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Examination of stresses created by zygomatic and dental implants applied in combined form and implants placed with the "All-on-Four" technique in bilateral atrophic maxilla by finite element analysis

Murat Özler[1], **Belgin Gülsün**[2]

[1]Department of Oral, Dental and Maxillofacial Surgey, Diyarbakır Oral and Dental Health Hospital, Diyarbakır, Turkiye
[2]Departman of Oral, Dental and Maxillofacial Surgery, Faculty of Dentistry, Dicle University, Diyarbakır, Turkiye

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ABSTRACT

Aims: In severely atrophic posterior maxillae, there is usually not enough bone to place conventional dental implants. Dental implants and zygomatic implants placed with the "All-on-Four" technique have frequently been preferred in recent years because they eliminate the need for grafting, shorten the treatment time, and reduce the morbidity rate. The aim of our study was to select the most accurate surgical planning according to the stress values resulting from the forces applied to the combined zygomatic and dental implants and dental implants placed with the "All-on-Four" technique in the models we created.

Methods: In the present study, 2 group models were established. In group 1 model, one dental implant was placed in the canine and second premolar tooth regions with the "All-on-Four" technique. In the group 2 model, one dental implant was placed in the canine tooth region and one zygomatic implant was placed in the 1st molar region. In the prosthetic superstructure, a force of 150 N was applied vertically from the region of teeth 4-5-6 and 100 N was applied obliquely at an angle of 30^{o}.

Results: In the present study, when the von Mises stress values on the implants were analyzed, it was found that the highest stress occurred in group 2 under vertical forces and in group 1 under oblique forces.

Conclusion: Based on these results, it is concluded that the most ideal planning in the rehabilitation of bilateral atrophic maxilla is group 1 with dental implants placed with the "All-on-Four" technique under vertical forces and group 2 with zygoma and dental implants under oblique forces.

Keywords: Atrophic maxilla, zygomatic implant, "All-on-Four" technique

INTRODUCTION

Dental implants enable the restoration of lost teeth without the need to prepare neighboring teeth, as well as providing fixed restoration in partial or complete edentulous patients. Studies on dental implantology first started in the 1960s.[1] Osteointegrated implants were introduced by Brånemark in 1965.[2] The aim of dental implants is to restore the function and aesthetics lost after tooth extraction.[3]

In patients with severe atrophy in the maxillary posterior region, insufficient bone quantity, poor bone quality and the presence of a severely pneumatized maxillary sinus limit standard dental implant applications.[4] The conventional surgical approach in patients with extreme atrophy of the maxilla is augmentation with autogenous block or cannellous grafts obtained from the intraoral/extraoral area or open sinus lifting. Interpositional application of corticocancellous iliac graft after Le fort I osteotomy is another technique. However, these techniques have disadvantages such as being more complicated, the inability to use the patient's temporary prosthesis during the healing period of the graft, prolonged treatment time due to grafting, the risk of morbidity at the recipient site, the high probability of infection especially in sinus lifting procedures and increased treatment costs.[5,6]

Due to some disadvantages of Le Fort I and iliac surgery for the reconstruction of atrophic posterior maxilla, researchers have developed other methods. It was in the 1990s that the zygoma was considered as an anchorage source for the application of implants in the prosthetic treatment of maxilla cases with excessive atrophy.[7] Aparicio et al.[8] first studied the

Corresponding Author: Murat Özler, muratozler89@gmail.com

possibility of applying dental implants to the zygoma. In 1993, it was decided that the zygoma could be used as a support for stabilization of implants.

The "All-on-Four" technique (Nobel Biocare AB, Goteborg, Sweden) was first introduced in 2003 in cases of mandibular complete edentulism and later in cases of maxillary complete edentulism.[9] In the maxillary "All-on-four" technique; maxillary sinus augmentation and sinus lifting applications are not necessary.[9,10]

Finite element analysis (FEA) is a method of analyzing the stresses and deformation of a complex geometric structure by converting it into a network structure in a computer environment. The structure is divided into finite elements connected to each other by nodes. The type, arrangement and number of these elements affect the result of the analysis.[11] The stress and displacement at each node can be calculated.[12] Weinstein et al.[13] were the first researchers to use FEA in implantology in 1976.

