Ball Head System screw and driver study:

Comparative evaluation of torsion resistance

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Ball Head System BHS

ABSTRACT

1. PURPOSE

The aim of the current study is to determine the torsion resistance of the Ball Head System (BHS) screw and driver set. The manufacturing company Ball Head System, s.l. supplied the following materials in order to carry out this study:

1. Workbench with six dental implant replicas fixed in angulations of 0 º, 20 º and 30 º.
2. 12 samples of BHS driver and screw sets (screw ref. M2 HE RP, Ball Head System).
3. 9 samples of BHS driver and screw sets in three different surface treatment conditions (TiN, CrN and DHC-TR coatings).
4. 9 samples of Allen Ball driver and screw sets (ref. TPD2+, Talladium, Lleida, Spain).
5. 9 samples of Hexalobular driver and screw sets (ref. 19.401, TruAbutment, Irvine, USA).

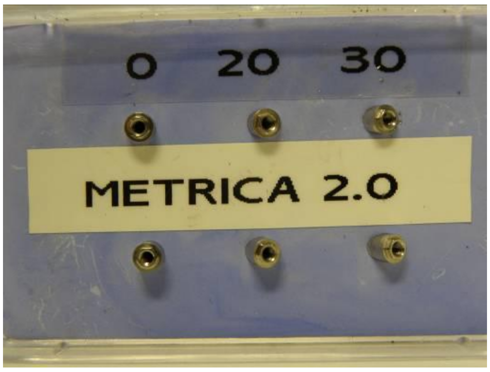

Figure 1. Workbench with 3 angulations to test (left). BHS driver and screw set (right).

2. MATERIALS AND METHODS

Torsion resistance of all driver and screw sets supplied by Ball Head System was evaluated with an analogical torquimetre (model BTG150CN, Tohnichi), by applying a progressive torque until failure of any of the components occurred, as it can be seen on Figure 2. All tests were made by the same technician and supervisor, according to the same procedure and materials.

The workbench was fixed on a grooved metallic bench. Drivers were fixed through their antirotational device, gripped on their ISO 1797 shaft and 4 mm below it, by a dental handler adaptor (ref. CCUNI0, Talladium, Lleida). Tests were divided into the following different tasks:

1. Evaluation of torsion resistance at 0 º, 20 º and 30 º of 9 BHS sets without treatment.
2. Evaluation of torsion resistance in 3 different surface treatment conditions applied to the drivers. 3 BHS sets tested in their more critical angulation, analysed in point 1.
3. Evaluation of torsion resistance at 20º of 3 Allen Ball connection sets. This angulation was chosen because it is the maximum deviation capacity of the Allen Ball system.
4. Evaluation of torsion resistance at 20º of 3 Hexalobular connection sets. By analogy.
5. Analysis of the condition of 2 BHS untreated sets after 10 and 30 iterations with a torque of 30 N·cm. Iteration defined as a complete fastening and loosening cycle.

Statistic differences have been analysed between BHS, Allen Ball and Hexalobular systems through a non-parametric analysis with a 95% confidence rate, performed using SPSS Statistics 17.0 software.

