Stress Distribution Analysis in Bone Adjacent to Implant in Various Abutment-Implant Connection Designs Using Finite Element Analysis

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Natural teeth have a periodontal ligament with viscoelastic properties, while implants are connected to the bone with a strong connection and osseointegration; therefore, the stress on the adjacent bone of the implant and its prosthetic components is more than that of natural teeth. This study examines the connection (Morse different tapers) to find the most suitable length and Morse angle of the taper and the angle of applying the force on the tooth to create the least stress using finite element analysis. Geometrical and 3D models of the mandible bone, implant, and its prosthetic components were made using engineering software and sizes of the DIO implant manufacturer. In this modeling, 4 types of connections with different lengths and tipping angles were designed, and then a constant force of 200 N was applied to them. Stress distribution was investigated in this experiment in 12 different conditions: 2 Morse taper lengths (1.3 mm and 2.6 mm), 2 Morse taper angles (11° and 16°), and 3 force application angles (0°, 30°, and 45°). By increasing the length of the Morse taper from 1.3 mm to 2.6 mm, the amount of stress in the bone adjacent to the implant and its prosthetic components is reduced. By increasing the tipping angle of the Morse taper from 11° to 16°, the amount of stress in the bone adjacent to the implant, the fixture, and the abutment decreases. Furthermore, by increasing the tipping angle of the morse from 11° to 16° the amount of stress in the implant screw increases. Increasing the angle of the force applied to the implant increases the amount of stress in the bone adjacent to the implant and its prosthetic components. The best Morse taper connection to create the least stress on the bone surrounding the implant and its prosthetic components is a long taper Morse with a length of 2.6 mm and a greater tipping angle (16°), This stress is less at the vertical force application angle.

Key Words: finite element analysis, dental implants, stress distribution

INTRODUCTION

Implants are integrated into the bone through a strong bond and osseointegration. In contrast, teeth have a periodontal ligament with distinct viscoelastic properties, which affect the surrounding bone's stress and strain distribution patterns during mastication.[1,2]

The increased force on the implant is critical in bone resorption and implant loss the implant. It generates stress that affects the implant-bone interface and supporting tissues. The internal stresses within the implant system and surrounding biological tissues under applied forces significantly impact the implant's long-term survival in the oral environment.[2,3]

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Contemporary implants and abutments are complementary to support 1 or multiple dental prostheses in edentulous patients. After placing the fixture in the jawbone through surgical intervention, it takes 2–6 months for the fixture to osseointegrate with the bone. The abutment is then connected to the implant. The abutment is mechanically secured to the implant, and a crown is subsequently attached. This connection is typically achieved through dental cementation, screws that fix the prosthesis to the abutment, or attachment via a socket connection, often used for removable prostheses.[4]

Ideally, the abutment should remain stable in its position on the implant. In the most precise mechanical connections, abutments with screws are used to attach the abutment to the implant.[5] Another method involves abutments with a long cone at their end (morse taper).[6] Additionally, some implants utilize a tapered interference fit (TIF) connection, where the abutment is designed as a cone and fits into a conical implant cavity. Various designs have been developed using both conical and screw mechanisms.[5,6]

Morse taper dental implants, with their platform-switching implant-abutment connection, help maintain soft tissue profiles, reduce bone loss, and ultimately decrease the incidence of peri-implantitis. According to the manufacturer's guidelines, these implants should be placed 1–2 mm below the bone crest, to ensure good maintenance of the surrounding soft tissues around the cervical third of the implant.[7] In this type of retention, which depends on friction, the force generated during mastication acts in the direction of the abutment placement, leading to increased cohesion.[8]

Several studies have used finite element analysis to investigate the stress distribution in dental implant-abutment connections. Cho et al[9] found that increasing implant wall thickness and connection surface length reduced stress distribution, while a zero vertical stop distance resulted in extremely high stress. Anami et al[10] showed that implants with solid abutments distributed loads more uniformly to surrounding bone than those with hexagonal abutments. Oliveira et al[11] found that stress and strain distribution in implants and surrounding bone were influenced by implant design, with thicker cortical bone reducing maximum stress and strain. Lin et al[12] concluded that conical implant-abutment connections induced the least stress on surrounding bone, while hexagonal connections were the least desirable. While previous studies studied stress distribution in dental implants, few studies specifically focus on evaluating different abutment-implant connection designs. In addition, there are a few studies that consider the use of Morse taper implants with platform-switching implant-abutment connections.