In the present study, the FEA method was used to investigate the amount and distribution of von Mises stress on the implants as a result of the application of vertical and oblique forces on the implants applied with zygomatic and dental implants and implants applied with the "All-on-Four" technique in bilateral atrophic maxillae.

METHODS

This study is not a clinical study, drug trial study, or a retrospective or prospective study. It is just an analysis study done on a computer. Therefore, no ethical committee decision is needed in such studies.

In the present study, a tomography scan of a total edentulous adult patient was taken to create a geometric model of the maxilla (Figure 1). The maxilla was scanned by Cone Beam Tomography (ILUMA, Orthocad, CBCT (cone beam computed tomography), 3M Imtec, Oklahoma, USA). In the scan, 601 slices were obtained with a 40-second scan at 120 kvp, 3.8 mA. The volumetric data was then reconstructed with a slice thickness of 0.2 mm. The reconstructed sections were exported in DICOM 3.0 format. The exported sections were imported into 3D-Doctor (Able Software Corp., MA, USA) software (Figure 2).

Figure 1. Tomography image of a completely edentulous adult patient

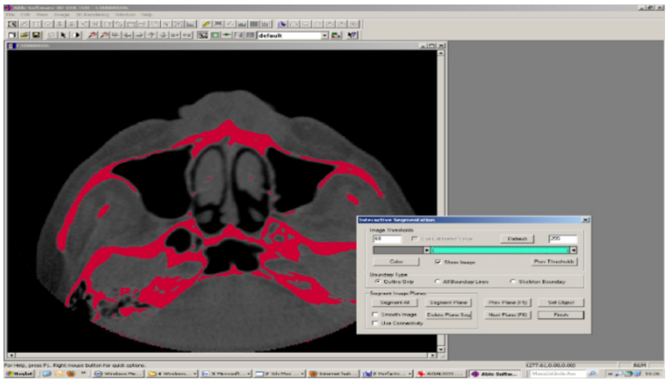

Figure 2. Transferring tomography images to 3D-doctor software

Bone tissues on the sections were separated with the "interactive segmentation" technique in 3D-Doctor software. The decomposed sections were converted into a 3D model with the "ComplexRender" technique. The modeling process of the upper jaw bone was completed by turning the 3D model into a smooth surface consisting of elements with low memory consumption and proper proportions with the simplification methods in 3D-doctor software. The 3D model was exported from 3D-Doctor software in .stl format. After the parsing process, the 3D model was obtained with the "3D ComplexRender" method and the bone tissue was modeled in this way (Figure 3).

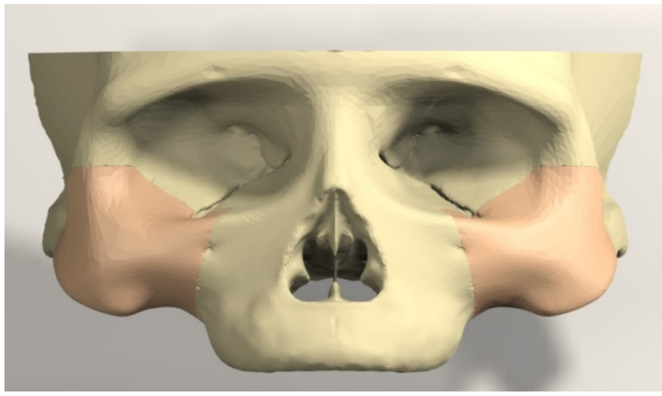

Figure 3. Bone model of the maxilla and zygoma

In the present study, 2 group models were established. In the group 1 model, one dental implant (Nobel Biocare AB, Goteborg, Sweden) was placed in the canine and second premolar tooth regions with the "All-on-Four" technique. The anterior implant with a diameter of 3.75 mm and a length of 11.5 mm was placed in the canine tooth region at a right angle, and the posterior implant with a diameter of 3.75 mm and a length of 13 mm was placed in the 2nd premolar tooth region at a 30º angle (Figure 4). In the group 2 model, one dental implant (Nobel Biocare AB, Goteborg, Sweden) with a diameter of 3.75 mm and a length of 11.5 mm was applied to the canine tooth area on the right and left sides at right angles, and one zygomatic implant (Nobel Biocare AB, Goteborg, Sweden) with a diameter of 4 mm and a length of 35 mm was applied to the 1st molar area at an angle of 45º using the extrasinus method (Figure 5). In the prosthetic superstructure, a force of 150 N was applied vertically in the region of teeth 4-5-6 and 100 N was applied obliquely at an angle of 30º (Figures 6, 7).

