NOVEL BALL HEAD SCREW AND SCREWDRIVER DESIGN FOR IMPLANT-SUPPORTED PROSTHESES WITH ANGLED CHANNELS. A FINITE ELEMENT ANALYSIS

Ball head screw and screwdriver for angled channels

Oriol Farré-Berga[1], Iñaki Cercadillo-Ibarguren[2], Alba Sánchez-Torres[2], Carles Domènech-Mestres[3], F Javier Gil[4], Tomás Escuin[5], Esther Berástegui[6]

[1]DDS, MS, Master in Study and Diagnosis of Occlusion in the "Zero Position" of the Stomatognathic System. School of Medicine and Health Sciences, University of Barcelona. Barcelona, Spain.

[2]DDS, MS, Master of Oral Surgery and Implantology. Associate Professor of Oral Surgery, School of Medicine and Health Sciences, University of Barcelona. Researcher at the IDIBELL Institute. Barcelona, Spain.

[3]Industrial Eng, MSc, PhD. Professor at the Center of Industrial Equipment Design, Polytechnic University of Catalonia. Barcelona, Spain.

[4]Materials Engineer, MSc, PhD. Professor of the School of Dentistry, International University of Catalonia. Barcelona, Spain.

[5]MD, DDS, PhD. Professor of Dental Prostheses. Professor of the Master of Rehabilitation and Maxillofacial Prostheses. School of Medicine and Health Sciences, University of Barcelona. Barcelona, Spain.

[6]MD, DDS, PhD. Professor of Endodontics. Professor of the Master of Endodontics. School of Medicine and Health Sciences, University of Barcelona. Researcher at the IDIBELL Institute. Barcelona, Spain.

Corresponding author:
Dr. Oriol Farré-Berga
Avda. Garrigues 17, entlo 2a
25001 - Lleida, Spain.
E-mail: orifarre@gmail.com

Acknowledgements
The authors thank Ramon Farré as the inventor of the system, and Pol Guixé and Vanessa Ruiz for revision of the technical part.

Conflicts of interest
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].

Funding
This work was supported by the company Ball Head System, S.L.

NOVEL BALL HEAD SCREW AND SCREWDRIVER DESIGN FOR IMPLANT-SUPPORTED PROSTHESES WITH ANGLED CHANNELS. A FINITE ELEMENT ANALYSIS

ABSTRACT

The primary objective of this study was to design the optimal geometry of a novel screwdriver; create the grooves on a ball head screw; and demonstrate its resistance to a torque of up to 40 Ncm at an angulation of 0, 15 and 30 degrees by using nonlinear finite element analysis. A secondary objective was to create a fool-proof and easily recognizable system.

The grooved ball head screw and geometry of the screwdriver, functioning from an angulation of 0° to 30°, was generated using Pro-ENGINEER Wildfire 5.0 software. Static structural analyses between bodies in contact were performed at different angles of 0°, 15° and 30° at a torque of 20 Ncm and 40 Ncm, using nonlinear finite element simulation by means of ANSYS 12.0.

The maximum stress supported by the ball head screw and screwdriver was similar at 20 Ncm and 40 Ncm. Although greater deformations were found at 40 Ncm, these were small and might not affect the performance of the system. Besides, the rupture torque value for the M2 connection was 55 Ncm for 0° and 30°, and 47.5 Ncm for 15°.

Numerical simulation showed that the ball head system design can achieve the mechanical strength requirements expected for screws used in implant-supported restorations at an angulation of up to 30°.

Finite element analysis showed this novel ball head screw and screwdriver system to be a good solution for angled screw channels in implant-supported prostheses.

Key words: Ball head screw, angled screw channel, finite element analysis, torque, preload, screw mechanics.

INTRODUCTION

Dental implants have been reported to be highly successful in treating completely [1,2] and partially edentulous patients [3-5].

Screw-retained prostheses were initially used for partial or full-arch rehabilitations [1,2,6], whereas single-tooth reconstructions were generally cemented on prefabricated abutments [7]. Both types of reconstructions exhibited satisfactory long-term clinical outcomes [1,8]. However, due to the need to customize prosthetic components to improve aesthetic outcomes or to correct angled implants, new components such as the cast-on UCLA abutment were developed for both screw- and cement-retained single-tooth reconstructions [9,10].

An accurate implant position is mandatory when screw-retained reconstructions are used, in order to achieve an optimal location of the screw access hole and to obtain good esthetic results. Reconstructions cemented on angulated abutments are the current solution to implants placed in an improper position or tilted implants placed to avoid sensitive structures or anatomical cavities [11-13]. However, screw-retained reconstructions seem to be preferable, as they are more easily retrievable, therefore facilitating the treatment of technical and biological complications [14-16].

The angulation of the screw channel to correct emergence of the prosthetic screw access hole constitutes an alternative to cemented reconstructions on tilted implants. This would allow the dentist and the dental technician to use screw-retained reconstructions despite the implant position. A special screwdriver with the capability to apply torque to the screw in an angled channel should be used [17,18]. It would be truly beneficial to develop a fool-proof new screw head and screwdriver system for use in screw-retained reconstructions with angled channels. This system should be able to achieve the recommended torque of 30 Ncm, even in the hardest situation of an angulation of 30°.

Nonlinear finite element analysis (FEA) has become an increasingly powerful tool for predicting stress and strain within structures in a real situation [19]. It has been successfully applied to assess the mechanical characteristics of different implant- and tooth-abutment connections [20,21].

