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Acetabular version angle measurement in 3D vs. 2D models using computed tomography images in patients with coxarthrosis. A single-center observational study.

Carlos Jacinto Valle Ochoa [1] ID *, Carlos Paul Villalba Meneses [1] ID, Stalin Santiago Celi Simbaña [2] ID, Paola Gonzalez Pazmiño [2] ID *, Carmen Navas Palma [2] ID, Jean Carlos Gallo Valverde [2] ID

1. Imaging Service, Alcívar Hospital, Guayaquil, Ecuador.
2. Postgraduate Department of Imaging, International University of Ecuador, Guayaquil-Ecuador.

Imaging

Abstract

Introduction: In Ecuador, approximately 70% of the inhabitants present coxarthrosis, whose treatment in advanced stages is total hip arthroplasty, which, because of its correct location, requires the measurement of the acetabular anteversion angle. The present study compares the 3D method (gold standard) vs. 2D method for measuring this angle.

Methods: This was an analytical, retrospective observational study. Based on the STROBE guide.

Results: Arithmetic means 3D right hips: 17.2 gr VS 2D: 16.4 gr; 3D left hips: 18.7 gr VS 2D: 18.9 gr; Student's t-test P value right hip 0.68 and left hip 0.92. The results of the weighting coefficient Spearman's right hips 3D vs. 2D weak classification; 3D vs. 2D left hips moved moderately to strongly, as demonstrated by scatter plots.

Conclusions: There was a difference in the arithmetic means between the 3D and 2D methods; the results of both methods were significantly different, with an ascending and linear trend that was directly proportional.

Keywords:

MeSH: acetabular anteversion angle, 3D model, 2D model, computed tomography.

Abbreviations

RH: Right hip. LH: Left Hip.

Supplementary information

No supplementary materials are declared.

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Author contributions

Carlos Jacinto Valle Ochoa: Conceptualization, data curation, formal analysis, acquisition of funds, research, writing - original draft.
Paul Villalba Meneses: Fund acquisition, Research, writing - original draft.
Stalin Santiago Celi Simbaña: Acquisition of funds, Research, writing - original draft.
All the authors read and approved the final version of the manuscript.

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Introduction

Degeneration of the coxofemoral joints represents a highly prevalent pathology worldwide as it progresses and requires total hip arthroplasty as a long-term treatment [1].

In Ecuador, it is estimated that approximately 70% of the inhabitants radiologically exhibit some degree of coxarthrosis, but the symptoms are evident in only a proportion of these patients [2].

Additionally, symptomatic hip osteoarthritis is prevalent in 58.5-year-old individuals (25%) [3].

As the degeneration of joint structures in patients with hip osteoarthritis progresses, the condition becomes increasingly symptomatic and limiting for patients who are directed to seek medical treatment ranging from analgesia to hip arthroplasty [4].

In advanced stages of coxarthrosis, the most efficient therapeutic option is total hip arthroplasty, which is generally associated with positive results concerning symptoms, stability, durability of the joint replacement, range of motion, and rehabilitation [5].

Total hip arthroplasty represents an extensive, complex surgery from a technical point of view. The orthopedist and his surgical team must control several details for proper performance. Within these sections, we considered the rotation angles of the different prosthetic components, which impact the mechanics of the patient's ambulation and the final postsurgical results [6].

The angles of rotation of these components and their correct measurement are part of the surgical planning of the orthopedic surgeon, who works together with the imaging department to, through different techniques, achieve the most appropriate approach to the values sought through noninvasive methods. Invasive procedures before surgery [3].

In particular, malpositioning of the acetabular cup during hip arthroplasty has been associated with adverse postsurgical outcomes, especially with an increased risk of dislocation of the femoral component of the prosthesis [7], increased wear of the prosthetic components [8, 9], dysmetria, limb rotation [10] and chronic pain when walking [8], factors that harm the revision rate [11].

Reports suggest that 48% of hip revision surgeries result from malpositioning of the prosthesis's acetabular component and, therefore, could have been avoided [2].

In response to this need, several radiological procedures have been developed to measure acetabular orientation before surgery; all of these methods have focused on the use of bioimages of the hip.

