread integrity, suggesting that it may represent a more reliable and clinically efficient method for fractured implant abutment screw retrieval.

DISCUSSION

Dental implant therapy has become an indispensable component of contemporary restorative dentistry owing to its high predictability, long-term success, and ability to restore esthetics and function. Despite considerable advancements in implant materials and implant-abutment connection designs, mechanical complications continue to represent a major challenge affecting treatment longevity. Among these complications, abutment screw fracture is considered one of the most technically demanding events encountered in implant prosthodontics because it compromises prosthesis stability and creates difficulties during maintenance procedures. Retrieval of fractured abutment screws without causing damage to implant structures remains a significant clinical concern.

The present in vitro study was undertaken to compare the efficacy of three retrieval techniques for fractured implant abutment screws, namely Claw-Type Retrieval Kit, Reverse Drilling Retrieval Kit, and Conventional Hand Instrumentation. The study evaluated retrieval success rates, number of attempts required, retrieval time, and preservation of implant thread integrity.

A total of 108 implant specimens were equally distributed among the three study groups with uniform representation of fracture morphology and implant location. The absence of statistically significant differences in baseline characteristics confirmed adequate standardization and ensured that variations in outcomes could be attributed primarily to the retrieval techniques rather than confounding variables. This uniformity increased internal validity and strengthened the reliability of comparisons among the three techniques.

The overall retrieval success rate observed in the present study was 72.2%, indicating that most fractured screw fragments could be removed successfully using available retrieval methods. Reverse Drilling and Conventional Instrumentation demonstrated higher success rates (75%) compared with the Claw-Type technique (66.7%), although the differences were not statistically significant. These findings suggest that while all three techniques may be clinically useful, Reverse Drilling and Conventional methods may provide comparatively better procedural outcomes.

The superior performance of Reverse Drilling may be attributed to its mechanism of action. Reverse drilling establishes controlled engagement with the fractured fragment and creates counterclockwise rotational movement that facilitates efficient dislodgement of the screw without applying excessive lateral forces on implant walls. In contrast, claw-type systems depend on direct mechanical engagement and gripping of the fragment, which may be more technique-sensitive and less effective in certain fracture configurations.

The findings of the present study are in agreement with the study by Agustín-Panadero et al.[15] who compared conventional retrieval methods with mechanical retrieval systems and reported superior outcomes with mechanical systems in terms of retrieval success and preservation of implant threads. They emphasized that controlled engagement of fractured fragments improved retrieval efficiency and reduced procedural difficulties. Similarly, Igarashi et al.[16] reported approximately 75%

retrieval success, which closely corresponds with the success rates observed for Reverse Drilling and Conventional methods in the present study.

The present investigation also demonstrated statistically significant differences regarding the number of retrieval attempts ($p=0.001$). Reverse Drilling exhibited superior procedural efficiency with 75% of cases successfully retrieved in a single attempt, while multiple attempts were frequently required with Claw-Type and Conventional methods. Furthermore, no specimen in the Reverse Drilling group required a third retrieval attempt.

The reduced number of attempts observed with Reverse Drilling may be explained by its precise engagement mechanism and guided instrumentation system. Multiple retrieval attempts increase operator fatigue, chairside time, and the possibility of damaging implant threads. Therefore, minimizing attempts is clinically important.

The results are consistent with those of Ming Shu-Lee et al.[17], who demonstrated improved retrieval efficiency and reduced procedural time with customized screw retrieval systems. Likewise, Kang Zeng et al.[18] reported that microtube extraction devices facilitated controlled retrieval and reduced repeated manipulations, thereby enhancing procedural success.

Retrieval time represents an important clinical parameter because prolonged procedures may increase patient discomfort, operator fatigue, and the risk of iatrogenic complications. In the present study, the mean retrieval time differed significantly among study groups ($p<0.001$). Reverse Drilling required the least time (10.31 ± 3.42 minutes), followed by Conventional instrumentation (13.72 ± 3.93 minutes) and Claw-Type retrieval (14.67 ± 3.68 minutes).

The reduced retrieval time associated with Reverse Drilling can be explained by guided instrumentation and controlled access to the fractured fragment. By creating direct engagement within the fractured screw, retrieval can be achieved with fewer procedural steps and reduced instrument manipulation.

These observations are supported by Moorthy et al.[19], who reported shorter retrieval times with specialized retrieval systems compared with conventional instruments. Similarly, Bufalá Pérez et al.[20] observed that drilling-based techniques produced less procedural complexity and reduced damage to implant structures compared with alternative methods.

