

# Bone Segmentation of a Human Vertebra Using the 3D Slicer Software: Technical-Methodological Contributions to Anatomy Teaching

Segmentación Ósea de una Vértebra Humana Mediante el Software 3D Slicer:  
Contribuciones Técnico-Metodológicas a la Enseñanza de la Anatomía

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**SUMMARY:** Human Anatomy education faces challenges related to the reduced use of cadavers, driving the adoption of complementary teaching strategies that promote active learning and integration with clinical practice. To describe, at a technical-methodological level, the feasibility of using the open-source software 3D Slicer as a complementary educational resource for teaching vertebral bone anatomy. A descriptive and exploratory study was conducted, involving bone segmentation of a human vertebra (L3) from computed tomography images using semi-automatic tools, manual refinement, and three-dimensional reconstruction, followed by 3D printing. Semi-automatic segmentation was effective for initial bone delineation but insufficient to ensure anatomical fidelity in complex structures, making manual refinement essential. Operational factors, such as learning curve, infrastructure requirements, and occasional software instabilities, affected workflow feasibility. 3D Slicer proved to be a viable complementary tool for teaching bone anatomy, supporting active learning, spatial understanding, and the integration of morphology with clinical practice, despite technical limitations.

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**KEY WORDS:** Human anatomy; Bone segmentation; Three-dimensional modeling; Anatomy education; 3D Slicer.

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## INTRODUCTION

Human Anatomy is a fundamental component in the education of health and biological science professionals, providing the indispensable morphological basis for understanding the human body and applying clinical knowledge (Siqueira-Neto & Ferreira, 2001). Traditionally, its teaching relies on books, atlases, physical anatomical models and, above all, on the use of human cadavers, with dissection being historically recognized as a central pedagogical strategy for understanding anatomical structures and their spatial relationships (Costa & Lins, 2012).

Despite its recognized educational value, in recent decades, there has been a reduction in active dissection, with a predominance of demonstrative approaches (Siqueira-Neto & Ferreira, 2001; Costa & Lins, 2012). This change is related, among other factors, to the scarcity of cadaveric specimens, the reduction in body donations, and bureaucratic and legal obstacles, a scenario aggravated by the expansion in the

number of higher education institutions (Almeida Neto, 2007, 2008). Added to this context is the repeated use of the same specimens over time, which can progressively compromise the integrity and quality of the anatomical structures available for study.

Given these limitations, the teaching of anatomy has increasingly incorporated complementary didactic resources—such as synthetic models, multimedia materials, and digital technologies—reinforcing the adoption of a multimodal teaching model that articulates physical and digital resources in the anatomical learning process (Costa & Lins, 2012). In this scenario, digital three-dimensional resources stand out, as they allow for greater student interaction with anatomical models, dynamic exploration of different planes and perspectives, and the understanding of complex spatial relationships, often represented two-dimensionally in atlases and textbooks.

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In addition to favoring spatial cognition, digital three-dimensional models expand student contact with anatomical and morphological variations and allow for direct integration with medical images widely used in clinical practice, such as computed tomography (CT) and magnetic resonance imaging (MRI). This integration contributes to a more applied approach to anatomy and to the approximation between anatomical teaching and clinical-radiological reasoning, benefiting the understanding of anatomical structures in sectional cuts and volumetric reconstructions (Pujol *et al.*, 2016).

In this context, the 3D Slicer software stands out, an open-source platform widely used for processing, visualizing, and analyzing medical images, which allows for the segmentation and three-dimensional reconstruction of anatomical structures from imaging exams in the DICOM standard (Zhang *et al.*, 2021; Dyaksa *et al.*, 2023). Its use is particularly relevant for the study of complex anatomical structures, such as the vertebral column, whose three-dimensional morphology and spatial relationships make its learning especially challenging in anatomy teaching (Pujol *et al.*, 2016).

Although 3D Slicer is widely cited in studies focused on the segmentation of anatomical structures for clinical and research purposes, exploratory surveys conducted on the CAPES Periodicals Portal indicated few records that explicitly associate 3D Slicer with the teaching of human anatomy, especially when bone segmentation is treated as a component of the pedagogical process.