Correct positioning of the acetabular component of the hips is one of the most critical stages affecting the stability and wear rate of prosthetic components. Different methods have been described for determining the anteversion angle of acetabular cups. However, there has yet to be a widely accepted consensus regarding the correct technique for evaluating acetabular anteversion [4] because the methods described here estimate the angles of interest but have low intra- and interobserver reproducibility.

The initial methods for measuring the inclination of the acetabular angle involved simple radiographs, which are the standard procedure for measurement; however, radiographs need to provide additional information about the orientation of the acetabulum in the sagittal and transverse planes [5].

In recent years, more than twenty protocols have been developed for measuring the acetabular anteversion angle in images obtained via computed tomography. These images allow for more adequate postprocessing of the photos and have improved the measurement of the acetabular anteversion angle. However, these methods still maintain a low rate of reproducibility. In recent years, 3D reconstructions have been used to measure the acetabular anteversion angle directly on reconstructed anatomical pieces [12], suggesting that this approach is the gold standard measurement method.

The present work compares 3D reconstructions (the gold standard) with 2D multiplanar reconstructions enhanced by pelvic tilt correction using standard anthropometric measurements of 64 and 68 degrees for male patients. The female-known PS-SP line was measured by the Head of the Imaging Department of the Alcivar Hospital, Dr. Carlos Valle Ochoa, in a previously published work [11]. This technical consideration has yet to be formerly used or described since it uses measurements from anthropometric sciences as a reference [13, 14]; this anatomical position correction allows the correct pelvis placement to be measured and positively impacts obtaining more precise results. The acetabular anteversion angle was assessed, providing an original and unpublished approach for estimating the acetabular anteversion angle.

The objective of this study was to observe the precision and reproducibility of the results of the compared measurement methods.

Materials and methods

Study design
This was an analytical, observational, and retrospective study. The results are based on the recommendations of the STROBE guide.

Study hypothesis:
Measuring the acetabular anteversion angle using 2D multiplanar reconstructions with pelvic tilt correction did not significantly differ in precision compared to the gold standard method (measuring the acetabular anteversion angle in 3D segmentation images).

Null Hypothesis:
Measuring the acetabular anteversion angle using 2D multiplanar reconstructions with pelvic tilt correction significantly differed in precision compared to the gold standard method (measuring the acetabular anteversion angle in 3D segmentation images).

Sample size:
Nonrandom, nonprobabilistic sampling was used, with type selection at convenience, since all the images from computed tomography studies of the bilateral pelvis and hip performed in the diagnostic imaging department of the Alcívar Hospital during the first quarter of 2023 were included.

Examinations were performed using a 128-detector Philips Incisive CT spiral computed tomography scanner with the following parameters: slice thickness of 5 mm, pitch of 2.0, reconstruction at 2 mm, 250 mA, 120 kVp, and a 500 × 500 mm matrix.

Inclusion criteria:
Images of bilateral CT scans of the hip and pelvis performed at Hospital Alcívar during the 1st quarter of 2023 in patients who did not have a hip prosthesis.

Exclusion criteria:
Images of unilateral hip and pelvis CT scans performed at Hospital Alcívar during the 1st quarter of 2023.

Images of CT scans of the hip and pelvis performed at Hospital Alcívar during a period other than the 1st quarter of 2023.

CT images of the hip and pelvis were acquired at Hospital Alcívar in a period other than the 1st quarter of 2023, which were not bilateral.

Images of CT scans of the hip and pelvis performed at Hospital Alcívar of a patient with a hip prosthesis.

Data sources/measurements
The PACS files of the Alcívar Clinic were used, from which the images were obtained in DICOM files for review, respective reformatting, and measurement of the acetabular anteversion angle.

Biases
The primary bias of the present work is sampling bias because random selection was not carried out due to a limitation in the number of available studies of the bilateral hip and pelvis performed during the evaluation period in the imaging department of Clínica Alcívar. However, at convenience, all available imaging studies that met the inclusion criteria were selected for analysis.