The primary objective of this study was to design the optimal geometry of a novel screwdriver; create the grooves on a ball head screw; and demonstrate its resistance to a torque of up to 40 Ncm at an angulation of 0, 15 and 30 degrees by using nonlinear FEA. A secondary objective was to create a fool-proof and easily recognizable system.

MATERIALS AND METHODS

Design concept

The concept behind the patented screw and screwdriver design called Ball Head System (BHS) is a spherical dented structure (Figure 1). The screw head constitutes the male component of the connection. The screwdriver, representing the female component, was designed to perfectly match the screw head from an angulation of 0° to 30°.

Final design

To design the optimal geometry of the screwdriver, the transmission angle formed between the force direction and absolute speed at the contact point between two bodies was taken as a key design parameter. Minimizing the transmission angle helps to improve load transmission and reduces the chances of stripping. If the transmission angle is 0°, the transmission function is satisfactory [22]. The contact surface between the screw head and the screwdriver must be radial to guarantee a 0° transmission angle. Radial lines represent contact surfaces between two bodies, where the contact force is normal to the surfaces involved. Linear speed in a circular movement is perpendicular to the radius. Hence, the angle between the force and speed direction is 0°, and the relationship between angles when the screwdriver is activated as follows: $\beta = atan(tan\,\alpha / cos\,\gamma)$ (Figure 2).

Two factors were taken into consideration for determining the final number of grooves in the screw head. Firstly, the number of grooves had to ensure that the forces were well balanced even if the screw and screwdriver were not well aligned, thus reducing the chance of stripping. Additionally, the number of grooves had to be sufficient to guarantee a proper gear between screw and screwdriver. Secondly, the material left between grooves had to be sufficient to withstand the forces applied without easy stripping. The optimal number of grooves was finally defined as four because with only two grooves, a proper gear between screw and screwdriver was not possible at certain inclination angles, while with 6 grooves the width between grooves was too small.

In order to build up the final geometry, a standard M2 abutment screw size was taken as a sample. Figure 3 shows the whole process for finally creating the system. First, the screwdriver was designed. In order to guarantee a perfect gear between the screw head and the screwdriver, a generation method was then applied. An assembly containing all possible positions of the screw head was created. The following step involved cutting the negative part of the groove to obtain the positive part of the groove on the sphere. Finally, the head was attached to the body of the screw. The final geometry can be seen in Figure 4. These geometries were generated using Pro-ENGINEER Wildfire 5.0 (PTC Corporation, MA, USA).

Analysis scenario

Non-linear FEA was performed to verify that this screwdriver and screw system is viable.

The material of choice for the screwdriver was steel 17-4PH, with a tensile yield strength of 1090 MPa and an ultimate tensile strength of 1210 MPa. Steel 17-4PH is 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 is also subjected to thermal treatment (reheating for dissolution). On the other hand, the screw was analyzed using a Ti6Al4V grade 5 alloy containing 6% aluminum and 4% vanadium, with a tensile yield strength of 970 MPa and an ultimate tensile strength of 1100 MPa [23].

The screwdriver and screw connection were analyzed as a static structure at and angulation of 0°, 15°, and 30°. Additionally, two torque values were analyzed for each angulation (20 Ncm, and the worst case scenario of 40 Ncm), and the rupture torque was calculated using an iterative process.

For the loading conditions, the screw was fixed at its base while the torque was applied to the top of the screwdriver. The analysis was performed within the elastic range. If the stress was higher than the yield strength, the analysis was performed within the plastic range. In this case, the screw and the screwdriver were analyzed separately (first the screw and then the screwdriver); otherwise, the result would not converge.

A different mesh for the screw and screwdriver was generated for each inclination angle, as it was refined around the contact points in order to increase accuracy (Figure 5). Table 1 shows the number of nodes and elements used for the screw and screwdriver mesh. The element size ranged from 0.4-0.05 mm, depending on the inclination and the torque applied.

The finite element analysis was performed by means of ANSYS v12 software (ANSYS Inc., PA, USA).

RESULTS

The nonlinear FEA yielded the following results.

Stress distribution

As seen in Figure 6, stress distribution was different for each inclination. However, in all cases, the maximum stress points at the screwdriver were located at the contact points on the teeth. Similarly, the maximum stress points at the screw head were also located at the contact points on the grooves and at its base.

Maximum stress analysis

Table 2 summarizes the maximum equivalent Von Misses stress obtained for each torque and angle of inclination. As can be seen, at 20 Ncm and 0°, the maximum stresses at the screw head and screwdriver were within the elastic range. However, in all the other cases the maximum stresses were higher than the yield strength, creating permanent deformations.

Probably due to the gentle slope, the maximum stresses for 20 Ncm and 40 Ncm were very similar. Although the deformations beyond 40 Ncm were greater, they were still very small and might not affect the operation of the screw and screwdriver. Nonetheless, mechanical tests with a prototype would be needed to confirm this.

It is worth noting that maximum stress and deformation on the screwdriver were higher at 15° than at 0° and 30°.

Rupture stress analysis

Table 3 shows the minimum rupture torque of a series of iterative analyses for each angulation, with the purpose of establishing the maximum torque causing rupture tensions in one of the two elements of the connection.

