Torsion Resistance of the Ball Head System Screw and Screwdriver for Angled Screw Channels on Implant Prosthetics

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The primary objective of this study was to determine the torsion resistance of the Ball Head System (BHS) screw and screwdriver set at 0°, 20°, and 30° angulations. The secondary objective was to compare the BHS set with the 1.3-mm hexagonal screwdriver system (HexS) at 20° and analyze the condition of the BHS after 10 and 30 iterations with 30 N·cm torque at 30° angulation. A workbench made from type 4 plaster with 6 steel implant replicas (external hexagon, 4.1 mm) inserted at 0°, 20°, and 30° angulation was designed. An analogical torque meter was used. The deformations produced on the whole set were examined by field emission scanning electron microscopy. A descriptive analysis was performed. The maximum torque performance for BHS at 30° angulation was 54 ± 12 N·cm. Most screws could be removed despite the deformations produced. At 20° angulation, the BHS set achieved an average torque resistance of 67 ± 12 N·cm, whereas the HexS failed at 45 ± 2 N·cm. Although the iterations performed at 30 N·cm torque and 20° angulation produced some deformations on BHS sets; these could be tightened and unscrewed. The BHS allows tightening at a torque of up to 54 N·cm. Under the same conditions, BHS showed more torque resistance than HexS. Deformation of BHS sets was directly related to the number of iterations.

Key Words: angled screw channels, torsion resistance, screw-retained prostheses, ball head screw, screwdriver

INTRODUCTION

Implant-supported prostheses can either be screw retained (directly onto the implant or onto an abutment) or cement retained. Prosthetic rehabilitation for implants placed in an improper or tilted position is currently solved by cemented reconstructions on angulated abutments.[1–3] Taking into consideration that screw-retained reconstructions are more easily disconnected to perform peri-implant maintenance therapy and the treatment of complications,[4–6] the development of a screw and screwdriver system for implant-supported prosthesis with angled channels would be of great help.

A prosthetic component called Dynamic Abutment (Talladium International Implantology, Lleida, Spain) was developed in 2004 to allow deviation of the restorative screw access angle up to 28°, based on a 1.3-mm hexagonal screwdriver design (HexS).[7]

Nowadays, restorative dentistry has turned digital. In fact, a recent randomized controlled trial[8] demonstrated that the digital workflow to restore single implants had lower costs in terms of economic costs and chair time and that it was also preferred by patients over conventional procedures. However, the decision-making process for the clinician starts before the clinical applicability. In this way, virtual models analyzed by finite-element analyses help researchers and practitioners to decide the best indication of the distinct components of a restoration such as ideal implant design,[9] cemented versus screwed restorations,[10] or prosthetic materials.[11] Specifically, computer-aided design/computer-aided manufacturing (CAD-CAM) technology is been used to fabricate screw-retained prostheses with angled channels up to 30° that show no differences regarding mechanical complications compared with straight channels.[12]

In this line, a new screw and screwdriver system for implant-supported prostheses with angled channels was developed, and a previous study by Farré-Berga et al[13] designed the optimal geometry of the so-called Ball Head System (BHS) by means of nonlinear finite-element analysis. In this system, the screw head constitutes the male component of the connection, being a spherical dented structure. The results showed that BHS could achieve the required mechanical strength for screws used in screw-retained reconstructions with angled channels, even at 30° angulation.