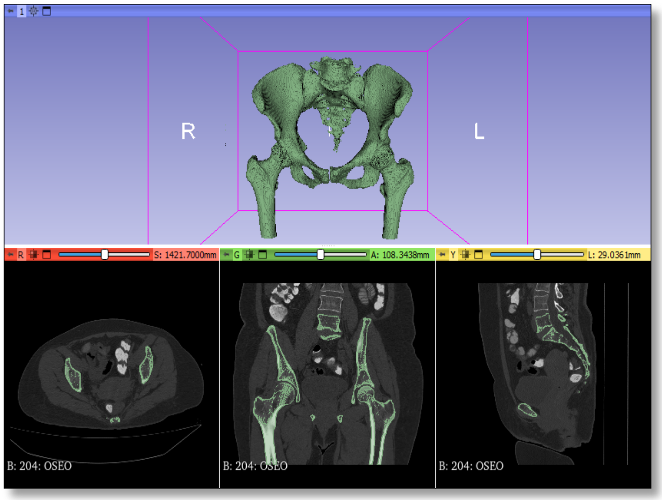
General objective
The correlation between the precision of the results obtained by measuring the acetabular anteversion angle in 3D segmentation images and that obtained by 2D multiplanar reconstructions with pelvic tilt correction was determined.

Participants
Imaging files from bilateral pelvis or hip computed tomography studies performed at the Alcívar Hospital in the City of Guayaquil during the 1st quarter of 2023.

Bioethical Declaration
The images used were anonymized to protect patient data, and all bioethical criteria were respected during the development of this work.

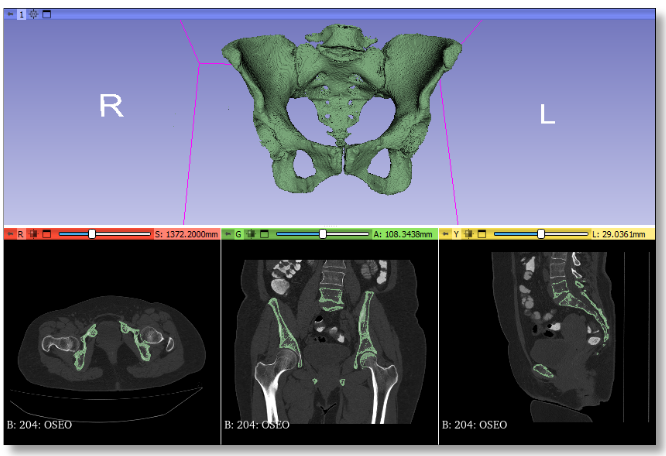
Test methods
1) The acetabular anteversion angle was measured according to Barlow's protocol. The "true" acetabular anteversion angle.
1. The bone structures of the pelvis were globally segmented using 3D Slicer software. Tested version 5.2.2. Free, open-source software was distributed under a BSD-style license (Figure 1).
2. The bilateral femurs were digitally subtracted (Figure 2).
3. The contour of the acetabular crest was delineated, and the plane of the acetabulum was defined (Figure 3).
4. The plane of the anterior pelvis (right anterosuperior iliac spine (ASIS), left anterosuperior iliac spine (ASIS), and pubic tubercle (Figure 4) were defined.
5. The angle α was calculated, and the 90-degree minus angle α (PITCH) was subtracted to obtain the acetabular anteversion angle (Figure 5).

Figure 1 . Step 1: Global segmentation.



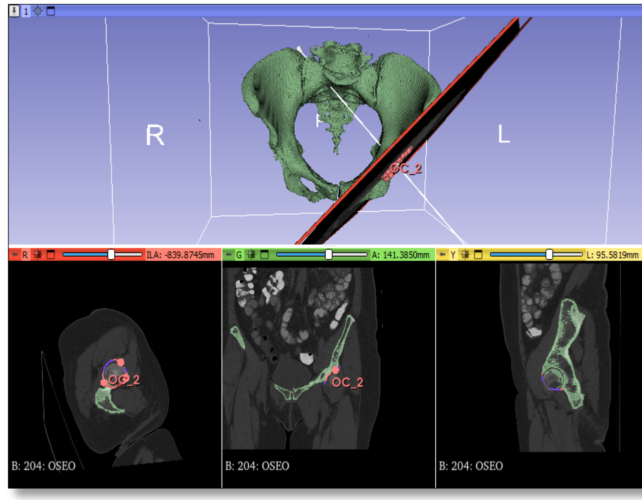
Description: Global segmentation of the bone structures of the pelvis using 3D Slicer software. Tested version 5.2.2. Free, open-source software was distributed under a BSD-style license.