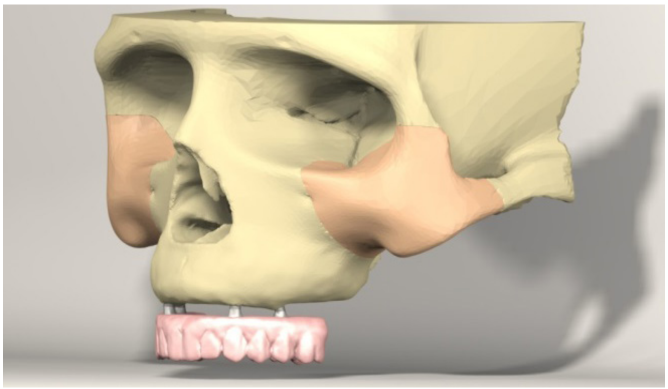

Figure 4. In the first group, the model with prosthetic superstructure and dental implant applied with the "All-on-Four" technique

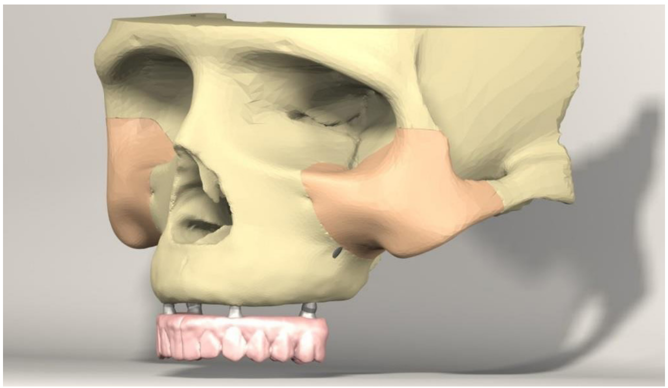

Figure 5. In the secondgroup, zygomatic and dental implant model with prosthetic superstructure

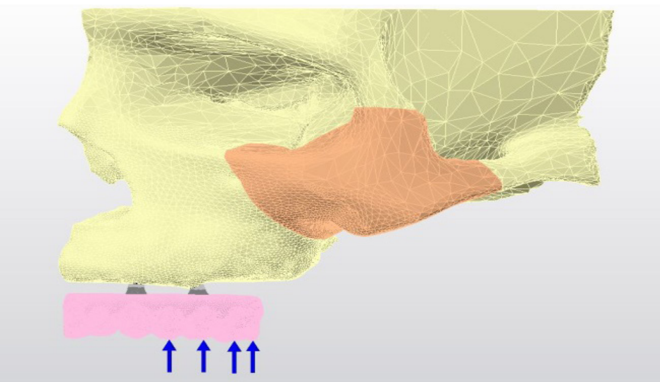

Figure 6. Force of 150 N applied perpendicular to the teeth

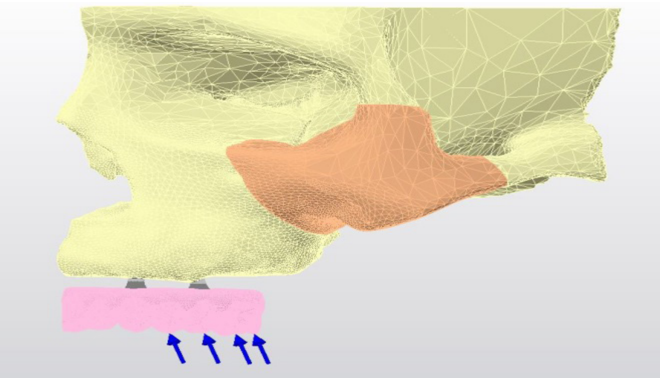

Figure 7. A force of 100 N applied obliquely to the teeth at an angle of 30°

The stresses on the implants were measured in megapascals (MPa) (N/mm^2). In the analysis, regions with high stress are shown in red and regions with low stress are shown in blue.

RESULTS

According to the results of the vertical forces, the maximum von Mises stress values in the neck regions of the implants of the groups were measured as 136.521 MPa in the first group (All-on-Four group) (Figure 8) and 179.016 MPa in the second group (zygoma and dental implant group), respectively (Figure 9).