When the clinician applies torque with a screwdriver to a

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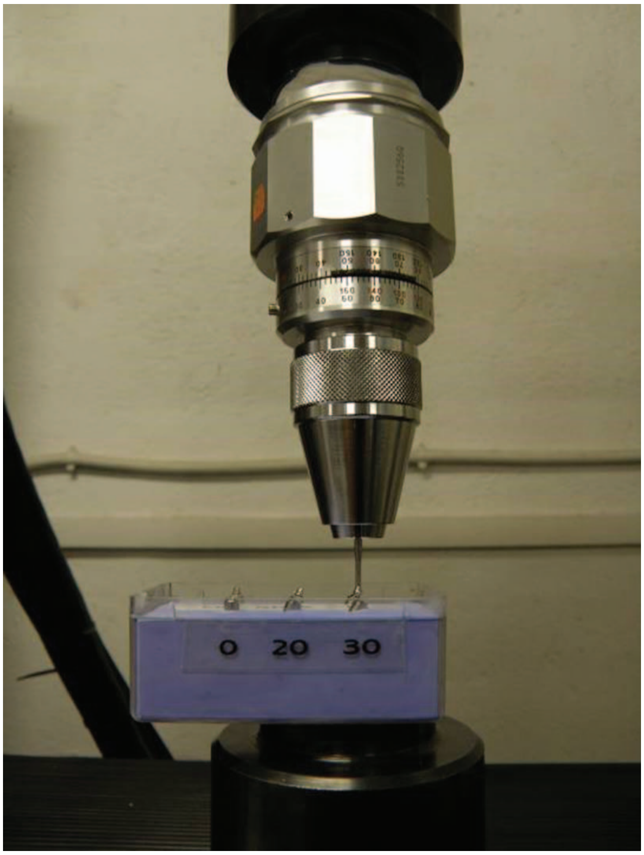


Figure 1. Analogical torque meter. Assembly of the analogical torque meter for the test set.

screw, the tightening torque creates preload. Then, the elastic recovery of the screw creates the clamping force that pulls the prosthesis and the implant together.[14] The established preload is proportional to the applied torque can be controlled by the clinician and can be reproduced. However, there are other factors that could affect preload, such as the screw alloy, screw head design, and the abutment surface.[15]

The present study was designed to validate the accuracy of this novel ball head screw and screwdriver system. The primary objective was to determine the torsion resistance of the BHS screw and screwdriver set at distinct angulations (0°, 20°, and 30°). The secondary aims were to compare the BHS set with the well-known 1.3-mm HexS at 20° angulation and to analyze the condition of 2 untreated BHS sets after 10 and 30 iterations with 30 N·cm torque at 20° angulation.

Materials and Methods

An in vitro experimental study was carried out. The screwdrivers were made from steel 17-4PH (an alloy containing 0.04% carbon, 0.25% silicon, 0.40% manganese, 15.30% chromium, 4.50% nickel, 3.25% copper, and 0.3% niobium and then subjected to thermal treatment), and the screws were made of a Ti6Al4V grade 5 alloy containing 6% aluminum and 4% vanadium. To perform the different torsion resistance tests, a workbench made from type 4 plaster with 6 steel implant replicas (external hexagon, 4.1 mm) inserted at 0°, 20°, and 30° were designed. These workbenches were fixed on a grooved metallic bench. An analogical torque meter (model BTG150CN, Tohnichi, Buffalo Grove, Ill) was used to perform the different tests. BHS screwdrivers were fixed through their antirotational device and gripped on their ISO 1797 shaft and 4 mm below it, by a dental handler adaptor (ref. CCUNI0, Talladium).

Evaluation of torsion resistance at 0°, 20°, and 30° angulation

The BHS screws were inserted into the replicas, and progressive torque until failure of any of the components was applied (Figure 1) by means of the screwdrivers inserted into the torque meter. A total of 9 BHS screwdriver and screw sets (ref. M2 × 0.4 HE 4.1 mm Ti) were tested, with 3 sets in each angulation.

Evaluation of torsion resistance of HexS fastening connection at 20° angulation

The torsion resistance of three HexS screwdriver-screw sets (screw ref. TPD2+, Talladium) was tested at an angulation of 20° until breakage of the connection. Tests were performed at 20° angulation because the HexS connection does not allow higher angulations.

Analysis of the screwdriver-screw set after 10 and 30 iterations with a torque of 30 N·cm

Two new screw and screwdriver sets were used. Thirty iterations were performed at an angulation of 20° and applying 30 N·cm torque to observe the deformation produced. An iteration was defined as a complete fastening and loosening cycle.

The registered variables were the maximum torque achieved (N·cm), the average torque (N·cm), failure location, and unscrewing capacity (unscrewed with the tested screwdriver, a new screwdriver, or a laboratory clamp). The deformations produced on the screw and screwdriver set were evaluated by field emission scanning electron microscopy (FESEM).

