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Three-dimensionally rendering of the sphenoid bone of adolescents using Materialise's Interactive Medical Image Control System software

Renderização tridimensional do osso esfenoide de adolescentes usando o Sistema Interativo de Controle de Imagens Médicas

Renderización tridimensional del hueso esfenoides de adolescentes usando el Sistema de Control de Imágenes Médicas Interactivas

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Abstract
The main goal of this study was to reconstruct three-dimensionally (3D) the sphenoid bone of adolescents with the software Materialise Mimics to test the accuracy and reliability of craniometric measurements performed with the software. The study was conducted according to Strengthening the Reporting of Observational studies in Epidemiology (STROBE) guidelines. Cone-Beam Computed Tomography (CBCT) was performed in adolescents before the orthodontic treatment as part of the orthodontic records. The CBCT images were exported as DICOM (Digital Imaging and Communication in Medicine) files, in a universal format, with a voxel size of 0.3 mm and sphenoid bone was three-dimensionally rendered with Software Materialise Mimics. Ten sphenoid measurements were performed in triplicate by two trained examiners. The studied population was composed of 26 adolescents, 16 females (61.5%), and 10 males (38.5%) with a mean age of 12.5 years (SD= 1.7). 60 measurements were taken and the intra and inter-examiner accuracy revealed a high degree of data reproducibility (Kappa test higher than 0.90). The reconstruction and rendering of the images obtained by CBTC allowed anatomical details of the sphenoid bone to be measured with very high reproducibility. The Software Materialise Mimics allows you to analyze anatomical structures in detail and presents useful tools to optimize craniometry analyses.
Keywords: Anatomic landmarks; Sphenoid bone; Software.

Resumo
O objetivo principal deste estudo foi reconstruir tridimensionalmente (3D) o osso esfenoide de adolescentes com o software Materialise Mimics para testar a precisão e confiabilidade das medidas craniométricas feitas com o software. O estudo foi conduzido de acordo com as diretrizes do *Strengthening the Reporting of Observational studies in Epidemiology (STROBE)*. A tomografia computadorizada de feixe cônico (CBCT) foi realizada em adolescentes antes do tratamento ortodôntico como parte dos registros ortodônticos. As imagens CBCT foram exportadas como arquivos DICOM (Digital Imaging and Communication in Medicine), em formato universal, com um tamanho de voxel de 0,3 mm e o osso esfenoide foi renderizado tridimensionalmente com o software Materialise Mimics. Dez medições do esfenoide foram realizadas em triplicata por dois examinadores treinados. A população do estudo consistia em 26 adolescentes, 16 mulheres (61,5%) e 10 homens (38,5%) com idade média de 12,5 anos (SD= 1,7). 60 medições foram realizadas e a precisão intra e interexaminadores revelou um alto grau de reprodutibilidade dos dados (teste Kappa superior a 0,90). A reconstrução e representação das imagens obtidas pelo CBTC permitiram que os detalhes anatômicos do osso esfenoidal fossem medidos com alta reprodutibilidade. O Software Materialise Mimics permitiu analisar os detalhes das estruturas e analisar as ferramentas úteis para otimizar as análises craniométricas.
Palavras-chave: Pontos de referência anatômicos; Osso esfenoide; Software.

Resumen
El objetivo principal de este estudio fue reconstruir tridimensionalmente (3D) el hueso esfenoides de adolescentes con el programa informático Materialise Mimics para comprobar la precisión y fiabilidad de las mediciones craneométricas realizadas con el programa. El estudio se llevó a cabo de acuerdo con las directrices del Strengthening the Reporting of Observational studies in Epidemiology (STROBE). Se realizó una tomografía computarizada de haz cónico (CBCT) a los adolescentes antes del tratamiento de ortodoncia como parte de los registros de ortodoncia. Las imágenes CBCT se exportaron como archivos DICOM (Digital Imaging and Communication in Medicine), en un formato universal, con un tamaño de vóxel de 0,3 mm y el hueso esfenoides se renderizó tridimensionalmente con el software Materialise Mimics. Se realizaron diez mediciones del esfenoides por triplicado por dos examinadores entrenados. La población estudiada estaba compuesta por 26 adolescentes, 16 mujeres (61,5%) y 10 hombres (38,5%) con una edad media de 12,5 años (SD= 1,7). Se realizaron 60 mediciones y la precisión intra e inter-examinadores reveló un alto grado de reproducibilidad de los datos (prueba Kappa superior a 0,90). La reconstrucción y la representación de las imágenes obtenidas por el CBTC permitieron medir los detalles anatómicos del hueso esfenoides con una reproducibilidad muy elevada. El software Materialise Mimics permite analizar los detalles de las estructuras y analizar las piezas ferramentadas para otimizar los análisis craneométricos.
Palabras clave: Puntos anatómicos de referencia; Hueso esfenoides; Programas informáticos.