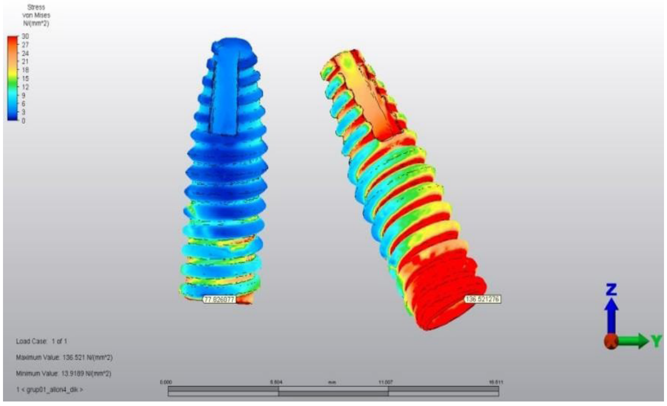

Figure 8. Maximum von Mises stress value of dental implants under vertical forces in group 1

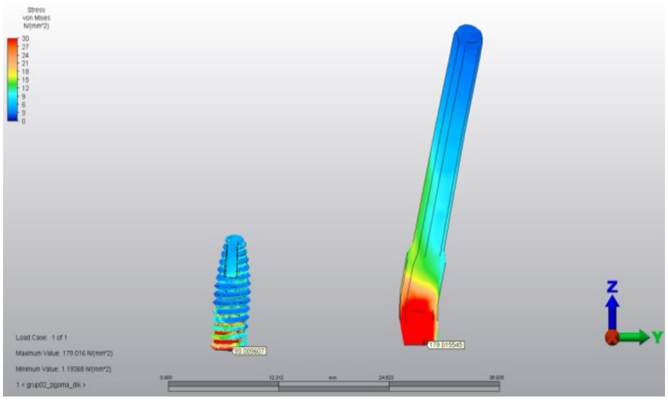

Figure 9. Maximum von Mises stress value of dental and zygoma implant under vertical forces in group 2

According to the results of the oblique forces, the maximum von Mises stress values in the neck regions of the implants of the groups were measured as 127.551 MPa in the first group (All-on-Four group) (Figure 10) and 103.223 MPa in the second group (zygoma and dental implant group), respectively (Figure 11).

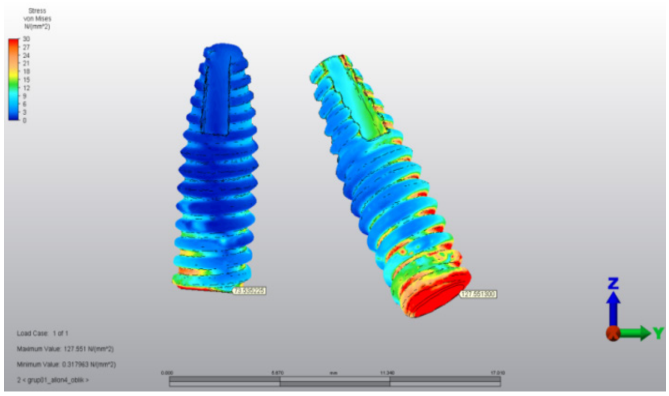

Figure 10. Maximum von Mises stress value in dental implants under oblique forces in group 1

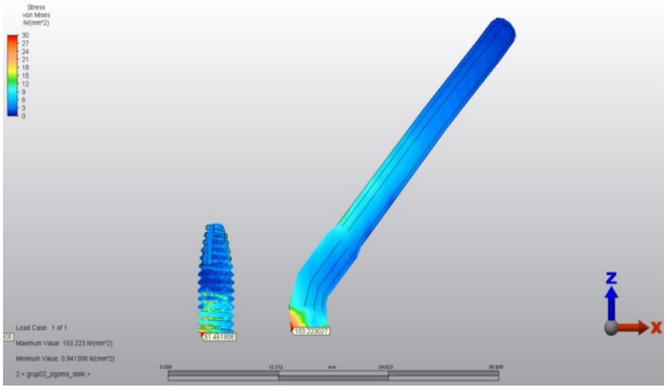

Figure 11. Maximum von Mises stress value in zygoma and dental implants under oblique forces in group 2

In the present study in which different systems were compared, the maximum von misses stress in the neck region of the implants in each group was evaluated in order to make a comparison between the systems. According to the results of our study, when the maximum von Mises stress values of the implants in each group were compared, it was seen that the least stress was observed in group 1 against vertical forces and in group 2 against oblique forces.