Given this context, the present study aims to describe, at a technical-methodological level, the feasibility of using the 3D Slicer software as a complementary educational resource in the teaching of bone anatomy of the vertebral column, based on the process of bone segmentation of a human vertebra. To this end, the technical steps of segmentation in 3D Slicer are described, the obtained digital three-dimensional model is presented, and the potentialities and limitations of this process and its visual product as a support resource for anatomy teaching are conceptually discussed. It is emphasized that the study does not aim to evaluate the replacement of traditional teaching based on the use of cadavers, or to perform formal educational evaluation.

## MATERIAL AND METHOD

Based on the proposed objective, a descriptive and exploratory methodological design was adopted, aimed at the technical characterization of the bone segmentation process and digital three-dimensional reconstruction of a human vertebra in the 3D Slicer software, version 5.10.0 (3D Slicer, s.d.). The study aims to describe the technical procedures involved, and does not propose to evaluate the pedagogical impact nor the formal educational validation of the generated model.

The segmentation was performed using thoracic and abdominal CT images in DICOM format, obtained from the institutional educational repository MedDream (DICOM Library, s.d.) (Fig. 1).



Fig. 1. Interface of the institutional educational repository MedDream. Note: Available at MedDream viewer

The submission to the Research Ethics Committee was waived because it is an educational repository and the data was previously anonymized, with no possibility of individual identification. Image processing and 3D reconstruction were performed using the 3D Slicer software, utilizing the Segment Editor and Volume Rendering modules. The methodological procedure comprised the following steps:

1. Importing the DICOM files into the software environment;
2. Delimiting the region of interest in the vertebral column and volumetric visualization (Volume Rendering), with a rendering preset for bone structures (Bone);
3. Initial semi-automatic segmentation using the Threshold tool (Segment Editor module), applying a density range between 140 and 1669 HU (Hounsfield Units), aiming to isolate the bone tissue;
4. Manual refinement of the margins and correction of artifacts to ensure the anatomical fidelity of the model;
5. Isolation of the target vertebra using the Scissors tool (Erase inside mode), removing unwanted adjacent structures;
6. Generation and export of the digital three-dimensional model of the vertebra.

For the segmentation process, a desktop computer with an Ryzen 8700G processor, 64GB of DDR5 RAM (Random Access Memory), a 1TB SSD, and an AMD RX 6800 GPU with the Linux Mint 22 Cinnamon operating system was used. Additionally, a Gaomon brand graphics tablet was employed, with an active workspace area of 16.51 cm × 10.16 cm, image resolution of 10,160 dpi, 8,192 levels of pressure sensitivity, multi-touch support, four shortcut keys, and a reading speed of 266 pps. This tool was used to replace the mouse, with the objective of providing greater precision and control during the segmentation process, favoring a more accurate delimitation of the anatomical structures.

The segmented model was printed with the objective of validating and enabling the tactile and spatial analysis of the vertebral anatomy. For this, the final segmented mesh was exported from the 3D Slicer software in STL format (Standard Triangle Language - standard mesh format for 3D printing). The file was submitted to the slicing process using the UltiMaker Cura software (version 5.11.0). Additive manufacturing was performed on the Creality Ender 3 v2 3D printer, using PLA (Polylactic Acid) filament as the deposition material.

## RESULTS AND DISCUSSION

### Characterization of the tool used

3D Slicer is an open-source platform widely used for processing, visualizing, and analyzing medical images, offering advanced tools for three-dimensional reconstruction and segmentation of anatomical structures from imaging exams (Fedorov *et al.*, 2012). It is a consolidated software in the health area, used in clinical and research contexts, especially in studies that require volumetric manipulation and detailed analysis of complex anatomical structures.

Among its main technical features, its compatibility with major operating systems (Windows, Linux, and macOS), the possibility of expansion through extensions and plugins, support for programming languages such as Python, and integration with artificial intelligence algorithms stand out, which expands its flexibility and potential application (Virzì *et al.*, 2020; Zhang *et al.*, 2024). Furthermore, the software has an active community of users and developers, which contributes to its continuous updating and the availability of tutorials and support materials.

Regarding bone segmentation specifically, the recognition of 3D Slicer stems from the combination of support for consolidated medical imaging standards, especially the DICOM format, and the availability of dedicated tools for segmentation and refinement of anatomical structures. This combination allows for the effective processing of CT and MRI, modalities widely used in clinical practice due to high spatial resolution and adequate contrast between bone and soft tissues. The software provides different segmentation approaches — manual, semi-automatic, and automatic — including thresholding methods based on Hounsfield units, region growing algorithms, and the Segment Editor module, which offers refinement tools, such as Paint and Erase, fundamental for ensuring the anatomical congruence of the reconstructed models (DenOtter & Schubert, 2025; Lang *et al.*, 2025).