Due to the rapid progress in dental implantology and the importance of stress distribution on implant longevity, the lack of a periodontal ligament around implants and the resulting pressure and stress on implants, leading to bone resorption, we aimed to investigate the stress distribution in the bone adjacent to the implant in different abutment-implant connection designs using finite element analysis and select the best connection-abutment implant design in terms of stress distribution on the implant and prosthetic components.

Methods and Materials

This study is a finite element analysis study, the most common method for evaluating stress performed on 3D models. The model is divided into smaller components with a limited number of elements, each of which is usually quadrilateral or triangular. In this study, 3D geometric models of the mandible bone, a fixture, various abutments, an abutment screw, and titanium implants were designed using Autodesk Inventor Professional 2022 software (San Francisco, CA) (Figure 1). The stress distribution for each designed implant was analyzed at 3 different angles of force application (0°, 30°, and 45°) and 2 different Morse taper angles (11° and 16°) with 2 Morse taper lengths (2.6 and 1.3 mm) using Ansys 2022 software (Ansys, Inc, Canonsburg, PA).

In total, 12 designed models were analyzed in terms of stress in the software, considering a 2-mm thick cortical bone layer of the mandible. The implant will be placed in the first molar region of the lower jaw. The endosseous bone level data provided by the manufacturer (DIO UF, DIO CO, Busan, South Korea) were used for implant modeling. The size and dimensions of the modeled implant are in accordance with the DIO company (Figure 2).