Figure 2. Step 2: Digital subtraction.



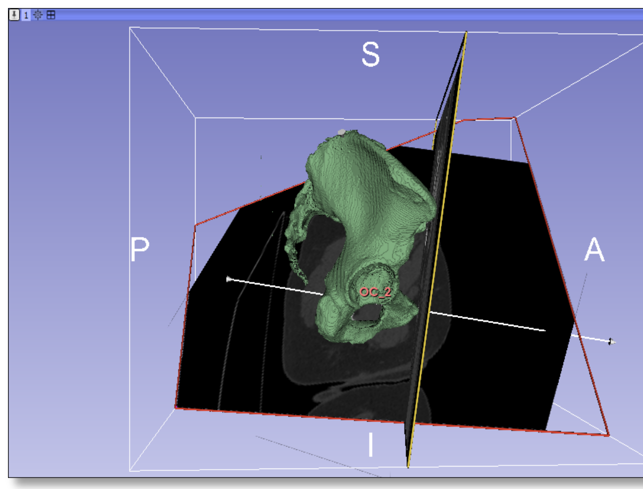
Description: Digital subtraction of the bilateral femur was performed using 3D Slicer software. Tested version 5.2.2. Free, open-source software was distributed under a BSD-style license.

Figure 3. Step 3: Delineation of the contour of the acetabular crest



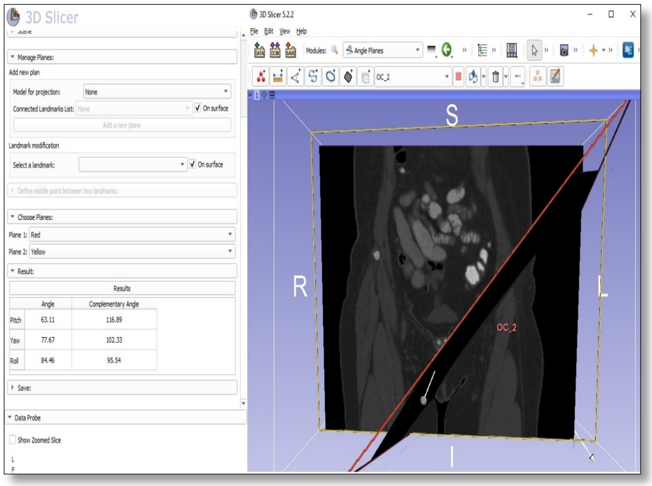
Description: Delineate the acetabular crest's contour and define the acetabulum's plane using 3D Slicer software. Tested version 5.2.2. Free, open-source software was distributed under a BSD-style license.

Figure 4. Step 4: Definition of the plane of the anterior pelvis.



Description: The plane of the anterior pelvis (right anterosuperior iliac spine (ASIS), left anterosuperior iliac spine (ASIS), and pubic tubercle) was defined using 3D Slicer software. Tested version 5.2.2. Free, open-source software was distributed under a BSD-style license.

Figure 5. Step 5: Calculation of the angle **α**.

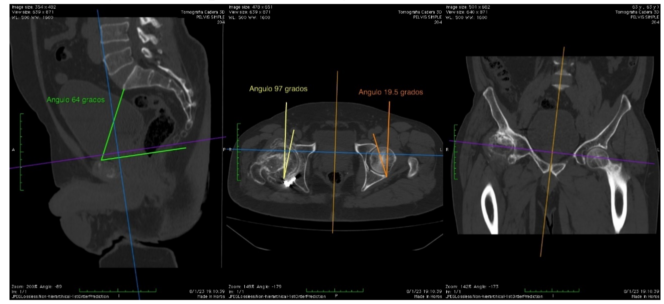


Description: The angle α was calculated, and the 90-degree minus angle α (PITCH) was subtracted to obtain the acetabular anteversion angle using 3D Slicer software. Tested version 5.2.2. Free, open-source software was distributed under a BSD-style license.