In addition to its technical robustness, the free and open-source nature of 3D Slicer significantly expands access to advanced medical image processing tools, especially in educational contexts and in institutions with budgetary constraints. This accessibility sustains its relevance as a support tool for anatomy teaching, by enabling the use of sophisticated technological resources without the need for high investments in proprietary software.

### Characterization of the bone segmentation process

The bone segmentation process enabled the

generation of a three-dimensional model of the L3 vertebra with adequate morphological representation of the main anatomical structures in the initial segmentation step. The application of semi-automatic tools provided by the 3D Slicer software proved effective for the initial delimitation of the bone tissue from the CT images, allowing the identification of the vertebra of interest in the volumetric dataset.

In the obtained digital model, it was possible to clearly individualize the vertebral body, the vertebral arch — composed of the pedicles and laminae —, as well as the spinous, transverse, and articular processes, preserving the geometry of the vertebral foramen. These findings indicate that the segmentation process was able to satisfactorily represent the bone morphology of the L3 vertebra, enabling its detailed three-dimensional analysis (Fig. 2). The choice of L3 is justified by its typical lumbar morphology and central position, making it a representative model for structural analysis without the particularities of transitional vertebrae (L1 and L5).

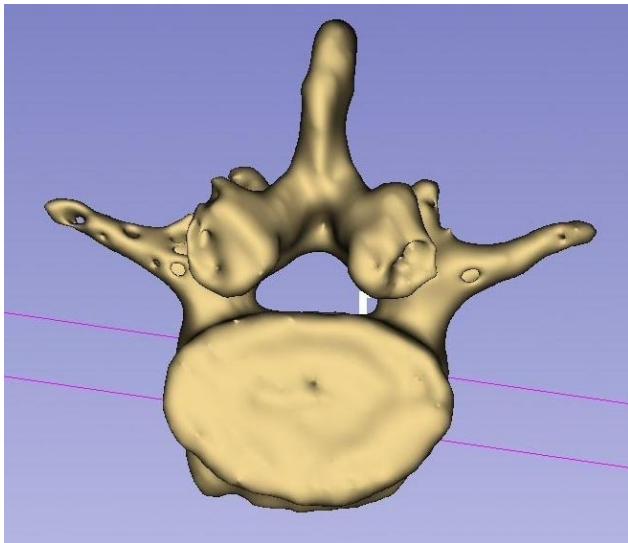


Fig. 2. Superior view of the L3 vertebra. Note: Segmented in the 3D Slicer software, showing the integrity of the articular, spinous, and transverse processes.

Although the initial segmentation allowed for the adequate identification of the main bone structures, subsequent refinement steps were necessary to ensure greater morphological integrity of the final three-dimensional model.

#### Limitations of the semi-automatic component and the need for manual refinement

The semi-automatic tools available in the 3D Slicer software proved effective in the initial delimitation of the bone structure; however, manual refinement was

indispensable to obtain a three-dimensional model with greater anatomical fidelity. For this step, the Scissors segmentation tool was used, which allowed the precise delimitation of the bone edge, the correction of imperfections, and the removal of artifacts and residual tissues improperly captured by the initial algorithm.

During the segmentation process, limitations of the semi-automatic component were identified regarding the integral recognition of the analyzed anatomical structure, resulting in discontinuities on the bone surface and the presence of gaps ("holes") in the segmented model. These artifacts were observed, especially in regions of lower bone density, such as porous bone, where the thresholding algorithm was unable to adequately identify the tissue of interest. This limitation is related to the fact that threshold-based methods tend to prioritize the delimitation of the cortical surface, showing lower performance in areas with density variation or structural fragility (Argüello *et al.*, 2019; Mandolini *et al.*, 2022).

These findings corroborate that, in the analyzed context, bone segmentation cannot be conducted in a totally automated manner, since semi-automatic methods prove efficient as an initial step, but insufficient when used in isolation, especially in complex anatomical structures such as human vertebrae (Argüello *et al.*, 2019). This finding is consistent with the literature, which points out limitations of these methods in regions of greater morphological complexity, although satisfactory results can be obtained in less complex structures, such as long bones, depending on the method employed (Rathnayaka *et al.*, 2011).