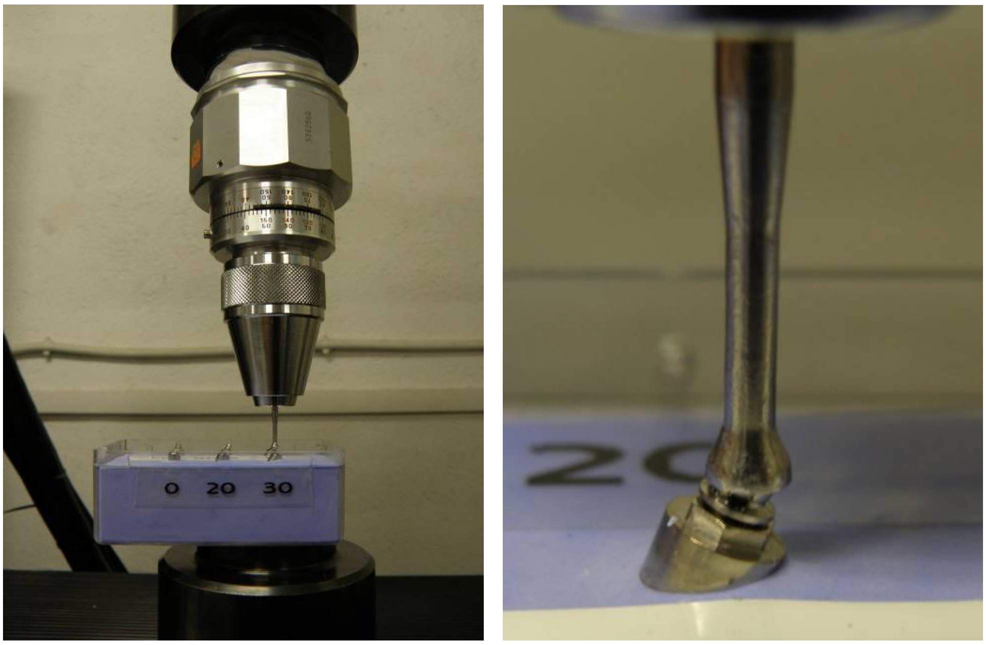

Figure 2. Assembly of the analogical torquimetre for the test set.

Detailed images of the screw and driver sets have been taken with a binocular microscope before and after each test. In the iteration tests, images were obtained by using a scanning electronic microscope FESEM (JSM-7001F, Jeol, Japan).

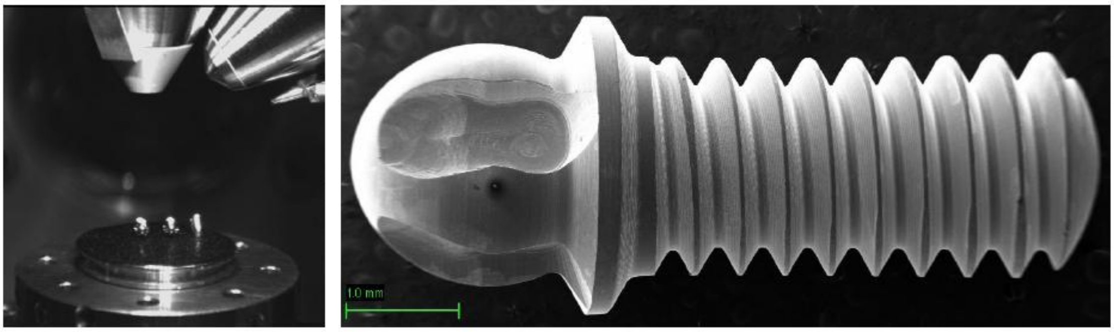

Figure 3. BHS screws inside the FESEM room (left) and BHS screw observed through the FESEM (right). Bar indicates 1 mm.

3. RESULTS AND DISCUSSION

3.1. TEST 1: EVALUATION OF TORSION RESISTANCE AT 0°, 20° AND 30°

Three BHS screw and non surface treated driver sets were tested for each angulation, by applying a progressive torsion force with the analogical torquimetre until failure of the system took place, see the results on Table 1. All the screws could be unscrewed with its corresponding tested driver, with a new driver or with a laboratory clamp, depending on the case. After that, failures and deformations found on the set were analysed.

Table 1. Results obtained in tests at different angulations.

Angulation	Sample	Max. Torque (N·cm)	Failure Location	Unscrewed	Average (N·cm)
0 º	1	110	Thread	Yes*[2]	**86**±20
	2	78	Grooves	Yes	
	3	72	Grooves	Yes	
20 º	1	70	Grooves	Yes	**67**±12
	2	54	Grooves	Yes	
	3	78	Driver & grooves	Yes	
30 º	1	40	Grooves	Yes	**54**±12
	2	60	Grooves	Yes	
	3	74	Driver & grooves	Yes*[1]	

[1] Unscrewed with a new driver.[2] Unscrewed with a laboratory clamp.

The different types of failure -Failure Location- experienced by the sets tested are described and classified as follows:

Failure by the thread

There is only one screw with this type of ductile fracture, sample M1 at 0 º. Maximum torsion reached at the moment of fracture was 110 N·cm. This torsion torque figure was the highest one reached in all the tests. Furthermore, it was observed that the screw head grooves had undergone through less deformation when compared to the rest of the screws tested at 0 º.

Figure 4. Details of the broken thread (left) and image of the fracture surface (right).

Failure by the grooves

A wide majority of the tested sets experienced failure by the screw's head grooves in contact with the driver protuberances. In these cases there was a variable deformation of the screw head, which was the main cause of the set failure. Furthermore, it was observed that higher angulations would cause slight increases on the plastic deformation of the screw's grooved head area.