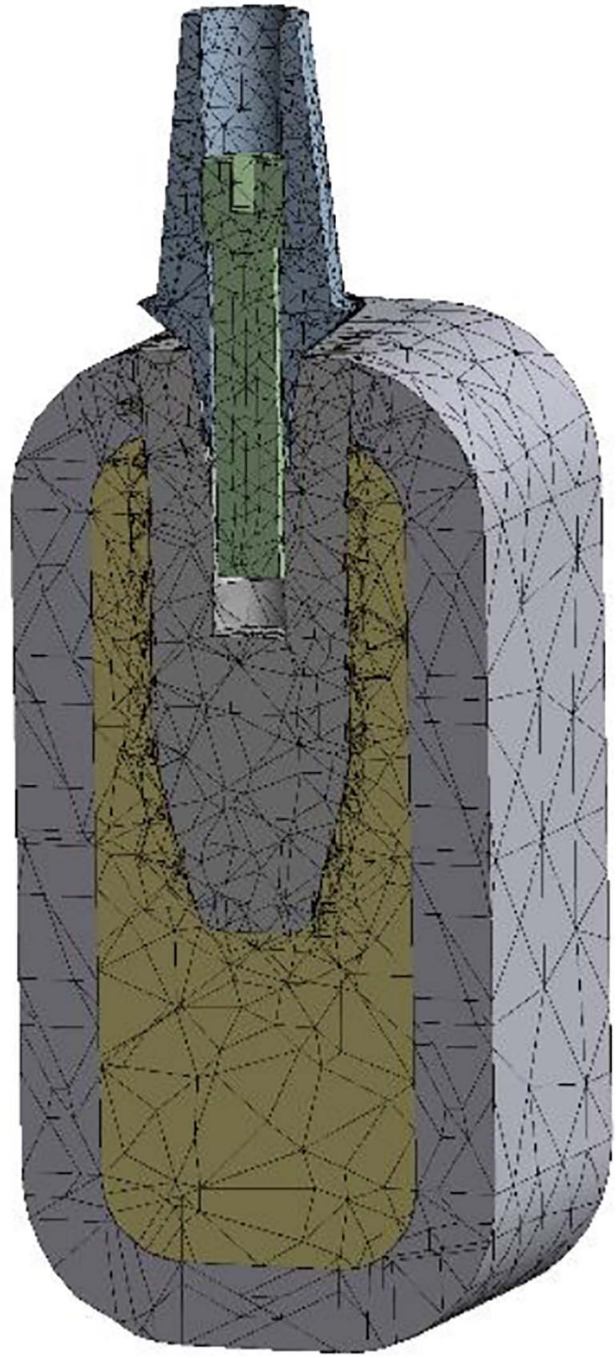

Figure 1. Designed 3D model.

The main length of the implant's morse taper was 1.3 mm. Still, we also investigated a hypothetical length of 2.6 mm to see which length causes less stress to determine the surrounding bone and prosthetic components.

After preparing the desired model in the finite element software, the stress at different points around the implant was considered. A force of 200 N was applied at various angles (vertical, 30°, and 45°), and the applied stress was then analyzed.

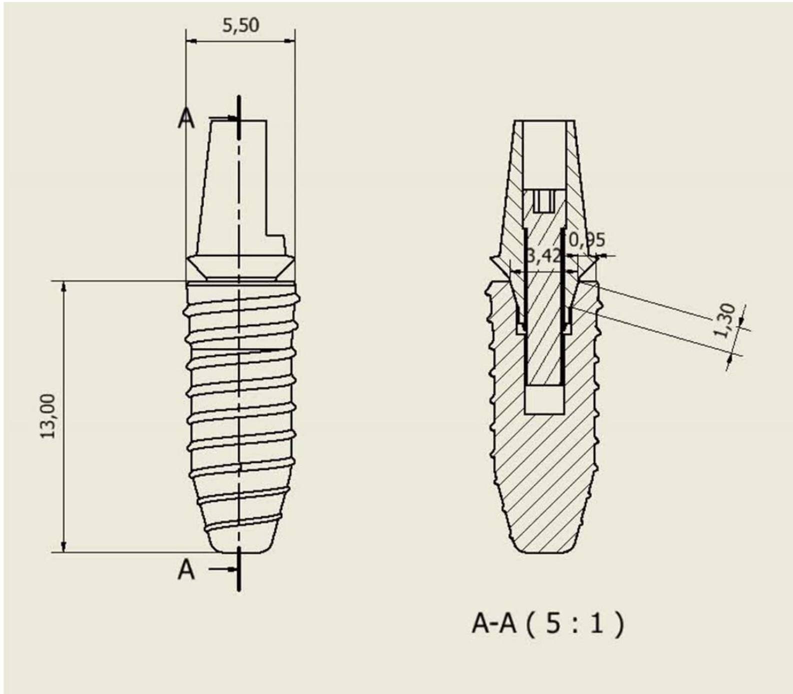

Figure 2. Dimensions of the implant (Reproduced from DIO Company's product manual. Copyright 2019 DUO Company. All rights reserved).

Finally, after applying the forces in the finite element software, the stress distribution in different connection-abutment designs and at various angles of force application in the surrounding bone and all prosthetic components were determined, and the results were shown using the von Mises metric.

Results

This study aimed to investigate the distribution of stress in the bone adjacent to the implant and its prosthetic components, including the abutment, screw, and fixture, in various connection designs (connections) between the abutment and implant using finite element analysis. The stress distribution was examined at 3 different angles of force application (0°, 30°, and 45°) and 2 different Morse taper angles (11° and 16°) with 2 Morse taper lengths (2.6 and 1.3 mm) (Table 1).

Furthermore, based on the results that are presented in Table 2, with an increase in the Morse taper angle, the stress on the implant screw increases, but it decreases in the bone, fixture, and abutment. These changes are more pronounced along the long Morse taper. According to the results of Table 3, with an increase in the length of the Morse taper, the stress on the bone and all prosthetic components of the implant decreases. This decrease is more pronounced at a Morse taper angle of 16°. In addition, with an increase in the angle of force application, the stress on the bone and all prosthetic implant components, including the abutment, fixture, and screw, increases (Table 4).