2) The acetabular anteversion angle was measured according to Dr. Carlos Valle Ochoa's protocol. (Pelvic tilt correction through anthropometric angulation (PS-SP line).

1. Multiplanar reconstruction of images obtained from the pelvis and hip axial sections.
2. The medial, transverse, and sagittal axes were corrected in the reconstructed planes.
3. The inclination of the sagittal axis was corrected through correction of the pelvic inclination angle, with anthropometric angulation values (PS-SP line) of 64 degrees in men and 68 degrees in women; the image on the sagittal axis shows the promontory and pubic symphysis.
3. Coronal axis correction, through horizontal and vertical axis inclination, in an image that shows the head of the femur ±4. Axial axis correction through horizontal and vertical axis inclinations in a picture that shows the bilateral femur head.
5. The acetabular anteversion angle was calculated between the line corresponding to the sagittal plane and the line drawn tangential to the anterior and posterior edges of the acetabulum (Figure 6).

Figure 6. The acetabular anteversion angle was measured according to Dr. Carlos Valle's protocol. (Correction of pelvic tilt through anthropometric angulation (PS-SP line)).



Description: Multiplanar reconstruction for measurement of the acetabular anteversion angle with pelvic tilt correction.

Statistical methods

The following statistics were applied to the free access software: Microsoft Excel 2010 and InfoStat version 2020. For the postprocessing of 3D images, segmentation, and measurement of the 3D acetabular anteversion angle, free s3D Slicer software was used. Tested version 5.2.2. Free, open-source software was distributed under a BSD-style license. Horos software was used for the postprocessing of 2D images and measurement of the acetabular anteversion angle. Version 3.0.

The epidemiological analysis of the participating population was carried out using measures of central tendency, such as the mean, mode, and median, and measures of dispersion, such as the standard deviation.

A comparative analysis of the results obtained from measurements using 3D vs. 2D methods will be carried out using central tendency and dispersion measures as standard deviations.

The hypothesis test will be carried out by applying the Student's t-test for independent means, with an α level of statistical significance of 0.05.

The correlation between 3D and 2D measurements was established by measuring Sperman's correlation coefficient.

Scatter plots that compare the values obtained using a 3D vs 2D measurement method.

Results

Epidemiological analysis of patients who underwent bilateral pelvis or hip CT scans during the first quarter of 2023. The age was 59.5 ± 18.6 years (Table 1). There were 18 men (42.9%) and 24 women (51.7%). There were 4/38 (9.6%) patients with prostheses. There were 27 bilateral studies (62.3%) and 15 unilateral studies (37.7%).

Table 1 . Patient age ranges.

Age ranges	N=42	%
<30 years	4	9.70%
30 to 60 years	16	38.0%
61 or more	22	52.3%

Analysis of anteversion angles.

A comparative analysis of the results obtained via 3D measurements and the 2D method using central tendency and dispersion measurements is presented in Table 2. The two methods had no significant differences (Table 2). The Spearman correlation coefficient is shown in Table 3. The most considerable correlation occurred in the anterversion angle in the left hip (Figure 7).

Table 2. Measurements of central tendency and dispersion of the results of Acetabular Anteversion Angles, 3D and 2D methods.

anteversion angle	2D N=27	3D N=27	*P*
RH	18.9±6.9	18.7±9.4	0.9254
LH	16.4±6.1	17.2±7.9	0.6870

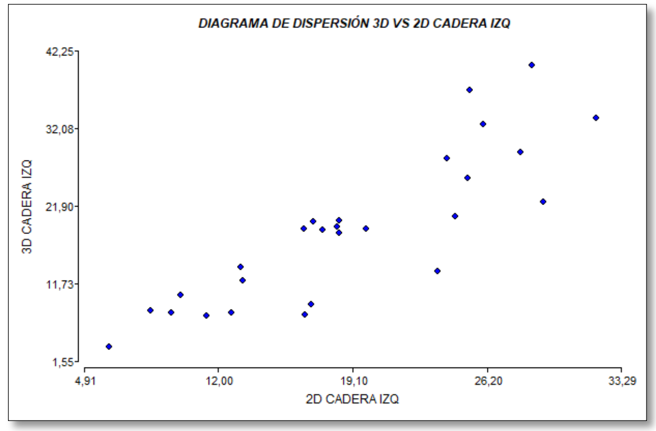
RH: Right hip. LH: left hip.