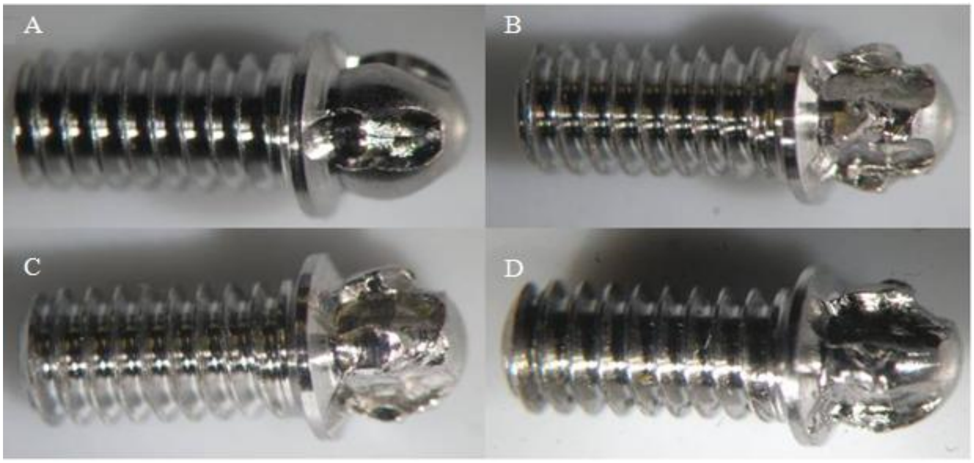

Figure 5. BHS screw broken by the grooves. (A) Non tested screw, (B) tested at 0 º, (C) at 20 º and (D) at 30 º.

The same pattern was observed in the case of the driver, although with more pronounced deformation of its interior walls and protuberances as the angulation of the test increased. Plastic deformation of the metal was concentrated on the contact surface between the driver and the screw, due to the mechanical load concentration on these specific areas.

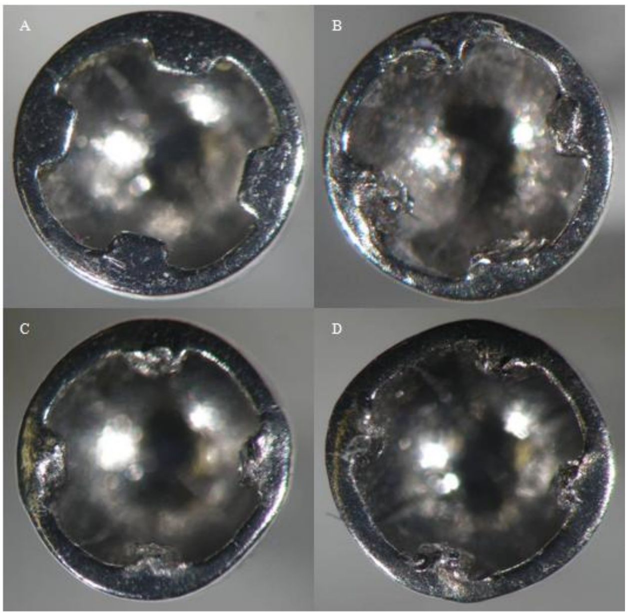

Figure 6. Driver inner aspect without deformation (A). Driver tested at 0 º (B), driver tested at 20 º (C) and driver tested at 30 º (D).

Failure by the grooves and by the driver

In one of the tests at 20º and another one at 30º, some deformation of the screw's grooves together with a breakage of the driver walls were experienced, as shown in Figure 7. Despite of the driver's walls breakage, the tool also suffered 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 among all the samples.

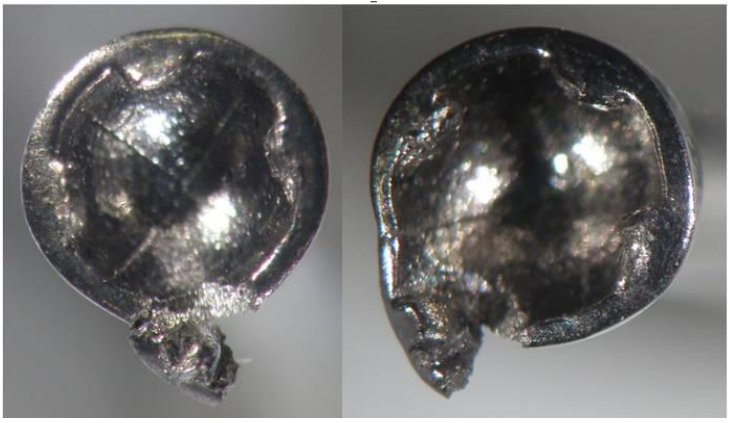

Figure 7. Interior details of the BHS driver tested at 20 º (right) and 30 º (left).