In group 1, the von Mises stress value in the anterior dental implant was 77.82 MPa and 136.52 MPa in the posterior dental implant against vertical forces. In group 2, the von mises stress value of the dental implant was 93 MPa and the stress value of the zygomatic implant was 179.01 MPa. In group 1, the von Mises stress value in the anterior dental implant was 73.535225 MPa and in the posterior dental implant was 127.551300 MPa against oblique forces. In group 2, the von Mises stress value of the dental implant was 51.461808 MPa and the stress value of the zygomatic implant was 103.223027 MPa.

When these results were evaluated; it was observed that the stresses accumulated in the neck regions of the implants increased with the increase in masticatory forces as we move posteriorly in both groups. When interpreted according to the stress values of the implants, it was seen that the most ideal planning was group 1 with "All-on-Four" under vertical forces and group 2 with zygoma and dental implants under oblique forces.

DISCUSSION

Implant applications have become widespread in the elderly population due to the increase in life expectancy, socioeconomic status, and aesthetic and functional expectations. The maxilla atrophies with advancing age and tooth loss, and the amount of bone to which traditional dental implants can be applied is not sufficient, especially if the amount of bone decreases with sinus pneumatization in the posterior field.[14]

Although it is possible to rehabilitate the maxilla with additional surgical procedures or modified implant applications and provide function to the patients, it is not preferred due to the degree of morbidity during and after additional surgical applications and the long duration of treatment, and recently, inclined, short, pterygoid and zygomatic implants have been applied.[15]

In 2003, Malò et al.[10] proposed the "All-on-Four" technique (All-on-4; NobelBiocare AG, Gothenburg, Sweden) for the prosthetic rehabilitation of mandibular edentulous jaws, which allows immediate loading with the application of 4 implants. The advantages of this technique are that it avoids the disadvantage of minimal bone height or sinus proximity in implant placement by placing two vertical implants anteriorly and two angled implants posteriorly and limiting the distal cantilever length. In 2005, this technique was introduced in the maxilla and requires sufficient alveolar bone height to allow the placement of 4 implants in the premaxillary area in highly resorbed maxillary alveolar crests. This planning has important advantages such as decreasing the treatment time, low patient morbidity and making the patient's quality of life more comfortable.[16,17] Studies have reported very high survival rates in the 3-year short and 5-year medium term. In a 5-year retrospective study of maxillary total edentulous cases, the "All-on-Four" treatment concept was reported to be a very suitable alternative treatment option.[18]

In the early loading protocol, the survival rates of the implants are 94.7-100% in the maxilla in the 1-3-year follow-up and 98.51-100% in the mandible in the 1-2-year follow-up, and 90.43-100% in the maxilla and 90-100% in the mandible in the 1-10 year follow-up has benn reported. In treatment based on the 'All-on-Four' concept, the survival rate of implants has been reported as 94.7% in the maxilla at the implant level, with a follow-up period of 5-13 years, and 93% in the mandible with a follow-up period of 10-18 years.[19,20] In the last review, the 13-year survival rates of implants in the maxilla were reported to be 93.9-100%, and the 18- year survival rates in the mandible were 91.7-100%.[21]

Kim et al.[22] investigated the effect of two posterior implant angles on stress distribution using photoelastic stress analysis according to the "All-on-Four" treatment method. Similar to other studies, they reported that the maximum stresses in the distal crestal bone of the posterior implant applied at an angle of 30° were on average 17% less than those of the vertically applied implants.

Bevilacqua et al.[23] reported more proportional load distribution with angled posterior implants. When the posterior implant placed at a 30° angle was compared with vertically applied implant-supported fixed prostheses with a longer cantilever, they reported that the angled implant reduced the amount of stress by 52% in compact bone and 47.6% in cancellous bone. In the present study, we placed the posterior dental implant at a 30° angle based on the advantages of a 30° angle reported in the literature.