1. Introduction

The craniofacial characteristics of the human species are the result of physiological adaptation and environmental variations that occurred during the evolutionary process, resulting in characteristic phenotypes that are easily used to identify population groups in anthropometric and evolutionary studies (Lieberman *et al*., 2004). In fact, the complex morphology of the skull can be decomposed into a series of craniometric measurements taken from landmarks in the skull that allow tracing a profile of the anatomical morphology of the individuals (Fuyamada *et al.,* 2011; Sidlauskas *et al.,* 2016) and comprises an essential part in the construction of anatomical-physiological knowledge, especially for professionals who work directly on this anatomical region. In this sense, the analysis of isolated or grouped craniometric landmarks is highly reliable for investigating the morphology of the skull and establishing craniofacial patterns of growth and development (Franklin, *et al.*, 2008; Karlo, Stolzmann *et al.*, 2010; Rupa *et al.*, 2015).

The sphenoid bone is recognized as one of the most relevant skull bones from a clinical and surgical point of view, once it contributes to the formation of the middle cranial fossa floor. Its intricate morphology can be divided into four main parts: the body, greater wings, lesser wings and pterygoid processes, bone structures that house and protect the brain (Er *et al.*, 2020; Roomaney *et al.*, 2021). Besides that, the sphenoid bone has several anatomical details such as channels, fissures and foramina that allow the passage of nerves, arteries and veins (Ramos *et al.*, 2021; Roomaney *et al.*, 2021) that not always evident on bidimensional images. However, with the development of Cone Beam Computer Tomography (CBCT), an image exam that allows visualization in 3 dimensions, it became easier to visualize subtill anatomical details and relationships between the analyzed structures (Singh *et al.*, 2021).

Accurate interpretation of the image is essential to a therapeutic approach and for that there are several software capable of creating 3D surfaces from an image obtained by CBCT. One of them is Materialise's Interactive Medical Image Control System software (Materialise Mimics, Leuven, Belgium), known as the gold standard tool for medical image analysis and 3D rendering and exporting (Shin *et al.*, 2015) and, although its use is not popularized due to the need for specific training to use the tools, the Materialise Mimics software seems to be promising in terms of measurement accuracy. Thus, the main objective of this study was to reconstruct three-dimensionally the sphenoid bone of adolescents with the Materialise Mimics software to evaluate the craniometric measurements performed with the software.

2. Methodology

2.1 Ethical Approval, Type of Study, and Sampling

This is a cross-sectional study that was approved by the local Ethics and Research Committee (#3.036.106) following resolution 466/12 of the National Health Commission. Appropriate written informed consent was obtained from all participants and legal guardians. A non-probabilistic convenience sampling composed by adolescents aged between 10 and 16 years old, scheduled for orthodontic treatment at the Positivo University, Curitiba, Brazil. Exclusion criteria were applicable to adolescents with previous orthodontic treatment. Also were excluded adolescents with systemic conditions, syndromes, oral cleft, bone disease or history of any serious trauma as well as those who had injury of the face.

2.2 Study Design

Data referring to the general characterization of the adolescents were collected through a self-reported questionnaire in the Portuguese language that addressed gender, age, ethnicity, school education, and previous medical or odontological treatment. All individuals who were not sure about their answers were excluded from the survey. For the clinical data collection, a team composed of previously trained orthodontists and note-takers performed anamnesis and clinical examination. They were calibrated by experienced examiners in epidemiological surveys who guided the conduct of the theoretical and practical training steps.

All individuals were submitted to Cone-Beam Computed Tomography (CBCT) before the orthodontic treatment as part of the orthodontic record, to perform the orthodontic treatment plan. CBCT scans were performed with standard head positioning (Frankfurt horizontal plane), scanning time of 17.8 seconds, a field of vision of 170 mm/170 mm, and patient in maximum intercuspation. i-CAT (Imaging Sciences International, Hatfield, PA, USA), model 9140, 115/230 Vca, 10 A/ 5 A, and 50/60 Hz was used. The CBCT images were exported as DICOM (Digital Imaging and Communication in Medicine) files, in a universal format, with a voxel size of 0.3 mm.