3.2. TEST 2: EVALUATION OF TORSION RESISTANCE IN DIFFERENT SURFACE TREATMENT CONDITIONS

Torsion resistance of 3 driver-screw sets for each surface treatment applied on the tools was also studied. All tests were carried out at an angulation of 30 º as this was the most critical situation resulting from previous tests (section 3.1.). Table 2 sums up the results obtained.

Table 2. Results obtained in the tests with different surface treatments applied on the drivers

Treatment	Sample	Maximum Torque (N·cm)	Unscrewed	Average (N·cm)
CrN	1	72	Yes	**82**±20
	2	68	Yes	
	3	106	No	
DHC-TR	1	88	Yes	**107**±31
	2	144	Yes	
	3	90	Yes	
TiN	1	80	Yes	**90**±10
	2	90	Yes	
	3	100	Yes	

After the test execution, it was impossible to extract the CrN-Num. 3 sample off the workshop implants because the grooves in the screw were completely damaged so it could not be removed neither with a new driver nor with a workshop pressure key (see Annex 5.1.). Finally, another attempt to remove it was done, by milling a clamping slot around its perimeter, also unsuccessfully. This fact caused the disabling of the device at 30 º.

The tests made with the CrN coated drivers presented lower maximum torque data in comparison with other treated drivers performance; although the differences were not statistically significant.

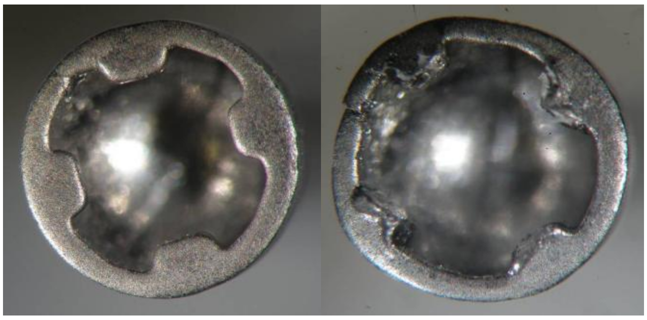

Figure 8. Inner details of the BHS driver CrN coating before (left) and after the test (right)

The drivers coated with DHC presented the highest torsion resistance. In this case, the drivers were deformed in their internal geometry, and in one of the samples, even the ISO1797 connection with the torquimetre -non coated area- was broken, see Figure 9.

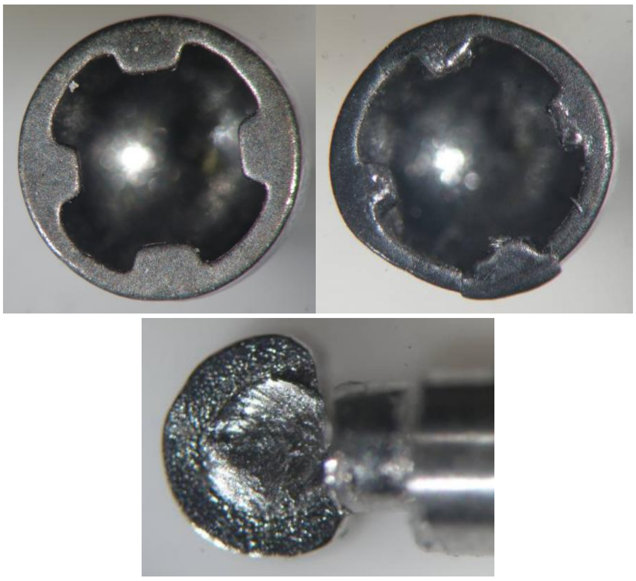

Figure 9. Interior details of the BHS driver coated with DHC without testing (left), after testing (right) and breakage surface of the upper part of the driver (bottom).