Table 1

Data obtained regarding stress distribution*

Screw	Abutment	Fixture	Bone	Morse Taper Length	Morse Taper Angle	Force Application Angle
1.62	3.78	4.41	3.26	2.6	11	0
2.29	11.2	8.55	4.17	2.6	11	30
2.76	14.2	10.1	5.4	2.6	11	45
1.67	4.03	4.56	3.99	1.3	11	0
3.48	14.8	8.7	4.21	1.3	11	30
4.14	17.8	12.8	5.89	1.3	11	45
1.65	3.62	1.92	1.2	1.3	16	0
3.35	6.7	4.49	2.73	2.6	16	30
4.09	10.4	6.21	4.46	2.6	16	45
1.71	3.88	4.47	3.9	1.3	16	0
3.68	14	8.58	4.2	1.3	16	30
4.58	16.3	12.2	5.58	1.3	16	45

*The measurement unit of stress in this table is e7 Pascals.

Table 2

The relationship between taper angle and stress distribution*

Screw		Abutment		Fixture		Bone		
°16	°11	°16	°11	°16	°11	°16	°11	AMT
1.71e7	1.67e7	3.88e7	4.03e7	4.47e7	4.56e7	3.9e7	3.99e7	S0
3.68e7	3.48e7	14e7	14.8e7	8.58e7	8.7e7	4.2e7	4.21e7	S30
4.58e7	4.14e7	16.3e7	17.8e7	12.2e7	12.8e7	5.58e7	5.89e7	S45
1.65e7	1.62e7	3.62e7	3.78e7	1.92e7	4.41e7	1.2e7	3.26e7	L0
3.35e7	2.29e7	6.7e7	11.2e7	4.49e7	8.55e7	2.73e7	4.17e7	L30
4.09e7	2.76e7	10.4e7	14.2e7	6.21e7	10.1e7	4.46e7	5.4e7	L45

*AMT, angle of morse taper; S, short (1.3 mm); L, long (2.6 mm).

Finally, the stress distribution of each group based on the finite element analysis has been shown in Figures 3–6.

Discussion

The primary cause of biomechanical problems arises from the type of connection to the bone. Dental implants are rigidly connected to the bone, whereas teeth have a periodontal ligament with distinct viscoelastic properties. Consequently, the stress and strain distribution patterns in the bone surrounding the implant and tooth will differ during mastication.[13] Internal stresses generated in the implant system and surrounding biological tissues under applied forces significantly affect the long-term survival of the implant in the living environment. Determining the maximum stress in the dental implant system and surrounding tissues provides valuable insights into the areas prone to implant failure and bone atrophy. Therefore, using finite element analysis, this study investigated the stress distribution in the bone adjacent to the implant in various abutment-implant connection designs.

According to the results of the present study, increasing the angle of force application increased the stress in the bone, fixture, abutment, and screw. Additionally, increasing the length of the Morse taper reduced the stress at the Morse taper angle, but the stress increased at larger angles. An inverse correlation was observed between the angle and length of the Morse taper with stress distribution, meaning that increasing the angle in a short Morse taper increased the stress, and vice versa.

One issue that arises in implantology is the angle of implant placement relative to the applied load and its effect on stress distribution around the implant. Himmlová et al[14] and Baggi et al[15] found that maximum stress occurs around the implant neck. Amornvit et al[16] demonstrated that increasing the force angle increases stress using finite element analysis and varying angles of 0°, 30°, 60°, and 90°, which is consistent with the present study. In a study by Watanabe et al,[17] increased bone stress, and the implant was subjected to significant bending moments. Iranmanesh et al[3] found that increasing the force angle from 0° to 30° increased the stress around the implant, which is consistent with the present study.