Regarding implant thread integrity, no statistically significant differences were observed among the study groups. Thread damage occurred in 33.3% of specimens in the Claw-Type group and 25% in both Reverse Drilling and Conventional groups. Although these differences did not reach statistical significance, a trend toward better preservation of implant integrity was observed with Reverse Drilling and Conventional techniques.

Preservation of implant internal threads is of considerable clinical importance because damage to implant threads can compromise future prosthetic rehabilitation and may necessitate implant replacement. The relatively low incidence of thread damage observed with Reverse Drilling may be attributed to the use of rescue drill guides that help direct instrumentation and minimize contact with implant walls.

The findings are comparable with those reported by Feng-Chou Cheng et al.[21] and Yuseyung Yi et al.[22], who highlighted the importance of minimally invasive retrieval techniques that preserve internal implant architecture. Their studies emphasized that maintaining implant integrity is as important as successful screw retrieval itself.

The present findings also support the observations of Chowdhary et al.[23], who suggested that fracture morphology significantly influences retrieval difficulty and reported greater challenges in managing ASF-3 fractures. Since equal distributions of ASF-1, ASF-2, and ASF-3 patterns were maintained in the present investigation, the influence of fracture morphology was minimized, thereby improving the comparability of retrieval techniques.

However, some findings in the literature contrast with the results of the present investigation. Moorthy et al.$_{19}$ observed no significant differences between commercially available retrieval kits and conventional instruments regarding retrieval success rates, whereas the present study demonstrated improved efficiency with Reverse Drilling. Such variations may be attributed to differences in implant systems, fracture simulation techniques, operator experience, and study methodologies.

Similarly, Mizumoto et al.[24] emphasized that retrieval difficulty varies according to fracture location and classified retrieval techniques according to procedural risk. Their findings suggest that no single retrieval technique can be universally applied in all clinical scenarios, indicating that technique selection should be individualized according to specific fracture characteristics.

Overall, the findings of the present study indicate that Reverse Drilling demonstrated superior procedural efficiency by reducing retrieval time and minimizing the number of attempts while maintaining acceptable implant thread preservation. Although overall retrieval success rates were comparable among groups, the Reverse Drilling technique appeared to provide a more predictable and clinically favorable approach.

Limitations of the Study

1. The present investigation was conducted as an in vitro study, and therefore clinical conditions such as saliva, blood contamination, restricted access, patient movement, and soft tissue interference could not be replicated.
2. Only one implant system and implant-abutment configuration were evaluated, which may limit generalization of the findings to other implant designs.
3. The study evaluated a limited number of retrieval techniques and did not include recently introduced customized retrieval systems or micro-extractor devices.
4. Operator variability was minimized by using a single operator; however, this may not accurately represent differences in clinical skill and experience.
5. Long-term outcomes following retrieval procedures and subsequent prosthetic rehabilitation were not evaluated.

Future Recommendations

1. Future studies should include clinical in vivo investigations to validate the findings under real oral conditions.
2. Comparative assessment of retrieval techniques across different implant systems, implant diameters, and connection designs should be performed.

3. Newly developed technologies such as microtube extraction systems, customized screwdrivers, and computer-assisted retrieval systems should be investigated.
4. The influence of fracture morphology and depth on retrieval outcomes should be analyzed separately.
5. Long-term follow-up studies evaluating implant survival and prosthetic outcomes following screw retrieval procedures are recommended.
6. Future studies should include assessment of thermal effects and microscopic evaluation of implant thread alterations after retrieval procedures.

CONCLUSION

Within the limitations of the present in vitro study, it can be concluded that all three retrieval techniques demonstrated acceptable efficacy in the management of fractured implant abutment screws. However, the Reverse Drilling Retrieval technique exhibited superior procedural efficiency, requiring fewer retrieval attempts and significantly less retrieval time compared with the Claw-Type and Conventional methods. Although retrieval success rates and implant thread preservation were comparable among the groups, Reverse Drilling provided more predictable and consistent outcomes without compromising implant integrity. Therefore, Reverse Drilling may be considered a reliable and clinically effective approach for retrieval of fractured implant abutment screws. Nevertheless, further long-term clinical studies are required to validate these findings and establish standardized treatment protocols for routine clinical practice.