Finally, the TiN coated drivers showed a maximum torque performance and a failure typology similar to the drivers coated with CrN surface treatment, slightly improving the results.

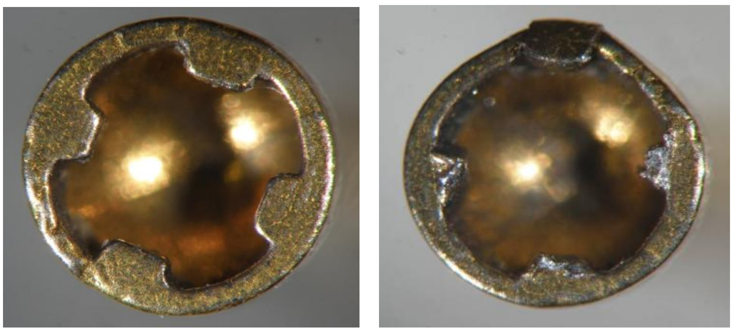

Figure 10. Interior details of the BHS driver coated with TiN before (left) and after testing (right).

3.3. TEST 3: TORSION RESISTANCE EVALUATION OF ALLEN BALL AND HEXALOBULAR SYSTEMS

Torsion resistance of 3 Allen Ball driver-screw sets was tested at an angulation of 20 ^{o} and the connection breakage was then observed. Tests were performed at 20 ^{o} because the Allen Ball connection does not allow higher angulations. Table 3 sums up the obtained results.

Table 3. Test results of the Allen Ball sets at 20 ^{o}.

Sample	Maximum torque (N·cm)	Unscrewed	Average (N·cm)
1	44	No*	
2	48	No*	**45**±2
3	44	No*	

* It was unscrewed by using a workshop pressure key.

In this case there was only one type of breakage: the drivers did not show significant deformation, as it is seen on Figure 11, while the inner part of the screws showed an important plastic deformation with some loss of material, as shown on Figure 12. In all these three cases, therefore, the driver-screw set failed due to the screw deformation, which led to a complete loss of gripping capacity and had to be unscrewed with a workshop pressure key, which is a difficult tool to use in prosthetic restoration.

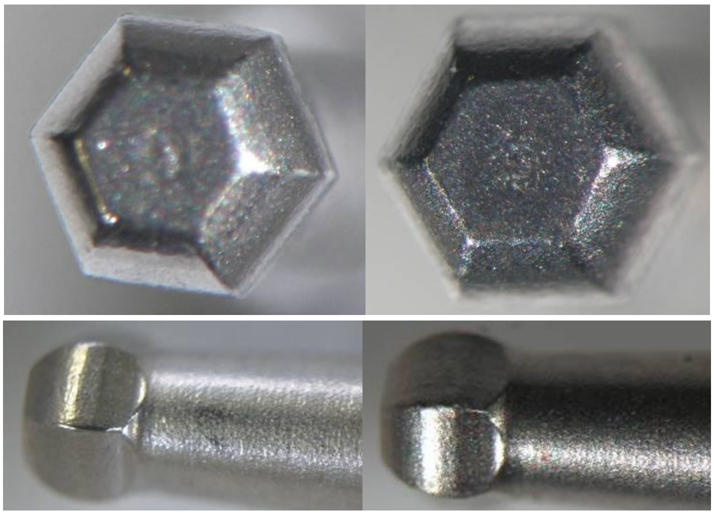

Figure 11. Original Allen Ball driver (left) and driver after testing (right).

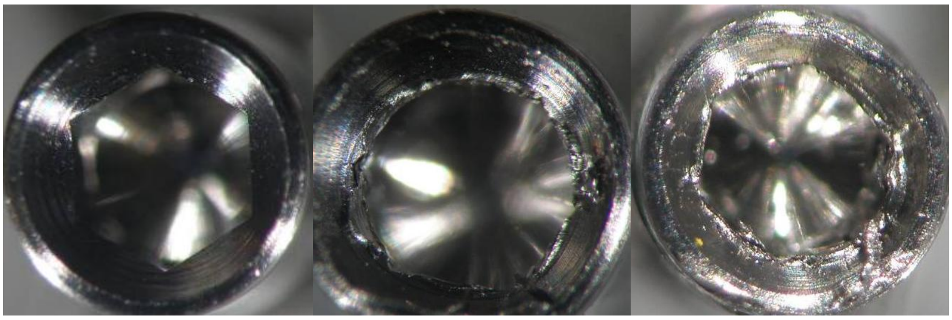

Figure 12. Original Allen screw (left) and screws, once tested (centre and right).