Alikhasi et al[18] evaluated the effect of bone quality, quantity, and implant placement angle on stress and strain in the buccal bone. They found that stress and strain decreased with decreasing load application relative to the implant axis and were distributed symmetrically. However, clinicians should consider bone quality, quantity, and diameter when placing implants. The results of the present study are consistent with those of Alikhasi et al.[18] In a study by Ebadian et al,[19] splinting implants reduced stress in all implants, while angulated implants without splinting reduced stress in the implant and bone; but increased stress in splinted implants. The results of Ebadian et al[19] contradict the present study, possibly due to differences in study design and methodology. Clelland et al[20] found that increasing the implant angle increases stress, which is consistent with the present study.

Most studies that have loaded implants individually have shown that angulating implants increase stress in the bone,[21,22]

Table 3

Relationship between Morse taper length and stress distribution*

Screw		Abutment		Fixture		Bone		
L	S	L	S	L	S	L	S	
1.62e7	1.67e7	3.78e7	4.03e7	4.41e7	4.56e7	3.26e7	3.99e7	0–11°
2.29e7	3.48e7	11.2e7	14.8e7	8.55e7	8.7e7	4.17e7	4.21e7	11–30°
2.76e7	4.14e7	14.2e7	17.8e7	10.1e7	12.8e7	5.4e7	5.89e7	11–45°
1.65e7	1.71e7	3.62e7	3.88e7	1.92e7	4.47e7	1.2e7	3.9e7	0–16°
3.35e7	3.68e7	6.7e7	14e7	4.49e7	8.58e7	2.73e7	4.2e7	16–30°
4.09e7	4.58e7	10.4e7	16.3e7	6.21e7	12.2e7	4.46e7	5.58e7	16–45°

*S, short (1.3 mm); L, long (2.6 mm).

Table 4

Relationship between the angle of force application and stress distribution

Screw			Abutment			Fixture			Bone			
°45	°30	°0	°45	°30	°0	°45	°30	°0	°45	°30	°0	
4.14e7	3.48e7	1.67e7	17.8e7	14.8e7	4.03e7	12.8e7	8.7e7	4.56e7	5.89e7	4.21e7	3.99e7	S°11
2.76e7	2.29e7	1.62e7	14.2e7	11.2e7	3.78e7	10.1e7	8.55e7	4.41e7	5.4e7	4.17e7	3.26e7	11°L
4.58e7	3.68e7	1.71e7	16.3e7	14e7	3.88e7	12.2e7	8.58e7	4.47e7	5.58e7	4.2e7	3.9e7	16°S
4.09e7	2.35e7	1.65e7	10.4e7	6.7e7	3.62e7	6.21e7	4.49e7	1.92e7	4.46e7	2.73e7	1.2e7	16°L

which confirms the results of the present study. However, in studies where angulating implants did not affect stress distribution around the implant, the implants were splinted and part of a supported prosthesis, which would reduce the stress and bending moments on the implant.[23–25]

When the length of the Morse taper increases, the stress in the bone and prosthetic components decreases, and this decrease is negligible at an 11° Morse taper angle. The reason for this is that the abutment has more freedom of movement at a 16° Morse taper angle, so changes in the length of the Morse taper have a more significant impact on stress, and vice versa. When the Morse taper angle increases, the stress in the bone and prosthetic components decreases, and the stress on the screw increases. However, this decrease is negligible in shorter lengths. This is because the abutment has more freedom of movement at longer lengths, so changes in the Morse taper angle significantly impact stress; and vice versa. The reason why the stress on the screw increases, unlike other implant components, is that when the Morse taper angle increases, the abutment's freedom of movement increases. The screw, as part of the implant, prevents movement and rotation of the abutment on the fixture, resulting in increased screw stress to avoid component implant movement. In conclusion, increasing the internal Morse taper angle in single implants leads to increased stress, which is related to the angle and length of the Morse taper, resulting in stress in the bone, fixture, abutment, and screw, and engaging the implant-abutment complex. Therefore, implant loading without angulation, with longer Morse tapers, and larger angles should be considered in patient treatment planning.