To reconstruct 3D the sphenoid bone, the Software Materialise Mimics was used from the definition of the density threshold of the Hounsfield scale (HU) between 226 HU and 3071 HU for bone tissue selection (figure 1). With the sphenoid highlighted, the Multi-Slice Edit tool was selected to remove unwanted structures in the sagittal, axial and coronal planes and set the parameters for rendering and was performed by three examiners.

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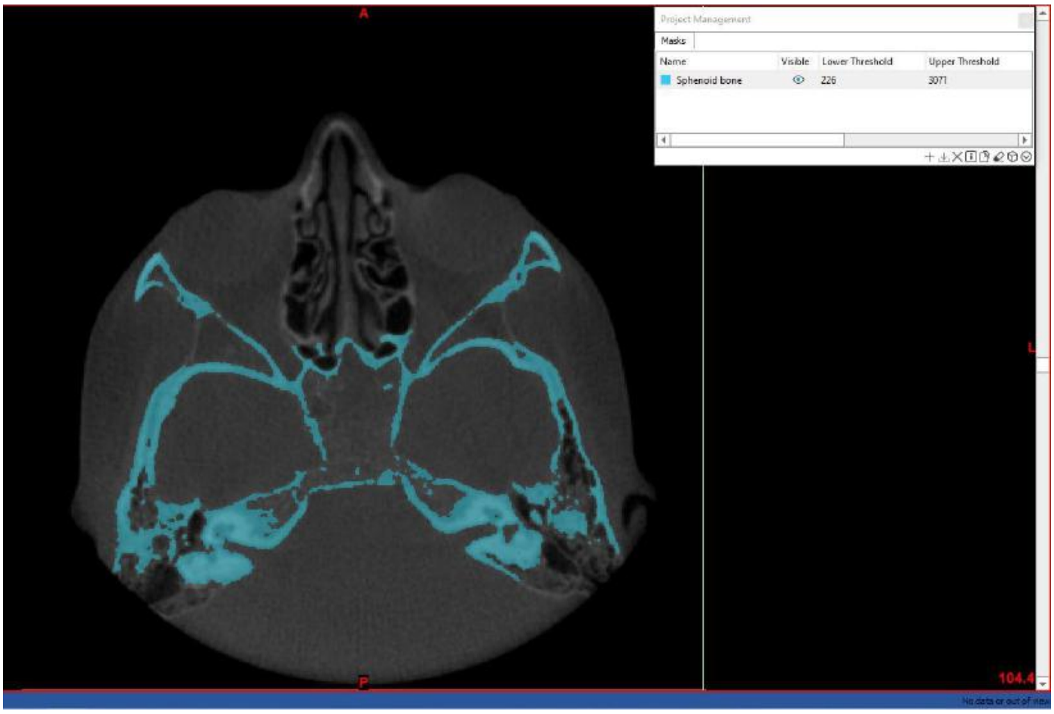
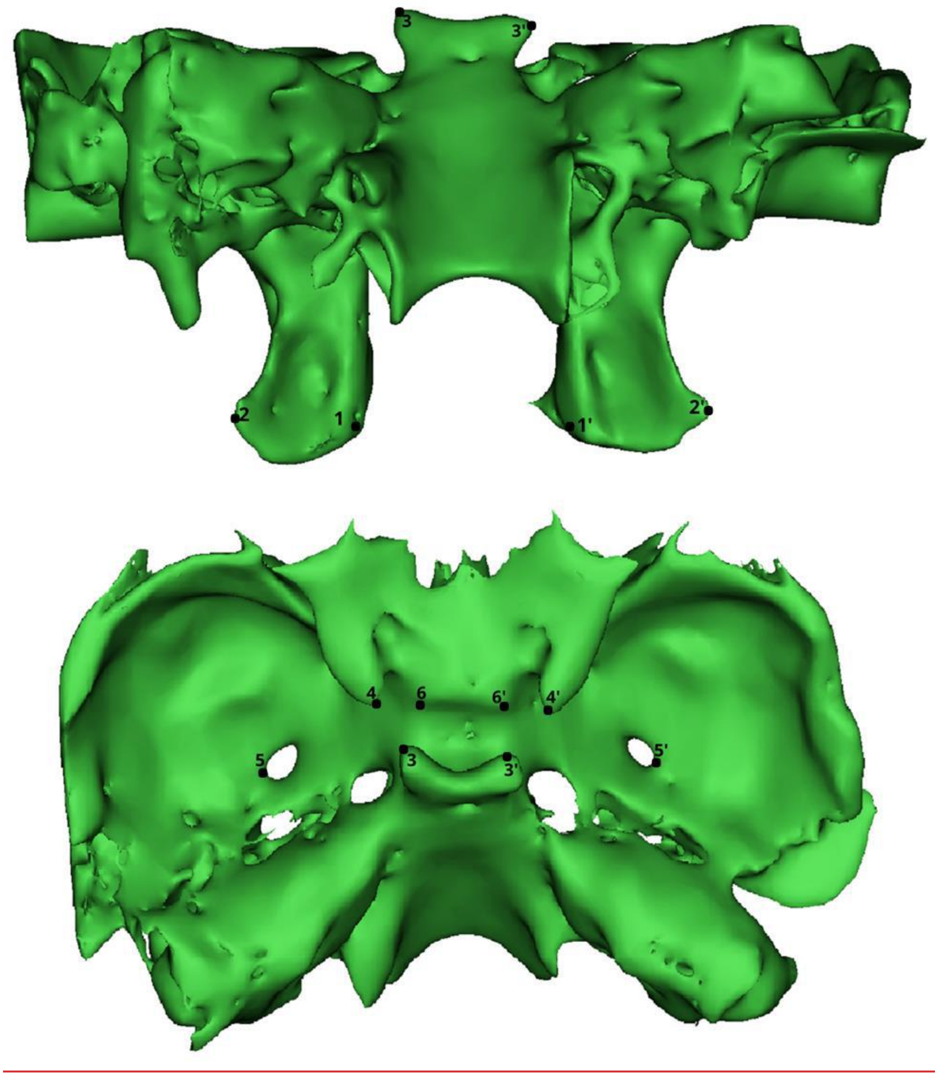
Figure 1 - Sphenoid highlighted in blue in an axial plane. The Multi-Slice Edit tool was used to set the parameters for rendering and remove unwanted structures in different planes.