A descriptive analysis of these variables was performed.

Results

Evaluation of torsion resistance at 0°, 20°, and 30° angulation

Table 1 shows the results of the torsion resistance tests at different angulations. One screw had a ductile fracture at 0°. The maximum torsion reached at the moment of fracture was 110 N·cm. This torsion torque was the highest reached among all the tests. Furthermore, the screw head grooves were seen to have undergone less deformation in comparison to the rest of the screws tested at 0° angulation.

Most of the tested sets experienced failure at the screw head grooves in contact with the screwdriver protuberances (Figure 2). In these cases, there was deformation of the screw head, which was the main cause of set failure. Higher

Table 1

Results obtained in tests at different angulations

Angulation	Sample	Maximum Torque (N·cm)	Failure Location	Unscrewed	Average (N·cm)
0°	1	110	Thread	Yes*	86 ± 20
	2	78	Grooves	Yes	
	3	72	Grooves	Yes	
20°	1	70	Grooves	Yes	67 ± 12
	2	54	Grooves	Yes	
	3	78	Screwdriver and grooves	Yes	
30°	1	40	Grooves	Yes	54 ± 12
	2	60	Grooves	Yes†	
	3	74	Screwdriver and grooves	Yes†	

*Unscrewed with a laboratory clamp.
†Unscrewed with a new screwdriver.

angulations caused slight increases in the plastic deformation of the screw grooved head area. The same pattern was observed in the case of the screwdriver, although with more pronounced deformation of its interior walls and protuberances as the angulation of the test increased (Figure 3). Plastic deformation of the metal was concentrated on the contact surface between the screwdriver and the screw because of mechanical load concentration in these areas.

In one of the tests at 20° angulation and another at 30°, some deformation of the screw grooves together with breakage of the screwdriver walls was observed. Apart from screwdriver wall breakage, the tool also had some interior plastic deformation, absorbing part of the torque force. Another notable fact is that, in both cases, these sets were the most resistant ones of all the samples.

Evaluation of torsion resistance of HexS fastening connection at 20° angulation

Table 2 shows the results obtained. In this case, there was only 1 type of breakage: the screwdrivers did not show significant deformation, and the inner part of the screws showed important plastic deformation with some loss of material (Figure 4). Thus, in all these 3 cases, the screwdriver-screw set failed because of deformation of the screw, which had to be unscrewed by a workshop pressure key, which is a difficult tool to use in prosthetic restoration.

Analysis of the screwdriver-screw set after 10 and 30 iterations with a torque of 30 N·cm

After 10 iterations, deformation on the screwdriver was noticed, located in the area corresponding to torque sense, together