For future studies, we recommend considering other variables such as the type of connection, connection design, zirconia abutments, tissue-level implants, tooth number, chewing force magnitude, and other materials.

This study's limitation is the simplification inherent in finite element analysis modeling. While this analysis is a powerful

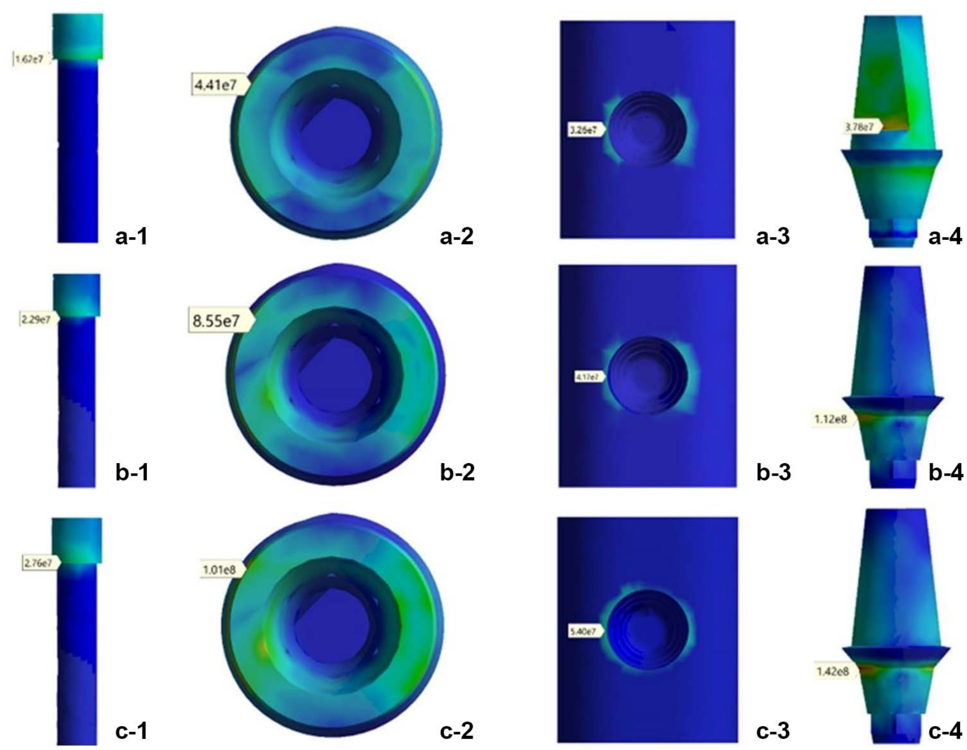

Figure 3. Stress distribution in 2.6 mm morse taper length with 11° morse taper angle group. (a) The angle of force application was 0°. (b) The angle of force application was 30°. (c) The angle of force application was 45°. (1: Screw, 2: Fixture, 3: Bone, 4: Abutment).