As can be seen, at 0° and 30° the screwdriver required significantly more torque to fail. In this case, the screwdriver was close to its strength limit, while the screw had more than 50 MPa of margin. Nevertheless, at 15° both the screw and screwdriver were very close to their failure limit.

DISCUSSION

Finite element analysis has been the most common and powerful tool for simulating dental restorations under various loading conditions [19]. It has also been extensively used to predict the biomechanical performance of various dental implant designs [24], as well as the effect of clinical factors on implant success [25]. According to Geng et al. [26], the results obtained from FEA are a good starting point and, could be extrapolated to clinical situations, with due consideration of the limitations of the method.

However, most previous reports lack rigorousness in model construction [20,27]. Thus, in the present study a different mesh for each inclination angle for both the screw and the screwdriver was generated. Moreover, refinement around the contact points was made to increase accuracy (Figure 5). Some other variables such as screw threads, abutment, implant and surrounding bone were ignored to ensure that screw head and screwdriver connection behavior was the only variable in this investigation. In this regard, our results may be extrapolated to other metrics and fields where accessibility and angulation are needed.

Within the limitations of the methodology used in this study, the results of the numerical simulation showed that the Ball Head System (BHS) could improve and easily achieve the required mechanical strength for screws used in screw-retained reconstructions with angled channels, even in the hardest situation of an angulation of 30°. Our study confirmed that both the required nominal torque of 20 Ncm and the required maximum torque of 40 Ncm were achieved. Based on iterations to determine the maximum torque which the connection was able to support, we demonstrated that with an angulation of 0° and 30° the screwdriver broke first at 55 Ncm, though at 15° the screw broke at 47.5 Ncm.

These rupture torques should be taken as an approximation and should be checked experimentally by means of torsion testing of the connection. Nevertheless, this would not constitute rupture *per se*, but rather a permanent deformation of the groove. There would be no danger of rupture of the screw head, because the slots required for removal would still be intact and it could be unscrewed.

A possible underestimation of the results obtained by FEA needs to be clarified. The material limits used for FEA are obtained from tensile tests. However, the screw and screwdriver connection is under compression and shear stress, which offers higher limits than under tensile stress conditions. The goodness of the model can be summarized as a realistic geometrical structure and elastoplastic model for the material description, affording correct definition of the contacts and the existing tolerance among the different system components, and with good reproduction of the preloading stress condition [28].

Few studies have addressed the influence of screw head design tested over a range of angles of application of the respective screwdriver, the torque value at which the screw head strips, or the torque at which screwdriver engagement fails. Spencer et al. [29] tested the behavior of titanium screws with four different head designs under different angulations. These screw head designs did not reach optimal torque values with increasing angulation. At 30°, slot and cross screw head designs were those which achieved a maximum torque value of 23.4 Ncm and 19.4 Ncm, respectively. Due to the fact that those designs were not specifically designed for applying torque with an angulation, the application of an axial force (amount of force applied to each screw along its axis) by the examiner proved necessary. This force increased with increasing angulation in order to maintain the radial force (amount of force at the screw head).

Hence, the BHS was designed with a transmission angle of 0° in order to achieve a minimum axial force and improve load transmission and patient comfort.

The use of tilted implants is an alternative to bone augmentation and sinus lift [30], and no negative effects have been seen in terms of implant survival or marginal bone loss compared to straight implants [31]. The BHS allows the application of 30 Ncm torque to screw-retained reconstructions with angled channels. Thus, it could become a good solution to solve esthetic demands and nonparallel situations between the axial direction of the superstructure and the implant. Besides, some publications [17,18] have shown that clinicians use the angled screw channel with suboptimal screw and screwdriver designs, implying a potential risk of damaging the screw head. This is an indicator that BHS offers the required solution, and is safe and easy to recognize.

Following the satisfactory results of the numerical simulation of BHS comprising a ball head screw and screwdriver, the next step should be to perform mechanical tests. These would help to obtain much more reliable data in terms of the static test, and to analyze the behavior of BHS under fatigue conditions with the aim of validating its use for implant-supported prosthesis.

CONCLUSIONS

Within the limitations of this study, the following conclusions can be drawn:

- The Ball Head System (BHS) is a state–of-the-art design composed of a ball head screw and screwdriver designed with the most severe requirements, and especially indicated for implant-supported restorations with angled channels.

- Numerical simulation showed that the BHS design can achieve the mechanical strength requirements expected for screws used in implant-supported restorations at an angulation of up to 30°.
- The ball head screw design is exclusive and easily recognizable by the operator, which ensures use of the right screwdriver, preventing potential damage to the screw head.
- Further research based on mechanical evaluation is required to validate the accuracy of this novel ball head screw and screwdriver system for implant-supported prosthesis.

LIST OF ABBREVIATIONS

- UCLA: acronym of "University of California at Los Angeles". It is a cast component used to create a custom abutment for a prosthesis.
- FEA: Finite element analysis.
- BHS: Ball Head System.
- Ncm: Newton centimeter. Torque unit.
- MPa: mega pascal. Strength unit.

REFERENCES

[1] Adell R, Lekholm U, Rockler B, Brånemark PI. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. *Int J Oral Surg.* 1981;10:387-416.

[2] Adell R, Eriksson B, Lekholm U, Brånemark PI, Jemt T. Long-term follow-up study of osseointegrated implants in the treatment of totally edentulous jaws. *Int J Oral Maxillofac Implants.* 1990;5:347-59.