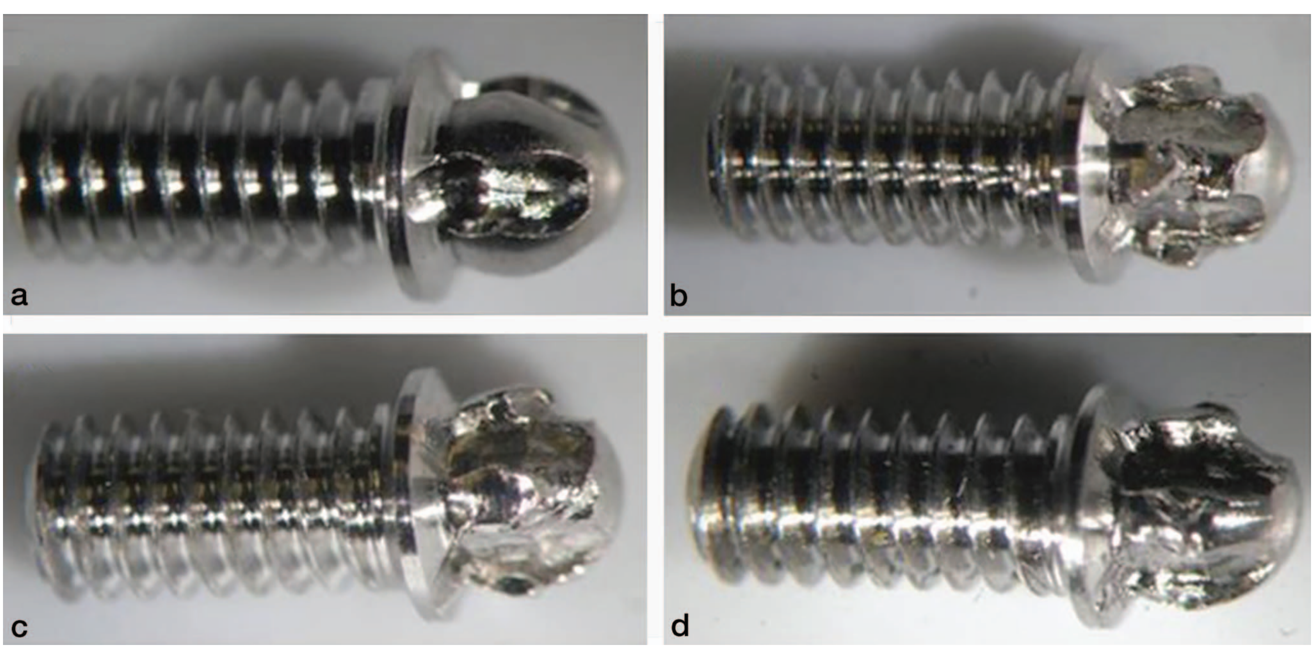
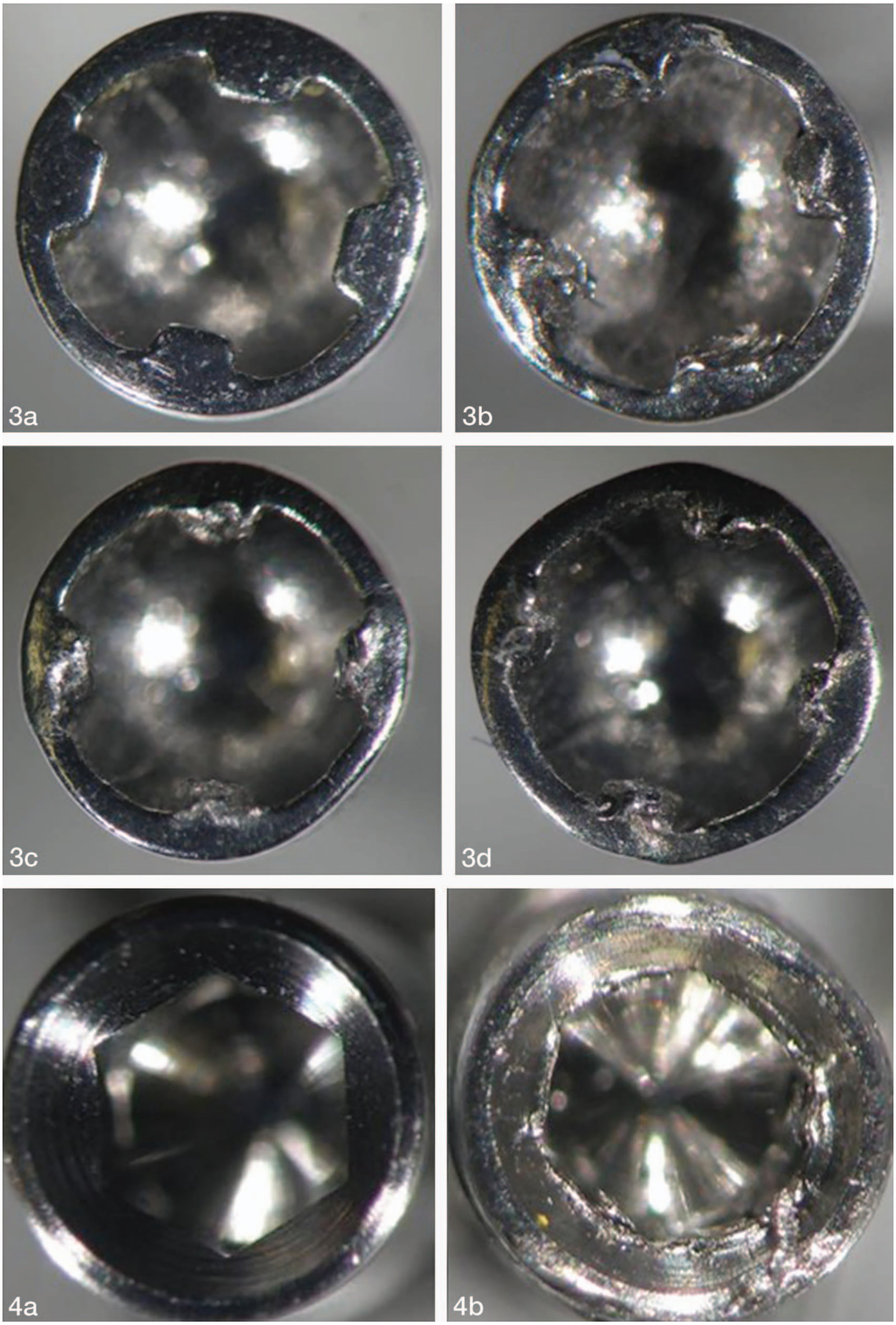