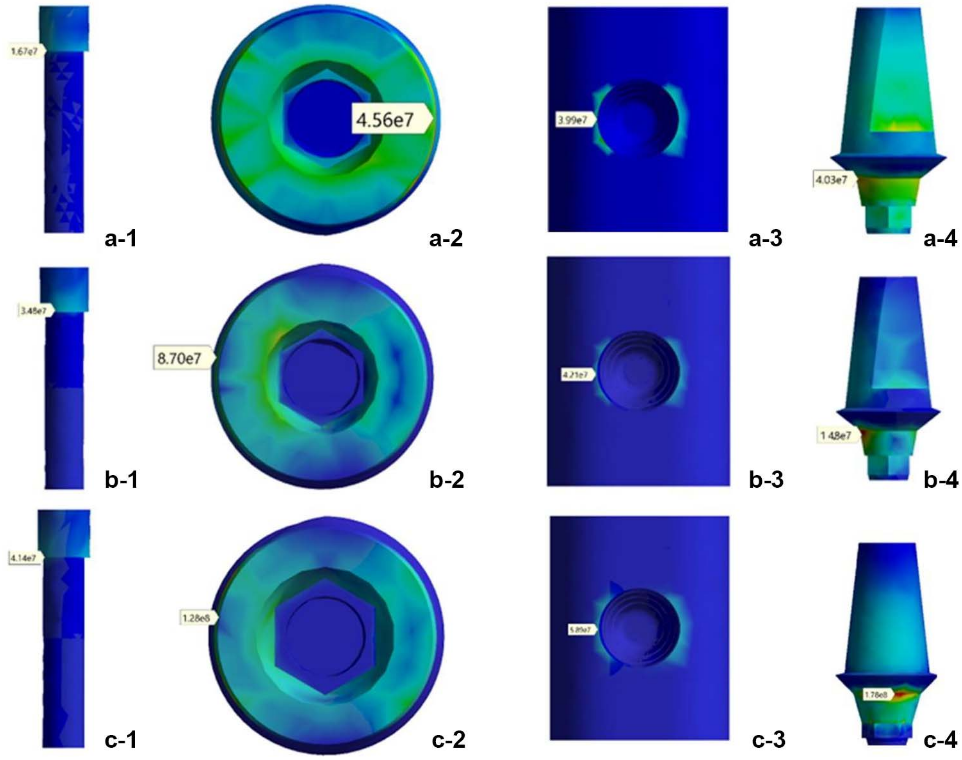

Figure 4. Stress distribution in 1.3 mm morse taper length with 11° morse taper angle group. (a) The angle of force application was 0°. (b) The angle of force application was 30°. (c) The angle of force application was 45°. (1: Screw, 2: Fixture, 3: Bone, 4: Abutment).

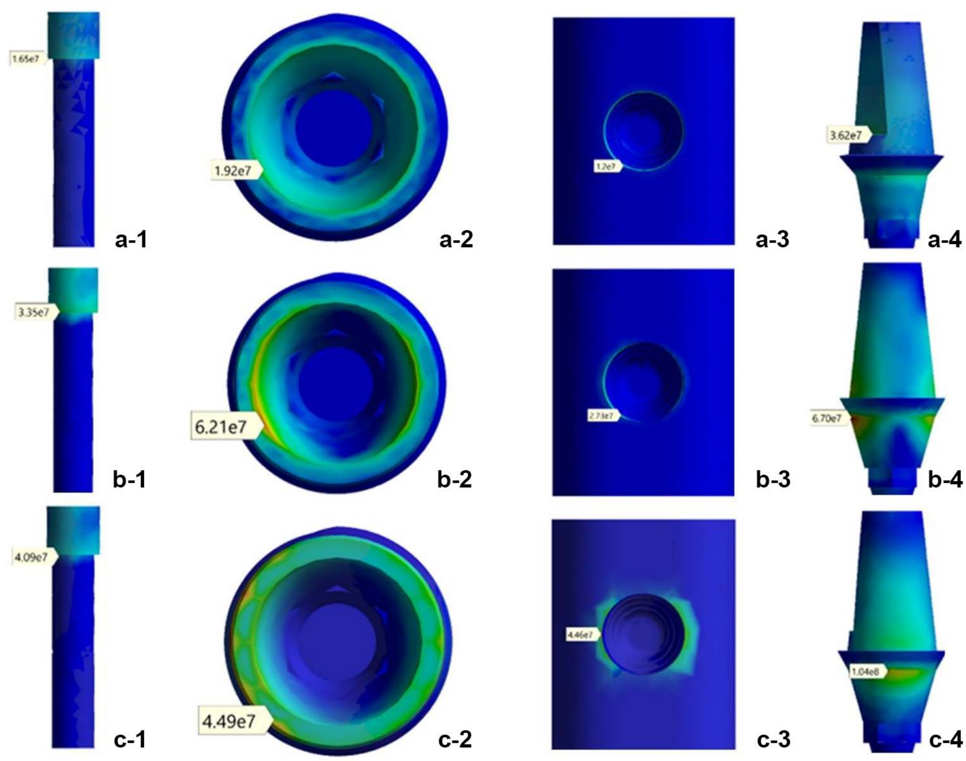

Figure 5. Stress distribution in 2.6 mm morse taper length with 16° morse taper angle group. (a) The angle of force application was 0°. (b) The angle of force application was 30°. (c) The angle of force application was 45°. (1: Screw, 2: Fixture, 3: Bone, 4: Abutment).