Based on the maxillary "All-on-Four" dental implant technique, it is emphasized that the anterior implants should be applied perpendicularly, and the implant length should be at least 10 mm and the length of the posterior sloping implants should be at least 11.5 mm.[16] In the present study, anterior implants with a diameter of 3.75 mm and a length of 11.5 mm were applied parallel and perpendicular to each other, and posterior implants with a diameter of 3.75 mm and a length of 13 mm were applied at a 30° angle.

In 2010, Davo et al.[15] reported in their prospective study that zygomatic implants would be a successful alternative application technique for procedures that do not require additional surgery.

In their finite element stress analysis study, Wen et al.[24] used zygomatic and standard dental implants in different numbers and in different localizations in models in which traditional (brånemark), extracineus and extramaxillary methods were applied. In these techniques, they reported that the model in which the extracineus method was applied was biomechanically superior to the others and the stresses on the zygomatic implant were the least. They also reported that occlusal loads were met by the zygomatic bone and transmitted in the direction of the zygomatic arch. When the results were analyzed, they reported that von Mises stress values were highest in the neck and coronal region of the implant.

In their study, Migliorança et al.[25] reported success rates of 97.5%, 95.9% and 95.2% for ZI, traditional dental implants and superstructure, respectively, in the 8-year follow-up of 40 zygomatic implants and 74 traditional dental implants loaded immediately with the extracinus method in 21 patients (13 women and 8 men) with an average age of 55 years in atrophic maxilla. They reported that zygomatic implant with extracinus application is a successful technique.

In line with the results of these studies, the extracinus method is preferred because it is more comfortable to apply than other techniques, postoperative results are more successful, prosthetic superstructure rehabilitation is more satisfactory and the stresses accumulated in the zygomatic implants are less. Considering the advantages of the extracinus method mentioned in the literature, zygomatic implants were applied with the extracinus method in the present study.

In 2019, Çetindağ et al.[26] applied a force of 150 N vertically and 50 N obliquely to the region of teeth 2-4-6-7 in another finite element analysis study on zygomatic implants and reported that both the increase in the number of zygomatic implants and the increase in the number of dental implants significantly reduced the stress values.

Although there are many advantages of using the finite element analysis method in determining approximate and predictive results, many randomized clinical studies on this subject need to be conducted to obtain reliable and definitive results. Di Pietro N, and Callea C suggested that further studies are needed to simulate all treatment alternatives for atrophic jaws to include the dynamic forces reproducing chewing, take into account the anisotropic and regenerative properties of native bone, or simply test other implant designs and prosthetic attachments as in previous studies.[27,28]

In the 2 different models we planned in the present study, 150 N force was applied vertically, and 100 N force was applied obliquely at an angle of 30 degrees to the buccal tubercles of teeth 4-5-6 in the prosthetic superstructure in order to mimic the average values of posterior masticatory forces in parallel with the forces applied in the literatures.

CONCLUSION

According to the results of our three-dimensional SESA study in which we evaluated the stress effect of different treatment options and implant designs on the implants to be applied in extremely atrophic maxilla; it was observed that the maximum von Mises stress value was higher in the neck regions of all implants and the stress increased as we move from anterior to posterior in both groups. The maximum von Mises stress values seen in the implants under vertical forces were highest in group 2 with zygomatic and dental implants and lowest in group 1 with "All-on-Four". Under oblique forces, the highest von Mises stress values were observed in group 1 with "All-on-Four" and the lowest in group 2 with zygomatic and dental implants.

The use of dental implants and zygomatic implants applied with the "All-on-Four" technique in the atrophic maxilla eliminates the need for grafts and reduces patient morbidity, duration of procedures and costs. The 3D models used in the present study were obtained from a tomography image of a toothless patient. The mechanical properties of the tissues and prosthetic materials used were determined and limited as described in publications. However, it is foreseen that anatomical changes and changes in the materials used may change the format of this study and the findings. Therefore, the results of our study may differ in different implant systems. For this reason, in the future, studies on different implant systems can be performed and the biomechanical properties of these systems can be compared.

ETHICAL DECLARATIONS

Ethics Committee Approval

It is just an analysis study done on a computer. Therefore, no ethical committee decision is needed in such studies.

Informed Consent

It is just an analysis study done on a computer. Written consent form is not required.

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Financial Disclosure

The authors declared that this study has received no financial support.

Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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