[3] Lekholm U, Gunne J, Henry P, Higuchi K, Lindén U, Bergström C, et al. Survival of the Brånemark implant in partially edentulous jaws: a 10-year prospective multicenter study. *Int J Oral Maxillofac Implants.* 1999;14:639-45.

[4] Henry PJ, Laney WR, Jemt T, Harris D, Krogh PH, Polizzi G, et al. Osseointegrated implants for single-tooth replacement: a prospective 5-year multicenter study. *Int J Oral Maxillofac Implants.* 1996;11:450-5.

[5] Simonis P, Dufour T, Tenenbaum H. Long-term implant survival and success: a 10-16-year follow-up of non-submerged dental implants. *Clin Oral Implants Res.* 2010;21:772-7.

[6] Albrektsson T, Zarb G, Worthington P, Eriksson AR. The long-term efficacy of currently used dental implants: a review and proposed criteria of success. *Int J Oral Maxillofac Implants.* 1986;1:11-25.

[7] Sharifi MN, Pang IC, Chai J. Alternative restorative techniques of the CeraOne single-tooth abutment: a technical note. *Int J Oral Maxillofac Implants.* 1994;9:235-8.

[8] Jemt T. Cemented CeraOne and porcelain fused to TiAdapt abutment single-implant crown restorations: a 10-year comparative follow-up study. *Clin Implant Dent Relat Res.* 2009;11:303-10.

[9] Lewis S, Beumer J 3rd, Hornburg W, Moy P. The "UCLA" abutment. *Int J Oral Maxillofac Implants.* 1988;3:183-9.

[10]Lewis SG, Llamas D, Avera S. The UCLA abutment: a four-year review. *J Prosthet Dent.* 1992;67:509-15.

[11]Sethi A, Kaus T, Sochor P, Axmann-Krcmar D, Chanavaz M. Evolution of the concept of angulated abutments in implant dentistry: 14-year clinical data. *Implant Dent.* 2002;11:4151.

[12]Wittneben JG, Millen C, Brägger U. Clinical performance of screw- versus cement-retained fixed implant-supported reconstructions--a systematic review. *Int J Oral Maxillofac Implants.* 2014;29:84-98.

[13]Assaf M, Abu Gharbyeh AZ. Screw-retained crown restorations of single implants: A step-bystep clinical guide. *Eur J Dent.* 2014;8:563-70.

[14]Michalakis KX, Hirayama H, Garefis PD. Cement-retained versus screw-retained implant restorations: a critical review. *Int J Oral Maxillofac Implants.* 2003;18:719-28.

[15]Sailer I, Mühlemann S, Zwahlen M, Hämmerle CH, Schneider D. Cemented and screwretained implant reconstructions: a systematic review of the survival and complication rates. *Clin Oral Implants Res.* 2012;23:163-201.

[16]Millen C, Brägger U, Wittneben JG. Influence of prosthesis type and retention mechanism on complications with fixed implant-supported prostheses: a systematic review applying multivariate analyses. *Int J Oral Maxillofac Implants.* 2015;30:110-24.

[17]Berroeta E, Zabalegui I, Donovan T, Chee W. Dynamic Abutment: A method of redirecting screw access for implant-supported restorations: Technical details and a clinical report. *J Prosthet Dent.* 2015;113:516-9.

[18]Gjelvold B, Sohrabi MM, Chrcanovic BR. Angled Screw Channel: An Alternative to Cemented Single-Implant Restorations--Three Clinical Examples. *Int J Prosthodont.* 2016;29:74-6.

[19]Wakabayashi N, Ona M, Suzuki T, Igarashi Y. Nonlinear finite element analyses: advances and challenges in dental applications. *J Dent.* 2008;36:463-71.

[20]Burak Özcelik T, Ersoy E, Yilmaz B. Biomechanical evaluation of tooth- and implantsupported fixed dental prostheses with various nonrigid connector positions: a finite element analysis. *J Prosthodont.* 2011;20:16-28.

[21]Kong L, Gu Z, Li T, Wu J, Hu K, Liu Y, et al. Biomechanical optimization of implant diameter and length for immediate loading: a nonlinear finite element analysis. *Int J Prosthodont.* 2009;22:607-15.

[22] Riba Romeva C. Disseny de màquines II. Estructura constructiva. 3rd ed. Barcelona: Edicions UPC; 2001.

[23]Matweb LLC. Online Materials Information Resource. Available at: http://www.matweb.com/index.aspx. Accessed January 10, 2017.

[24]Cehreli MC, Akça K, Iplikçioğlu H. Force transmission of one- and two-piece morse-taper oral implants: a nonlinear finite element analysis. *Clin Oral Implants Res.* 2004;15:481-9.

[25]Hansson S, Ekestubbe A. Area moments of inertia as a measure of the mandible stiffness of the implant patient. *Clin Oral Implants Res.* 2004;15:450-8.

[26]Geng JP, Tan KB, Liu GR. Application of finite element analysis in implant dentistry: a review of the literature. *J Prosthet Dent.* 2001;85:585-98.

[27]Balik A, Karatas MO, Keskin H. Effects of different abutment connection designs on the stress distribution around five different implants: a 3-dimensional finite element analysis. *J Oral Implantol.* 2012;38:491-6.

[28]Necchi S, Migliavacca F, Gastaldi D, Pizzagalli M, Del Fabbro M, Weinstein R, et al. The effect of fixture neck design in a realistic model of dental implant: a finite element approach. *Comput Methods Biomech Biomed Engin.* 2003;6:289-97.