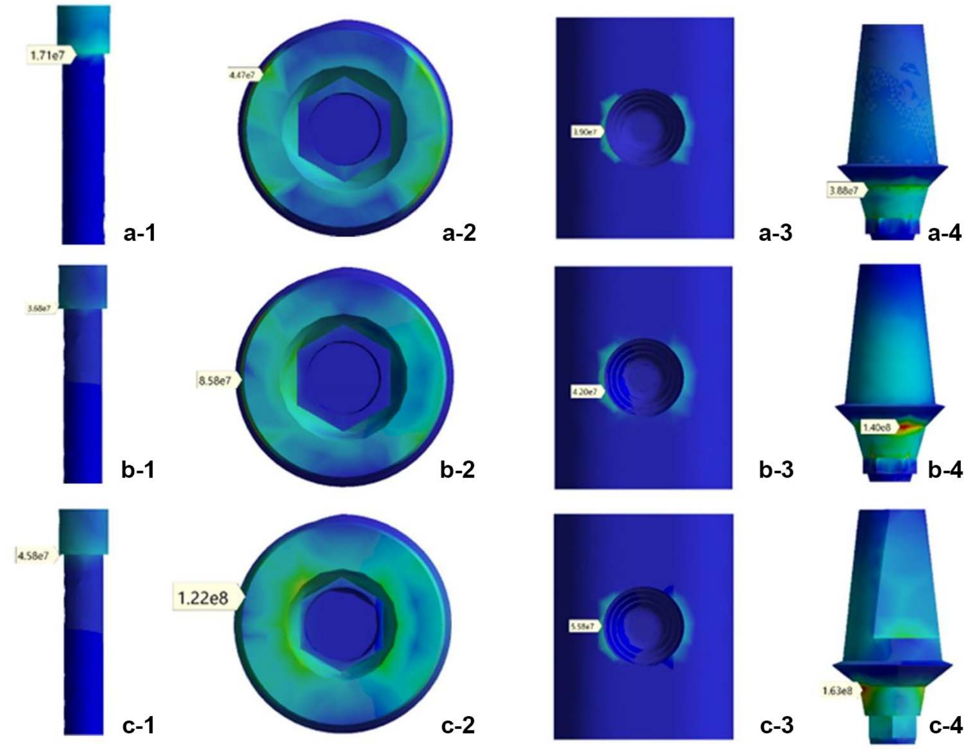

Figure 6. Stress distribution in 1.3 mm morse taper length with 16° morse taper angle group. (a) The angle of force application was 0°. (b) The angle of force application was 30°. (c) The angle of force application was 45°. (1: Screw, 2: Fixture, 3: Bone, 4: Abutment).

tool for simulating stress distribution, it relies on assumptions and simplifications that may not fully capture the complexity of real-world conditions. Therefore, careful interpretation of results in the context of these limitations is essential for drawing meaningful conclusions and informing clinical practice.

Conclusion

Increasing the Morse taper angle increases the stress on the implant screw, but decreases the stress in the bone, fixture, and abutment. These changes are more pronounced at longer Morse taper lengths. Increasing the length of the Morse taper reduces the stress on the bone and all prosthetic components of the implant, including the abutment, fixture, and screw. This reduction is more significant at a 16° Morse taper angle. Finally, increasing the force angle increases the stress on the bone and all prosthetic components of the implant, including the abutment, fixture, and screw.

Note

The authors declare no conflicts of interest related to this study.

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