Figure 2. Deformed Ball Head System screw grooves. (a) Nontested screw. (b) Screw tested at 0°. (c) Screw tested at 20°. (d) Screw tested at 30°.



Figures 3 and 4. Figure 3. Inner aspect of the Ball Head System (BHS) screwdrivers. (a) Nontested screwdriver. (b) Screwdriver tested at 0°. (c) Screwdriver tested at 20°. (d) Screwdriver tested at 30°. **Figure 4.** 1.3-mm hexagonal screwdriver system. (a) Nontested screw. (b) Tested screw.

Table 2

Test results of the HexS sets at 20°*

Sample	Maximum Torque (N·cm)	Unscrewed	Average (N·cm)
1	44	Not†	45 ± 2
2	48	Not†	
3	44	Not†	

*HexS indicates 1.3-mm hexagonal screwdriver system.
†It was unscrewed by using a workshop pressure key.

with minimum deformation in the opposite sense, because of the torque that was applied for loosening the screws and preparing them for the next iteration.

In the case of 30 iterations, the screwdriver became more deformed than in the previous test with regard to the torque sense area of the tool protuberances (Figure 5). Nevertheless, all sets could be screwed and unscrewed easily through the complete round of iterations, although deformation appearing on the loosening sense was also slightly greater than in the 10 iterations test.

The screws in turn showed some deformation on the head grooves in both cases, although it was in the 30 iterations test where deformation was greater (Figure 6). Nevertheless, as mentioned before, this deformation did not prevent the test from continuing until all iterations had been performed.

Discussion

The results of the present study show that this screw and screwdriver system accepts tightening at a torque of up to 54 N·cm. Moreover, most screws could be removed despite the deformations produced on the screw grooves or on the internal surface of the screwdriver. The HexS system failed at lower torques than the BHS, and no screws could be removed by means of their own screwdrivers. This new system therefore has shown superiority compared with the HexS system.

A study published by Spencer et al[16] examined torsion resistance of distinct types of screw head designs (slot, cross, square, and star) depending on the angle of application of the screwdriver. The specimens were osteosynthesis screws made from titanium, commonly used in oral and maxillofacial surgery. The authors concluded that the slot and cross designs were preferable because they tended to preserve the original shape, and they would be easier to remove. Comparing their results with the ones found in the present study, BHS showed a considerable improvement in the maximum torques because it almost doubled the values obtained by Spencer et al.[16] Moreover, this system can be easily removed with the same screwdriver or a new one.