[29]Spencer KR, Ferguson JW, Smith AC, Palamara JE. Screw head design: an experimental study to assess the influence of design on performance. *J Oral Maxillofac Surg.* 2004;62:473-8.

[30]Asawa N, Bulbule N, Kakade D, Shah R. Angulated implants: an alternative to bone augmentation and sinus lift procedure: systematic review. *J Clin Diagn Res.* 2015;9:10-3.

[31]Chrcanovic BR, Albrektsson T, Wennerberg A. Tilted versus axially placed dental implants: a meta-analysis. *J Dent.* 2015;43:149-70.

TABLES

	Screw		Screwdriver	
Angulation	Nodes	Elements	Nodes	Elements
20 Ncm				
0°	13001	7822	13001	7822
15°	21374	13082	14790	8967
30°	38933	25653	38975	25638
40 Ncm				
0°	13001	7822	13001	7822
15°	18406	11356	14790	8967
30°	39241	25823	39241	25823

Table 1. Number of nodes and elements used for the screw and screwdriver mesh.

Angulation	Screw maximum stress (MPa)	Screwdriver maximum stress (MPa)	Screw maximum deformation (mm)	Screwdriver maximum deformation (mm)
At 20 N cm				
0°	796.9	1037.3	0.0093	0.0042
15°	1040.3	1141.1	0.018	0.058
30°	1041.5	1103.9	0.011	0.046
At 40 N cm				
0°	996.0	1145.8	0.019	0.085
15°	1048.6	1159.2	0.03	0.213
30°	1067.6	1153.8	0.039	0.11

Table 2. Maximum tensions in relation to torque.

Angulation	Torque (Ncm)	Screw maximum stress (MPa)	Screwdriver maximum stress (MPa)
0°	55	1048.0	1184.6
15°	47.5	1092.9	1182.5
30°	55	1049	1202.5

Table 3. Minimum rupture torque.

FIGURE CAPTIONS

Figure 1. Screw and screwdriver design. Left: ball screw head; Right: screwdriver.

Figure 2. Optimal geometry of the screw and screwdriver. Left: diagram of force and linear speed. Due to the radial contact surfaces, the transmission angle is 0°; Right: angles influencing angular misalignment.

Figure 3. Generation of the final geometry. Step 1: the screwdriver geometry was generated; Step 2: the generation method was used to create a geometry which includes all the possible positions of the screwdriver around a spherical screw head from 0° to 30°; Step 3: the negative part of the generated groove was cut, obtaining the positive part of the generated groove; Step 4: the geometry obtained in Step 3 was used to make a cut to the sphere to obtain the final screw head geometry; Step 5: the screw head was attached to the body of the screw.

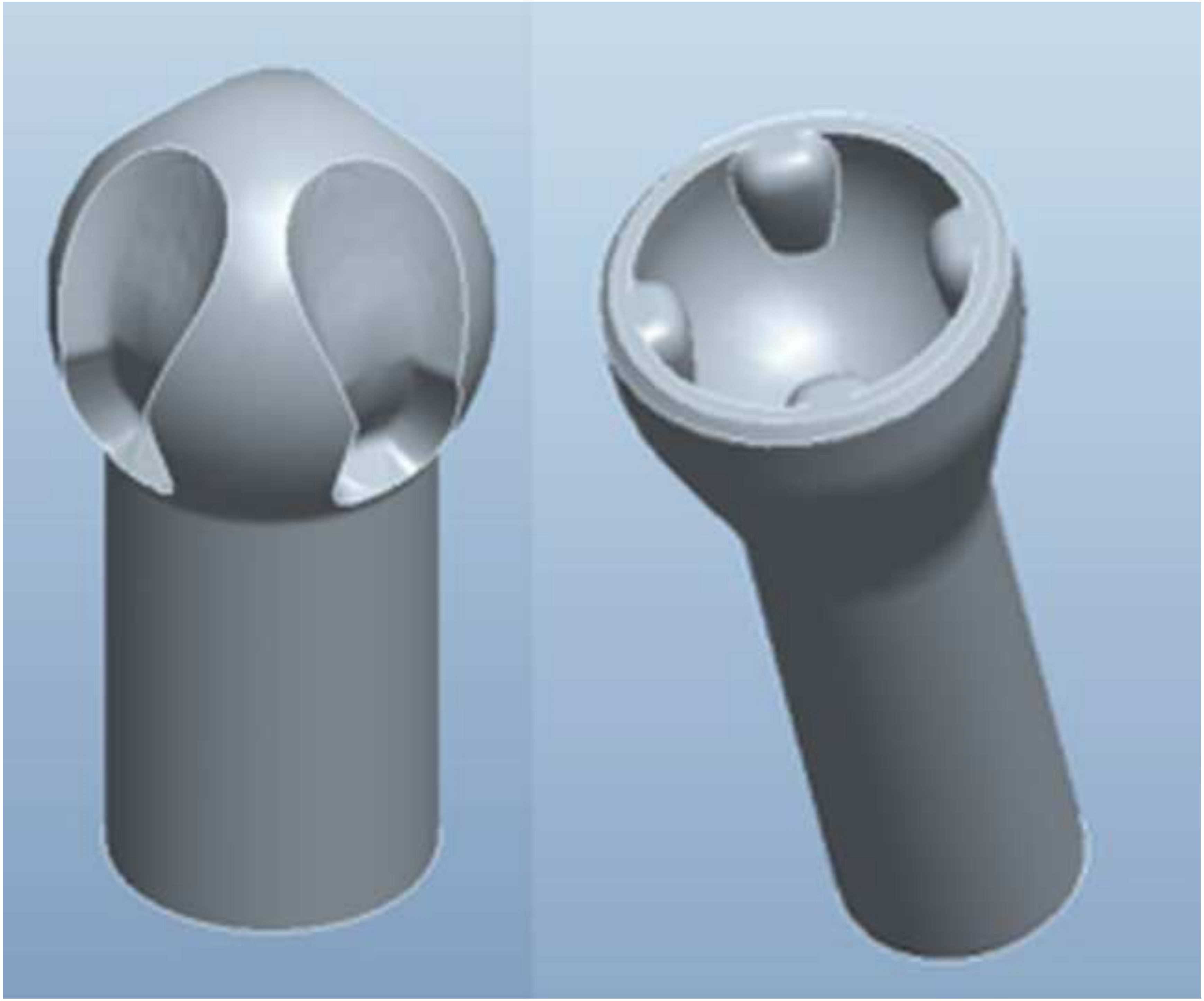
Figure 4. Final geometry of the screw and screwdriver. Left: final geometry of the screw head; Right: final geometry of the screwdriver.