Additionally, torsion resistance of 3 Hexalobular Torx-shaped driver and screw sets was tested at an angulation of 20 º and the connection breakage nature was then observed. Angulation of 20 º was chosen to obtain comparable results to the ones previously achieved by the Allen Ball sets. Table 4 sums up the obtained results.

Table 4. Test results of the Hexalobular sets at 20 º.

Sample	Maximum torque (N·cm)	Unscrewed	Average (N·cm)
1	43	No*	
2	47	No*	**46**±3
3	48	No*	

* Sample unscrewed by using a workshop pressure key.

Hexalobular driver-screw sets also presented a single type of failure: the drivers did not show any signs of deformation after their use, as it can be seen on Figure 13, while the interior recess of the screws showed important plastic deformation with significant loss of material, localized mainly in the grooves, as it is shown on Figure 14. In all the cases with these samples, therefore, the driver-screw set failed due to the screw deformation, which led to a complete loss of gripping capacity and had to be unscrewed with a workshop pressure key, which is a difficult tool to use in prosthetic restoration.

Figure 13. Hexalobular driver after testing (right).

Figure 14. Original Hexalobular screw (left) and tested screws (centre and right).

3.4. TEST 4: ANALYSIS OF THE DRIVER-SCREW SET AFTER 10 AND 30 ITERATIONS WITH A TORQUE OF 30 N·CM

Iterations were performed at an angulation of 20 ° and applying a 30 N·cm torque, which is frequently used in prosthetic retention screws. Once tested, non-treated sets were observed at the FESEM to analyse the deformation produced after the iterations.

After 10 iterations a deformation on the driver was noticed, located in the area corresponding to the torque sense, and a minimum deformation in the opposite sense, due to the torque that was applied for loosening the screws and prepare them for the next iteration.

In the case of 30 iterations, the driver became more deformed than in the previous test when referring to the torque sense area of the tool's protuberances, as it is seen on Figure 15. Nevertheless, all sets could be screwed and unscrewed easily through the complete round of iterations, although deformation appearing on the loosening sense is also slightly higher than in the 10 iterations test.

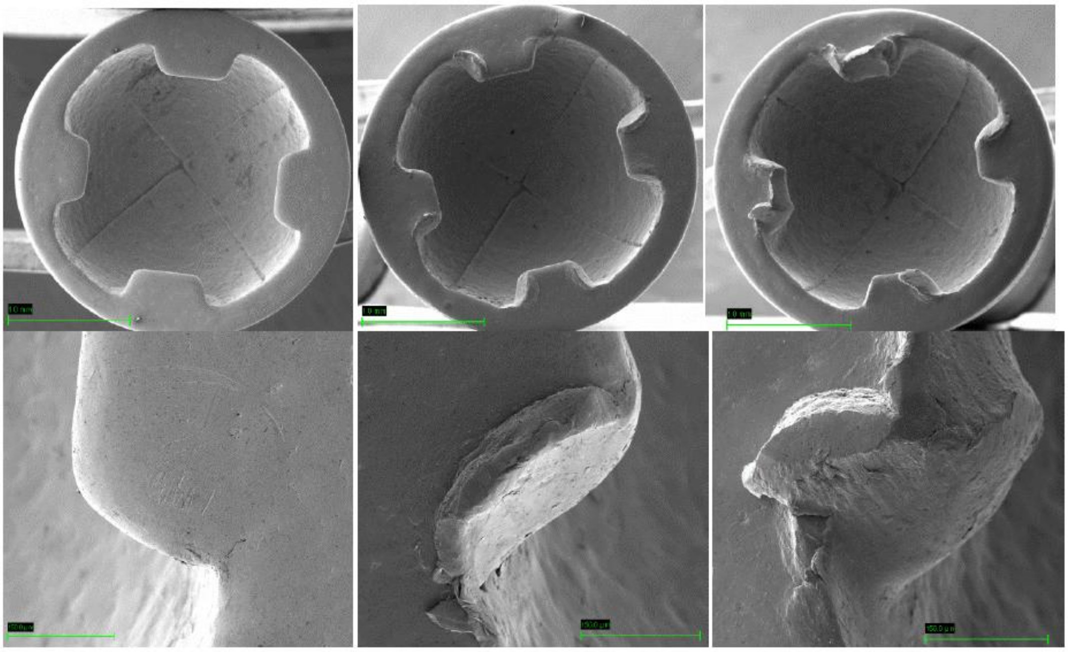

Figure 15. Detail of the original BHS driver (left), the driver after 10 iterations (centre) and the driver after 30 iterations (right). The upper bars show 1,0 mm and the lower ones 150 µm.