In the field of fixed[11] and removable[17] implant-supported prostheses, former articles have assessed the biomechanical properties of prosthetic components using computer-aided design and finite-element analyses. These virtual models permit the establishment of technical suggestions to help the decision-making process for researchers and clinicians to choose the best reconstructive material for each clinical situation.[9,11] This rationale was the one used to design the present study, as a previous finite-element analysis study on BHS has been performed.[13]

It is widely described in the literature that the use of tilted implants may reduce the need of bone augmentation procedures, which decreases treatment complexity, postoperative complications, and costs.[18] For these cases, the present screw and screwdriver system allows for correct angulations. Moreover, screw-retained reconstructions have an advantage over cemented ones because they can be removed easily to treat biological and mechanical complications and to perform peri-implant maintenance care.[19,20]

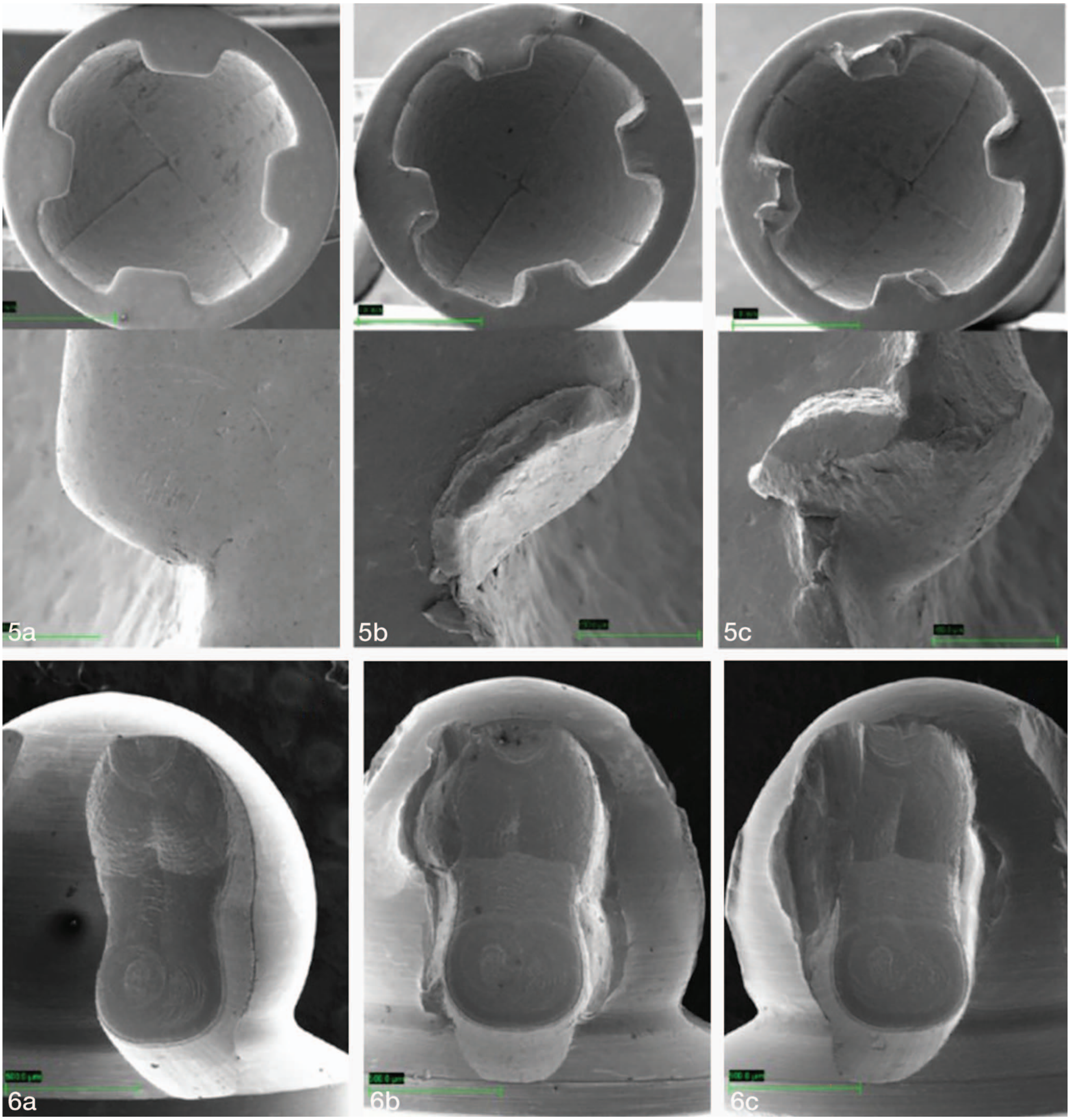
In the case of tilted implant reconstructions solved by an angled screw channel, if the screw head is deformed or stripped, further seating or removal of the screw may not be possible without drilling the screw out of the prosthesis and implant. Fortunately, most BHS screws were able to be removed with their own screwdriver even in the presence of deformation.