Source: Authors.

After that, 10 sphenoid landmarks were selected and measurements between these landmarks were taken using the “distance” tool of the Materialise Mimics® software. The selected landmarks were measured in latero-lateral view and postero-anterior view after theoretical and practical discussion about anatomy of sphenoid bone and are described in figure 2.

Figure 2 - Selected landmarks in sphenoid bone and abbreviations used. (A) Three landmarks were taken in posterior view: (A) 1→1’ distance between left to right margins of Medial Pterygoid Plates (lpMPP-rpMPP); 2→2’ distance between left to right margins Lateral Pterygoid Plates (lpLPP-rpLPP); 3→3’ distance between left to right Posterior Clinoid Process (lPCP-rPCP). (B) Seven landmarks were taken in superior view: 3→3’ distance between left to right Posterior Clinoid Process (lPCP-rPCP); 4→3 distance between left Anterior Clinoid Process to left Posterior Clinoid Process (lACP-lPCP); 4’→3’ distance between right Anterior Clinoid Process to right Posterior Clinoid Process (rACP-rPCP); 4→4’ distance between left to right Anterior Clinoid Process (lACP-rACP); 5→5’ distance between left to right lateral margin of oval foramen (lFO-rFO); 6→6’ distance between left to right Middle Clinoid Process (lMCP-rMCP); 6→3 distance between left Middle Clinoid Process to left Posterior Clinoid Process (lMCP-lPCP); 6’→3’ distance between right Median Clinoid Process to right Posterior Clinoid Process (rMCP-rPCP).



Source: Authors.