#### Software stability and impact on workflow

During the execution of the bone segmentation process in the 3D Slicer software, specific operational instabilities were observed, impacting the technical workflow. These instabilities manifested as unexpected software interruptions, occasionally requiring the environment to be restarted and previously performed steps to be repeated. Such occurrences did not compromise the final quality of the three-dimensional model obtained but did increase the total time required to complete the segmentation process.

These findings indicate that the practical feasibility of using digital tools for anatomical segmentation does not depend solely on the quality of the medical images or the user's technical proficiency, but also on the stability and reliability of the computational platform employed. In activities involving multiple sequential steps — such as semi-automatic segmentation, manual refinement, and three-

dimensional model export — software interruptions can fragment the workflow and demand technical rework.

In the educational context, although this study does not aim to evaluate the pedagogical impact of using the software, such operational limitations deserve consideration, as they can influence the organization and planning of practical activities based on digital technologies. The adoption of stable and adequately configured software is, therefore, a relevant aspect for the efficient implementation of educational strategies that use segmentation and three-dimensional visualization of anatomical structures as a complementary resource for anatomy teaching.

### Segmentation time and technical requirements

The total time spent for the segmentation process was approximately five hours, of which about three hours corresponded to the familiarization stage with the interface, functionalities, and operational logic of the 3D Slicer software, while approximately two hours were dedicated to the actual segmentation of the L3 vertebra. This finding highlights that the software's learning curve is a relevant factor to be considered, especially when discussing its application in educational contexts.

Previous studies corroborate this observation by indicating that novice users need to invest significant time to acquire proficiency in using 3D Slicer and its segmentation tools (Zhang *et al.*, 2024). Furthermore, segmentation time is influenced by multiple factors, including the complexity of the anatomical structure analyzed, the performance of the semi-automatic component, and the need for subsequent manual interventions (Pujol *et al.*, 2016). In this regard, Dot *et al.* (2024), report that manual bone segmentation processes can demand between two and five hours, values compatible with those observed in the present study.

These results reinforce that, although semi-automatic tools contribute to accelerating the initial delineation of structures, the total process time remains strongly conditioned by the manual refinement stage. This finding has driven the development of methods based on deep learning, aimed at partial or total automation of bone segmentation, with the potential to reduce execution time (Dot *et al.*, 2024). Even so, even in more advanced approaches, manual validation remains essential to ensure the anatomical quality of the generated models (Heckelman *et al.*, 2022).

Regarding technical requirements, the need for

equipment with adequate graphic processing capacity and visual resolution was verified for the efficient execution of the segmentation and three-dimensional visualization stages. The use of a digitizing tablet proved to be particularly relevant during manual refinement, as the exclusive use of the mouse presented limitations regarding the precision and fine control of the interventions performed.

Similarly, Zhang *et al.* (2024), highlight that 3D Slicer demands relatively robust hardware to handle large volumes of data and complex computational operations, which can be a limiting factor for its use in environments with restricted technological infrastructure. These aspects highlight the importance of considering not only the functional potential of the software but also the technical conditions necessary for its effective implementation.

### Filters, parameters, and visual quality of the three-dimensional model

In the context of three-dimensional bone segmentation, the limitations associated with the use of automatic filters become particularly relevant in bone regions, where the preservation of precise contours is fundamental for anatomical integrity and for educational and clinical applications (Dyaksa *et al.*, 2023). These authors highlight the contribution of filters such as Fill Holes and Median for noise reduction and improvement of the visual quality of the segmentation.

However, in the present study, it was decided not to apply smoothing or automatic segmentation enhancement filters, since such resources can alter the real boundaries of bone structures and compromise the geometric accuracy of the three-dimensional model. This methodological decision prioritized the preservation of the original vertebra geometry over any aesthetic gains resulting from automated post-processing.

Instead of automatic filtering processes, a rigorous visual inspection was adopted using the CT-Bone volumetric rendering preset. This configuration allowed the segmented mask to be contrasted directly over the original volumetric reconstruction, facilitating the identification of discrepancies and favoring the maintenance of the anatomical fidelity of the model without the need for interventions that could modify its real dimensions (Figs. 3 and 4).