One of the most common mechanical complications in metal-resin implant-supported full-arch restorations is abutment or prosthetic screw loosening. The estimated annual event rate was 2.1% (95% CI, 1.3%–2.8%). Forces greater than the clamping force of the screw joint can cause screw loosening and even fracture.[20] Screw loosening is mainly caused by an inappropriate tightening torque, by overload that causes screw deformation and preload loss,[21] and by functional load vibration. Besides, prosthetic misfit could be another factor producing screw loosening. To compensate for preload loss and increase the contact area between threads, some authors recommend applying torque again 10 minutes after screw fastening.[14,21] To increase the torque beyond 30 N·cm could even decrease the screw loosening rate and prosthetic stability.[14] However, Bacchi et al[22] did not observe any influence from the screw refastening after 10 minutes. These authors explain that the preload and tightening technique do not have an effect after long-term function.

Spencer et al[16] emphasized the importance of a screw and screwdriver system allowing screw tightening at a greater angulation with the least possible disengaging or stripping of the screw head. According to these authors, there are some regions in the oral cavity where access and placement of a screw is difficult. Thus, although the design of this novel screw and screwdriver system was initially intended for angled prosthetic channels, it could also be implemented in other medical areas such as maxillofacial surgery or even trauma surgery.

Further clinical studies are needed to assess the real performance of this screw and screwdriver system under masticatory forces and parafunctional habits. The fact that the screw was directly tightened into a replica made from steel could be a limitation in our study, inducing some changes in the behavior of the screw.

Moreover, the use of a coating to improve or increase the number of uses or to avoid deformities could be investigated. Such modifications may promote greater preload stability and more stable joints. Diamond-like carbon (DLC) over titanium surface decreases friction resistance, thereby incrementing preload.[22,23] Likewise, a study published by Bacchi et al[22] found that conventional titanium screws achieved higher loosening torque values than DLC-coated screws for universal abutment fixation.



Figures 5 and 6. Figure 5. Ball Head System (BHS) screwdrivers visualized by field emission scanning electron microscopy (FESEM). Upper bars show 1.0 mm and lower show 150 μm. (a) Nontested screwdriver. (b) Screwdriver condition after 10 iterations. (c) Screwdriver condition after 30 iterations. **Figure 6.** BHS screws visualized by FESEM. Bars show 500 μm. (a) Nontested screw. (b) Screw condition after 10 iterations. (c) Screw condition after 30 iterations.

Conclusions

- The most critical angulation analyzed with the BHS sets was 30° deviation from the screw insertion axis, where maximum torque performance corresponded to 54 ± 12 N·cm.
- The most common failure when testing the BHS sets was deformation experienced by the screw grooves and the internal part of the screwdriver.
- At 20° angulation, the BHS sets achieved an average torque resistance of 67 ± 12 N·cm, whereas the HexS system failed at 45 ± 2 N·cm, under the same conditions. The BHS screws taken to failure could all be unscrewed with their own screwdriver, whereas the HexS screws had to be unscrewed using a workshop pressure key in all cases.
- Deformation and wear of the BHS sets were directly related to the number of iterations at 30 N·cm torque and 20°

angulation. The deformations were more relevant after 30 iterations, although the screw could be tightened and unscrewed easily throughout the complete test.

Abbreviations

BHS: Ball Head System
DLC: diamond-like carbon
FESEM: field emission scanning electron microscopy
HexS: 1.3-mm hexagonal screwdriver system

Acknowledgments

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Note

The authors have conflicts of interest, as patent registrations have been obtained for the external connection (BHS30 EXTERNAL: WO/2009/150350) and for the internal component (UBH INTERNAL: US8978525 / EP2420354 B1 / CN102395447 B).

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