Regarding the screws, they showed some deformation on the head grooves in both cases, but it was in the 30 iterations test where the deformation experienced was bigger, as shown in Figure 16. Nevertheless, as mentioned before, this level of deformation would not prevent the test to continue until all iterations had been performed.

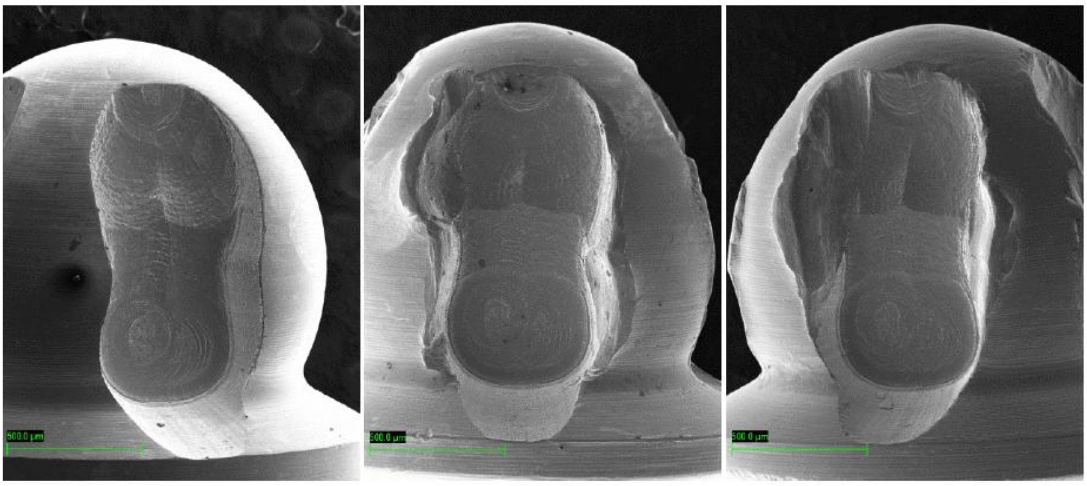

Figure 16. Detail of the original grooves of the BHS screw (left), after 10 iterations (centre) and after 30 iterations (right). The bars show 500 µm.

In addition, the wear due to the different iterations can be seen in the thread turns, as observed on Figure 17.