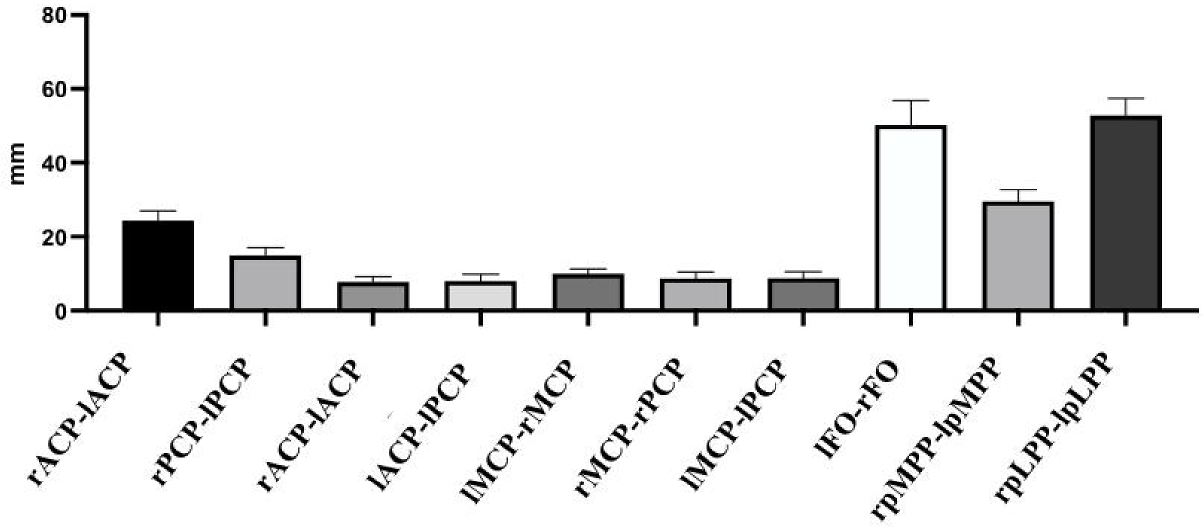
The measurements were carried out by three researchers at three different times, with a space of one week between one measurement and the other. The values obtained were submitted to descriptive statistical analysis, with mean, maximum value, minimum value and standard deviation.

3. Results

The studied population was composed of 26 adolescents, 16 females (61.5%), and 10 males (38.5%) with mean age of

12.5 years (SD= 1.7). Ten measurements were performed in triplicate by three trained examiners, totaling 90 measurements. The test to verify the intra and inter examiner accuracy revealed a high degree of data reproducibility (Kappa test higher than 0.90). The distances measured in millimeters between the selected landmarks are showing in table 1 and graphic 1. All measurements, except distance between left to right lateral margin of Oval Foramen (lFO-rFO) and distance between left to right Anterior Clinoid Process (lACP-rACP), were higher in boys than in girls. The construction of the 3D model made it possible to measure the distances more easily, both the greater distances, which approached 50mm, including lFO-rFO and rpLPP-lpLPP, as well as the smaller ones. Small distances such as the distance between left to right Anterior Clinoid Process (lACP-rACP) and the distance between left to right Posterior Clinoid Process (lPCP-rPCP) could be easily measured.

Figure 3 – Mean and standard deviation of the ten measurements performed on the sphenoid bone.



Source: Authors.

Table 1 – Distribution of measurements in millimeters of the ten landmarks measured, according to gender.

		Female (n=16)			Male (n=10)		
Anatomycal sphenoid landmarks		Mean (SD)	Min - Max	Range	Mean (SD)	Min - Max	Range
Latero-lateral measurements	rACP-lACP	23.68 (1.61)	20,66 - 27,38	6.72	25.29 (3.66)	19.57 – 31.90	12.33
	rPCP-lPCP	14.22 (2.01)	11.29 -17.77	6.48	15.99 (2.04)	13.68 – 19.73	6.05
	lMCP-rMCP	9.51 (1.22)	7.16 – 11.38	4.22	10.76 (0.79)	9.70 – 12.47	2.77
	lFO-rFO	50.52 (6.39)	33.3 – 60.11	26.81	49.70 (7.38)	34.90 – 60.81	25.91
	rpMPP-lpMPP	29.05 (2.98)	23.65 – 34.15	10.5	30.33 (3.46)	24.84 – 37,31	12.47
	rpLPP-lpLPP	52.76 (3.33)	48.1 – 57.8	9.7	52.86 (6.22)	45.55 – 67.12	21.68
Anteroposterior measurements	rACP-lACP	7.52 (1.40)	4.25 – 9.06	4.81	7.04 (1.76)	6.03 – 12.08	6.05
	lACP-lPCP	7.93 (1.98)	3.67 – 11.98	8.31	8.08 (1.77)	5.72 - 10.43	4.71
	rMCP-rPCP	8.25 (1.61)	5.71 – 11.21	5.5	9.38 (1.80)	6.78 – 12.59	5.81
	lMCP-lPCP	8.60 (1.83)	6.63 – 12.16	5.53	9.10 (1.57)	6.63 - 11.55	4.92

Note: SD= standard deviation; Min= minimum; Max= maximum. Bold form indicates measurements that were greater in girls than in boys.
Source: Authors.