This approach prioritized qualitative visual validation of anatomical congruence, in line with the technical-methodological nature of the study.

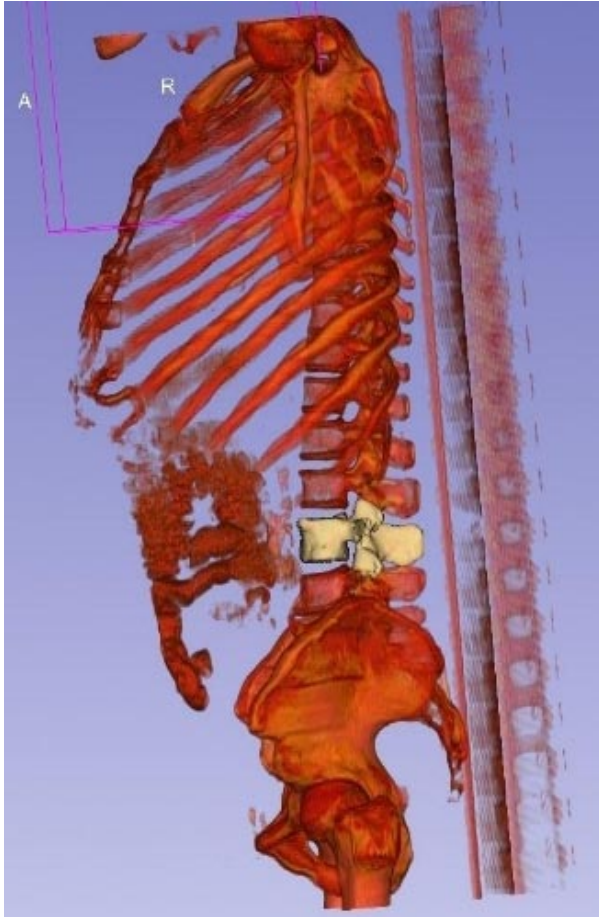


Fig. 3. Volumetric rendering (Volume Rendering) of the lumbar spine evidencing the segmentation of L3 in situ (A) and the isolated model (B)

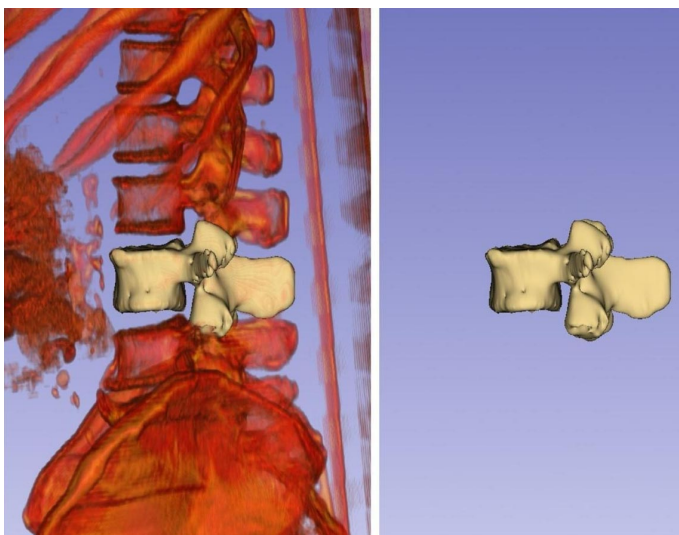


Fig. 4. Visual validation of the segmentation and isolation of the model. On the left, the segmented L3 vertebra (beige) is superimposed on the volumetric rendering (CT-Bone preset) of the lumbar spine for verification of anatomical congruence and detection of failures. On the right, the final three-dimensional model of the isolated L3 vertebra.

### Educational implications of using 3D Slicer and the segmentation process

In the search strategy adopted, the combination of the terms '3D Slicer', 'bone segmentation' and 'education' returned a reduced number of results, suggesting a gap in the literature regarding the investigation of the use of the bone segmentation process itself, based on real medical images, as a didactic strategy in teaching complex structures, such as human vertebrae.