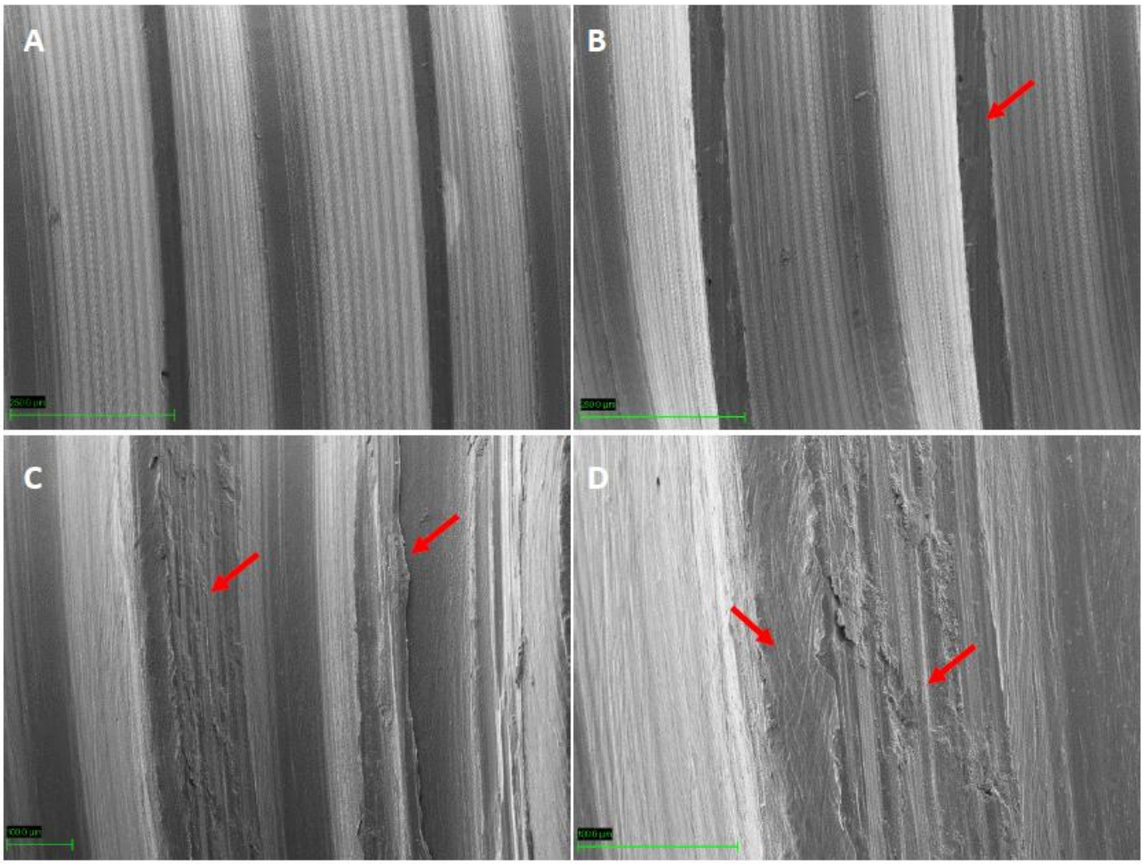

Figure 17. Detail of the BHS original screw's thread (A), screw after 10 iterations (B), the screw after 30 iterations and an enlargement of the superficial erosion observed after 30 iterations (C and D). The upper bars show 250 µm and the lower ones 100 µm.

4. CONCLUSIONS

From the results obtained in the different test we can conclude that:

The most critical angulation analysed for the BHS sets (screw and driver without surface treatment) is 30º deviation from the screw's insertion axis, where the maximum torque performance was found at 54±12 N·cm.

At 20º deviation, the BHS sets (screw and driver without surface treatment) achieved an average 67±12 N·cm torque resistance, while the Allen Ball system sets failed at an average 45±2 N·cm torque and the Hexalobular system ensembles experienced failure at 46±2 N·cm, all of them tested in the same conditions. Additionally, at 20º, BHS screws taken to failure could be unscrewed with its own original driver in all cases, while on the other hand, the Allen system screws and the Hexalobular ones presented such damage level after testing them, that they had to be systematically unscrewed by using a workshop pressure key.

The most common failure when testing the BHS sets was the deformation experienced by the screw's grooves and the internal part of the driver.

The three surface treatment conditions applied on the drivers increased the maximum torque allowance with regard to the non coated drivers tested at 30º, the most demanding angulation. The DHC coated drivers are the ones that achieved the maximum torque resistance values, with 107±31 N·cm performance in its test, although differences are not statistically significant when compared to the other surface treatments studied, namely CrN and TiN.

For those BHS screw and driver sets without surface treatment, deformation and wear increase is directly related to the number of iterations at 30 N·cm torque and 20º angulation. Deformations are more relevant after 30 iterations although as it was observed, the screw can be tightened and loosened easily through the complete test.

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5. ANNEXES

5.1. Workshop pressure key

Figure 18. Picture of a workshop pressure key

5.2. Surface hardness of the different surface treatments

Vickers hardness has been determined for the different surface treatments applied on the BHS drivers by using a microdurometer Vickers Akashi MVK-HO in the driver longitudinal axis, and then compared with the data obtained for the non coated tools, through the same procedure.

Indentation strength was 200 gr. for a period of 30 seconds. Three drivers were analysed for each surface treatment studied and three measurements were taken on each driver.

The surface hardness values obtained are summarized in Table 5. The higher values of the Vickers strength correspond to superior surface strengths.

Table 5. Surface hardness of the different coatings -average value is standard deviation-.

Surface Treatment Condition	Average Vickers Value (N·cm)
No coating	339±38
DHC-TR	597±37
TiN	776±73
CrN	873±35

The results show that the three different coating conditions increase the surface hardness of the tools, reaching maximum average values in the case of TiN and CrN coatings. In conclusion, those coatings show more resistance to surface deformation and wear.