REFERENCES

1. Adell R, Lekholm U, Rockler B, Brånemark PI. A 15-year study of osseointegrated implants in the treatment of edentulous jaw. *Int J Oral Surg.* 1981;10:387–416.
2. Ekelund JA, Lindquist LW, Carlsson GE, Jemt T. Implant treatment in the edentulous mandible: a prospective study over 20 years. *Int J Prosthodont.* 2003;16:602–608.
3. Jemt T. Failures and complications in 391 consecutively inserted fixed prostheses supported by Brånemark implants. *Int J Oral Maxillofac Implants.* 1991;6:270–276.
4. Jemt T, Lekholm U. Oral implant treatment in posterior partially edentulous jaws. *Int J Oral Maxillofac Implants.* 1993;8:635–640.
5. Brägger U, Aeschlimann S, Bürgin W, Hämmerle CH, Lang NP. Biological and technical complications with fixed partial dentures on implants and teeth. *Clin Oral Implants Res.* 2001;12:26–34.
6. Schwarz MS. Mechanical complications of dental implants. *Clin Oral Implants Res.* 2000;11:156–158.
7. Binon PP. The effect of implant/abutment hexagonal misfit on screw joint stability. *Int J Prosthodont.* 1996;9:149–160.
8. Bozkaya D, Muftu S. Mechanics of the tapered interference fit in dental implants. *J Biomech.* 2003;36:1649–1658.
9. Bakeen LG, Eckert SE, Wollan PC. Influence of implant diameter and prosthetic design on screw loosening. *J Prosthet Dent.* 2001;85:68–74.
10. Williamson RT, Robinson FG. Retrieval technique for fractured implant screws. *J Prosthet Dent.* 2001;86:549–550.
11. Yokoyama K, Ichikawa T, Murakami H. Fracture mechanisms of retrieved titanium screw threads in dental implants. *Biomaterials.* 2002;23:2459–2465.
12. Eckert SE, Meraw SJ, Cal E, Ow RK. Analysis of incidence and associated factors with fractured implants. *Int J Oral Maxillofac Implants.* 2000;15:662–667.
13. Chowdhary R, et al. Classification and management of abutment screw fractures. *J Prosthet Dent.* 2023;129:142–149.
14. Raju S, Kini V, Kumar L. Risk assessment in management of fractured abutment screws. *J Prosthodont Res.* 2021;65:198–204.
15. Agustín-Panadero R, Serra-Pastor B, Fons-Font A, Solá-Ruiz MF. Comparative evaluation of fractured screw retrieval techniques from dental implants. *Med Oral Patol Oral Cir Bucal.* 2017;22:e399–e405.
16. Igarashi K, Kamijo R, Nakajima K, Arisaka Y, Baba K. Retrieval of fractured implant screws using a repair service set and assessment of completeness of removal. *J Prosthodont Res.* 2019;63(3):320-326.
17. Ming SH, Lee MS, Chen HC, Lin CY, Chang HP. A modified custom-made screwdriver technique for retrieval of fractured implant abutment screws. *J Prosthet Dent.* 2023;129(4):512-518.
18. Zeng K, Li X, Wang Y, Zhang H, Liu J. Efficacy of a microtube extraction device in retrieval of fractured implant abutment screws. *J Prosthodont.* 2022;31(7):605-611.
19. Moorthy A, Nayana P, Bhat VS, Kumar P. Comparative evaluation of retrieval effectiveness and procedural time between commercially available screw retrieval kits and conventional dental instruments. *J Indian Prosthodont Soc.* 2022;22(4):352-358.
20. Bufalá Pérez M, Sánchez-Pérez A, Martínez-González JM, López-Quiles J. Comparative analysis of ultrasonic and drilling techniques for extraction of fractured abutment screws in conical internal implant connections. *Clin Oral Investig.* 2022;26(5):4121-4129.
21. Cheng FC, Lin YH, Wang HL, Chen YC. A minimally invasive technique for retrieval of fractured implant abutment screws while preserving implant thread integrity. *J Prosthet Dent.* 2023;130(2):240-246.
22. Yi Y, Kim JH, Lee DH, Park EJ. Minimally invasive retrieval of fractured implant screw remnants while preserving implant integrity: A clinical report. *J Prosthet Dent.* 2021;126(5):621-626.
23. Chowdhary R, Sharma A, Gupta N, et al. Classification and management of implant abutment screw fractures: A comprehensive review. *J Prosthet Dent.* 2023;129(2):142-149.