The results of this study demonstrate that the bone segmentation process in the 3D Slicer software requires students to have prior anatomical knowledge, consult reference materials, and make continuous decisions while delimiting the structures. Unlike approaches based on the use of previously prepared three-dimensional models, this study proposes segmentation as a formative activity in itself, in which the student actively participates in the process of building the anatomical model. In this active involvement, the student ceases to act as a passive observer and progressively constructs the object of study, reinforcing the tool's potential as a complementary educational resource in anatomy teaching.

The use of CT images as a basis for segmentation additionally contributes to the integration between anatomy teaching and clinical practice, by exposing the student to exams widely used in healthcare. This approximation favors the development of applied anatomical reasoning, expanding the spatial understanding of structures and their correspondence with radiological findings, as described by Pujol *et al.* (2016), especially in the three-dimensional recognition of anatomical relationships and their representation in sectional slices.



Fig. 5. Biomedical model of the L3 vertebra. Note: Materialized through 3D printing, allowing for tactile and three-dimensional analysis of the anatomical structure.

Additionally, the export of the segmented mesh in STL format and its materialization through 3D printing allowed the obtainment of a physical biomodel faithful to the anatomy of the segmented vertebra (Fig. 5). The possibility of materialization expands the didactic potential of the resource, by enabling the tactile and three-dimensional exploration of the anatomical structure, as well as its reuse, reproduction, and adaptation in different educational contexts, reinforcing the complementarity between digital and physical resources in the teaching-learning process.

The segmentation process can be understood as a form of learning through the development of task-based learning. In this regard, Lopes Jr. (2022) and Keshmiri & Mehrparvar (2023) highlight that the Task-Based Learning (TBL) methodology proves to be a fundamental pedagogical approach for the development of complex competencies, by articulating theoretical knowledge with practices oriented toward problem-solving. By focusing on authentic tasks, task-based learning promotes motivation, autonomy, and knowledge transfer, in addition to favoring the consolidation of content and optimizing formative feedback. Together, these findings indicate that 3D Slicer is configured as a relevant complementary didactic resource in the teaching of human anatomy, by promoting active learning, integrating anatomical knowledge with clinical practice, and expanding didactic possibilities through digital segmentation and 3D printing.

## CONCLUSION

This study technically and methodologically described the bone segmentation and three-dimensional reconstruction of a human vertebra (L3) in 3D Slicer based on CT images. Semiautomatic tools allowed for the initial delimitation and the obtainment of a model with adequate morphological representation, but manual refinement proved indispensable to ensure greater morphological integrity and anatomical fidelity.

The observed limitations—need for manual interventions, time demand, learning curve, infrastructure requirements, and occasional instabilities—indicate that the applicability of the workflow depends on both the method and the operational conditions. Although quantitative metrics were not applied in this exploratory study, future work may adopt this approach. Still, the results support 3D Slicer as a complementary didactic resource, due to the three-dimensional product and the segmentation process as an active learning activity, which can be enhanced by future educational assessments and by advances in segmentation process automation and interface usability, reducing rework, the learning curve, and technical barriers to pedagogical use.

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**RESUMEN:** La enseñanza de la anatomía humana se enfrenta a desafíos relacionados con la disminución del uso de cadáveres, lo que impulsa el uso de estrategias didácticas complementarias que promuevan el aprendizaje activo y la integración con la práctica clínica. Describir, a nivel técnico-metodológico, la viabilidad del uso del software de código abierto 3D Slicer como recurso educativo complementario para la enseñanza de la anatomía ósea vertebral. Se realizó un estudio descriptivo y exploratorio que incluyó la segmentación ósea de una vértebra humana (L3) a partir de imágenes de tomografía computarizada mediante herramientas semiautomáticas, refinamiento manual y reconstrucción tridimensional, seguida de impresión 3D. La segmentación semiautomática fue eficaz para la delineación ósea inicial, pero insuficiente para garantizar la fidelidad anatómica en estructuras complejas, lo que hizo esencial el refinamiento manual. Factores operativos, como la curva de aprendizaje, los requisitos de infraestructura y las inestabilidades ocasionales del software, afectaron la viabilidad del flujo de trabajo. 3D Slicer demostró ser una herramienta complementaria viable para la enseñanza de la anatomía ósea, apoyando el aprendizaje activo, la comprensión espacial y la integración de la morfología con la práctica clínica, a pesar de las limitaciones técnicas.

**PALABRAS CLAVE:** Anatomía humana; Segmentación ósea; Modelado tridimensional; Educación anatómica; 3D Slicer.

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