Figure 5. Different meshes for the screw and screwdriver generated for each inclination angle to increase accuracy. Left: sphere used to refine the mesh around the contact point at an inclination angle of 15°; Middle: screw and screwdriver mesh; Right: refinement of the screw mesh at the contact point.

Figure 6. Stress distribution for each inclination. Von Miss equivalent stresses at 0°, 15° and 30°, and at 40 Ncm of torque. At 20 Ncm the stress distribution was similar; however, the absolute stress values were different.

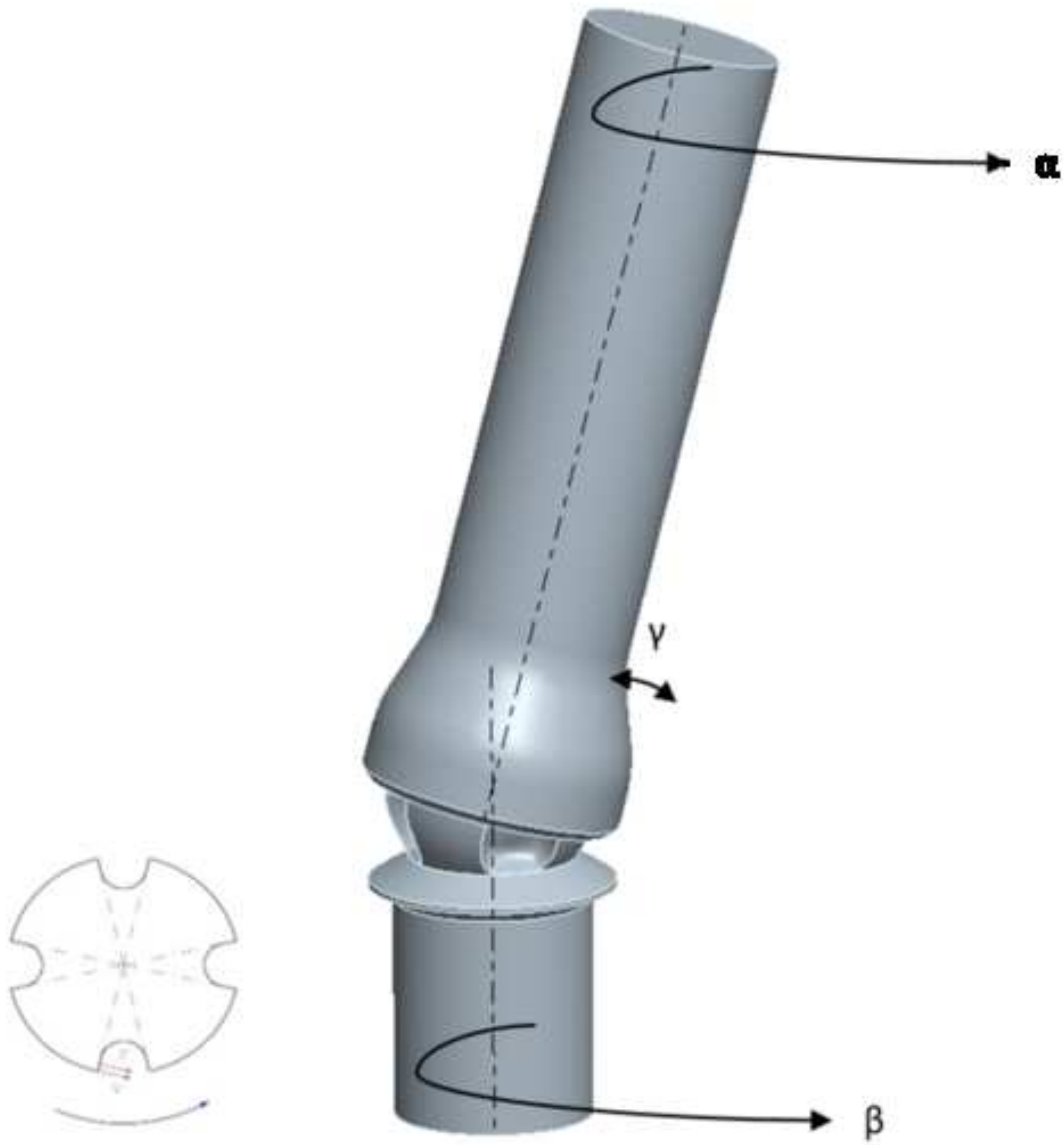
Figure

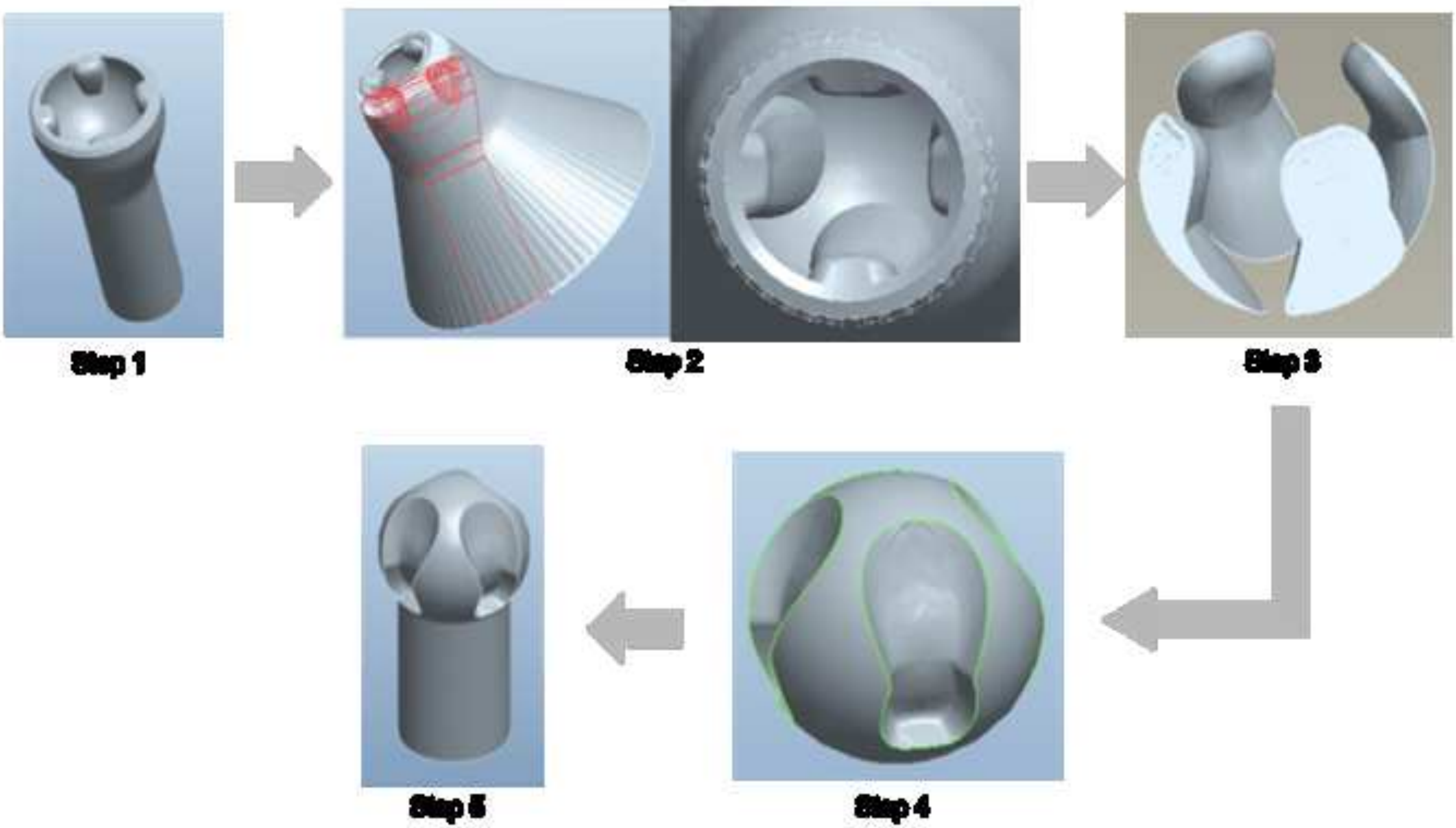
Click here to download Figure FIGURE 1.tif