4. Discussion

This cross-sectional study aimed to reconstruct the sphenoid bone of 26 adolescents who were about to start orthodontic treatment using the Materialise Mimics software. The results obtained, both in the reconstruction process and in the morphometric analysis of the craniometric landmarks, provide relevant information that allow some discussion about the use of the software used in this research.

The sphenoid bone is an irregular bone that has surfaces that can be seen from the inferior, lateral and internal views of the skull. Its largest bone mass, the body, occupies the central portion and contains the depression called sella turcica that houses and protects the pituitary gland. The dorsum sella also makes up the upper clivus from which the posterior and anterior clinoid processes project. In addition, between the anterior and posterior clinoids processes, there is also a pair of middle clinoids. Two vertical processes, with their blades, called pterygoid processes of the sphenoid, project downward from the body on either side. Each pterygoid process has a lateral and a medial lamina, separated by a depression, the pterygoid fossa (Patel *et al.*, 2016; Shrestha *et al.*, 2018).

All these anatomical details appear on a relatively small surface which makes them difficult to visualize in two-dimensional images (Shrestha *et al.*, 2018). Thus, there is no doubt that CBCT technology helps tremendously in locating these anatomical details through reconstruction in a three-dimensional model that allows observation without overlapping structures. Likewise, it allows cephalometric tracings and measurement of small distances in the sagittal, coronal and axial planes between subtle anatomical structures (Lou *et al.*, 2007; Schlicher *et al.*, 2012; Naji *et al.*, 2014). In the case of the sphenoid bone, 3D analysis allowed the visualization of internal structures, increasing the accuracy of the images (Sathyanarayana *et al.*, 2013).

More recently, the images obtained by CBCT started to be rendered, which is nothing more than a set of techniques used to display a 2-dimensional projection of a 3D discretely sampled that allows the images to be rotated in space, which undoubtedly provide new information and accurate assessment of the bone's morphology (Katkar *et al.*, 2018). Several image rendering software are available, including Materialise Mimics software, initially developed for pre-surgical planning, modeling and 3D printing of various models (Li *et al.*, 2015). A key point of the software is the customization of densities and the surface rendered in 3D, which increases the chance of observing small flaws in the mesh and avoids observer error (Chou *et al.*, 2021).

On the other hand, Materialize Mimics is not so intuitive and requires training to use. Therefore, the objective of this work was to reconstruct three-dimensionally and rendering the sphenoid bone with the Materialise Mimics software and test the accuracy and reliability of craniometric measurements performed with the software. For that, 60 measurements were performed and intra- and inter-examiner reproducibility was very good. In this study, the rendering process allowed even the measurement of small distances, a bone full of anatomical details and difficult to define, to be quite reliable. Even distances of less than 8 mm such as the distance between right Anterior Clinoid Process to left Anterior Clinoid Process and the distance between right Posterior Clinoid Process to left Posterior Clinoid Process could be easily reproduced at different times by different examiners.

It is important to mention that the anatomical details were easily evidenced on the surface of the sphenoid; the measurements observed, except for two, were greater in boys than in girls, revealing that the sphenoid, in this age group, is greater in boys. The discussion about this difference is beyond the scope of this work because it may involve hormonal, nutritional and other factors that were not evaluated in this study. Obviously, this study has limitations, among them, the small sample number, however, the craniometric analyzes combining the diagnostic method of Computed Tomography and the creation of three-dimensional rendered surfaces significantly improved the segmentation and reconstruction of the anatomical surfaces of the sectioned and processed images of the sphenoid bone and provided a possible high reproducibility and accuracy of measurements.

5. Conclusion

The reconstruction and rendering of the sphenoid bone using the Materialise Mimics software allowed the visualization of anatomical details and the craniometric measurements were easily performed. The use of the Materialise Mimics© software significantly improved the segmentation and reconstruction of the anatomical surfaces of the sphenoid bone and will serve as a basis for future research in which craniometric evaluation is necessary.

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