Figure

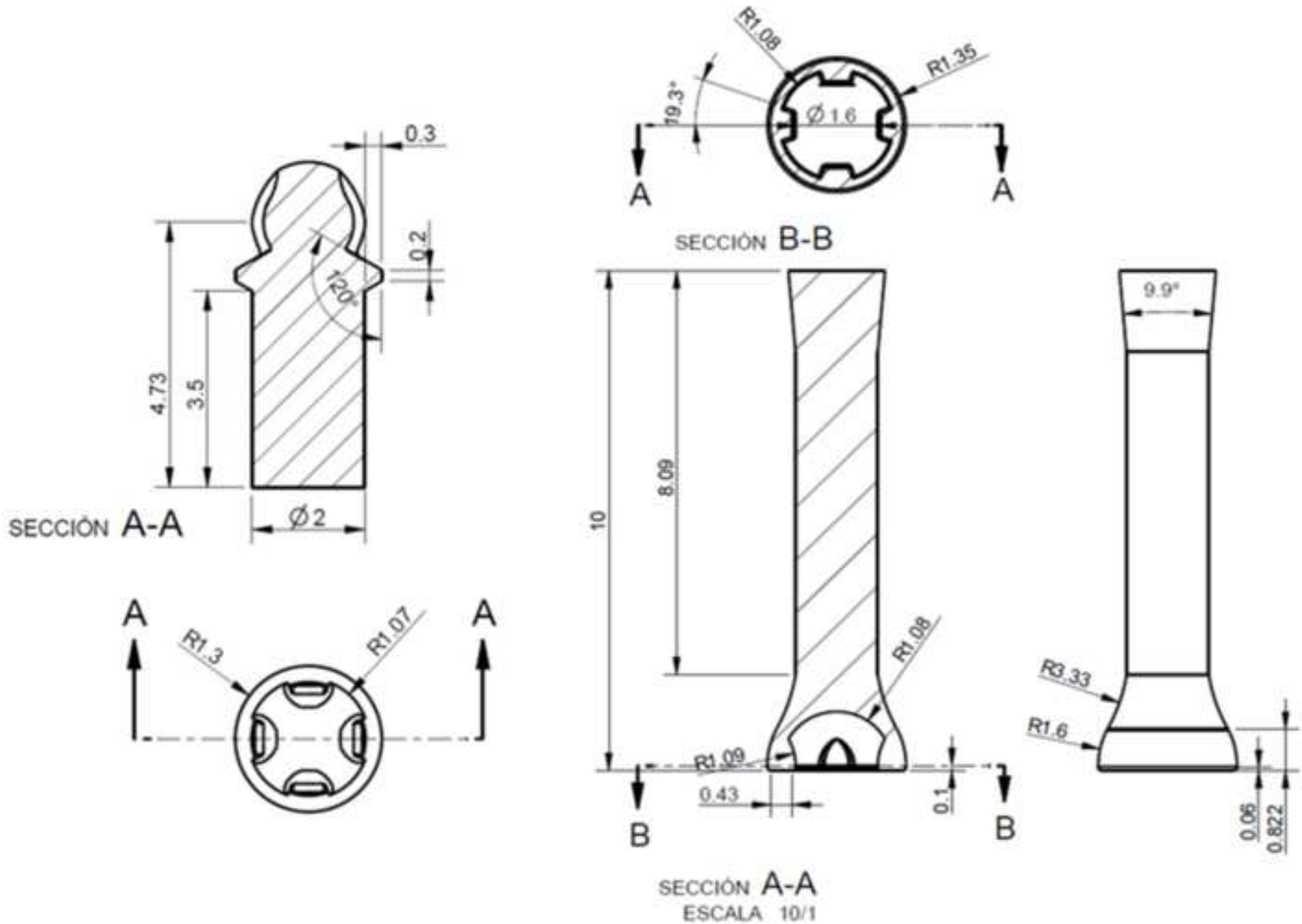
Click here to download Figure FIGURE 2.tif




Step 1
Step 2
Step 3
Step 4
Step 5

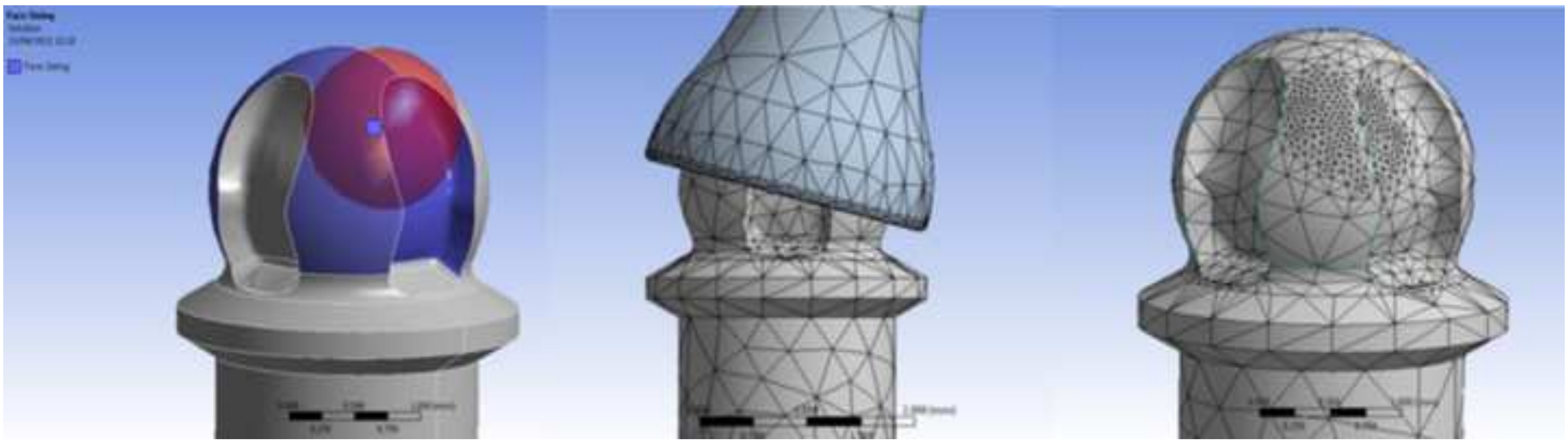
Figure

Click here to download Figure FIGURE 4.tif



Figure

Click here to download Figure FIGURE 5.tif



Figure

Click here to download Figure FIGURE 6.tif