Table 3. Correlation between 2D and 3D studies.

anteversion angle	2D-3D N=27	*P*
RH	0.68	<0.01
LH	0.48	<0.05

RH: Right hip. LH: left hip.

Figure 7. Dispersion angles of acetabular anteversion in the 3D and 2D left hips.



Discussion

Several methods have been developed for measuring the acetabular anteversion angle in recent years, with various measurement protocols and similar results [15- 20]. However, the main problem of all the methods described is the poor reproducibility of their results. Both intraobserverally and over time, this characteristic has led to several solutions being sought worldwide to address this problem [15]; one of the most recent perspectives is the measurement of the acetabular version or anteversion angle using 3D segmentation models. Evidence shows these are the most reproducible methods and have been positioned as the current gold standard techniques [16].

However, these options are technically complex and involve more time-consuming postprocessing of DICOM images than classical 2D measurement methods.

In this study, the segmentation of hip images was achieved according to validated 3D protocols. However, we agree with Barlow et al. that these methods require more time to execute (approximately 30 minutes per patient) and can be considered their main drawback; in this section, the most significant advantages of the multiplanar reconstruction method combined with pelvic tilt correction can be achieved in less time (approximately 5 minutes per patient), especially given its precision.

On the other hand, we highlight the scientific importance of the results obtained in this work since acquiring knowledge of image segmentation provides a broader range of possibilities for radiologists and orthopedists in surgical preparation before a joint arthroplasty is performed [17] since segmented images allow more varied interactions with patient photos, including printed 3D models of actual size, with which surgical planning could be carried out on real-size models safely for patients at the forefront of current radiodiagnosis methods in first-world countries.

On the other hand, when acquiring the knowledge of segmentation of 3D tomography images, it was essential to understand the knowledge of vectors and navigation angles known in aeronautics, such as PITCH, YAW, and ROLL, which allow locating vectors in the 3D space of the segmented structures. These angles have yet to be described in previous studies related to the correct location of the acetabular component during hip arthroplasty. This opens new and exciting lines of research based on these angles, which could provide more data for an adequate location of prosthetic components, allowing innovation in their use and clinical application for the benefit of our patients.

Considering the limitations of the present study, we highlight the need to expand the sample size in future works to obtain data closer to the representation of the population of patients who need planning before hip arthroplasty; these findings will reinforce the statistical results already observed, and will provide additional details about this group of patients.

In the future, DICOM bioimage postprocessing methods are expected to evolve and will allow the necessary and more specific measurements to be more accessible; however, with the application of artificial intelligence models, postprocessing methods dominated by radiologists could become automated, overcoming the main current problem of 3D image segmentation and turning this method into a more accessible method for the general public, benefiting from the precision and reduction of complications for orthopedic surgeons when performing arthroplasties.

Furthermore, teamwork between medical specialties such as imaging and orthopedics is enjoyable since it provides a broader overview of the patient, which allows us to achieve more complex, precise, and integrated technical results, benefiting our patients.

Conclusions

In summary, there is a difference in arithmetic means between the 3D and 2D methods; however, the results of both methods are significantly correlated with an ascending and linear trend that is directly proportional.

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Editor's Note

Statements

Ethics committee approval and consent to participate

The ethics committee of the Alcívar Hospital approved the study.

Publication consent

Permission is obtained for the publication of tomography scans by patients admitted to the study.

Conflicts of interest

The authors declare that they have no conflicts of interest.

Author information

Carlos Jacinto Valle Ochoa is a doctor in medicine and surgery from the University of Guayaquil (Guayaquil, 2002) and a specialist in imaging from the University of Guayaquil (2007). Team member and technical director of the Imaging Service, Hospital Alcívar, Guayaquil, Ecuador.
Email: drcvalleo@hotmail.com
ORCID https://orcid.org/0009-0009-2509-2136

Carlos Paul Villalba Meneses is a doctor from the Central University of Ecuador (Ecuador, 2014). Specialist in Imaging from the University of Guayaquil (2023). Member of the Imaging Service Team, Alcívar Hospital, Guayaquil, Ecuador.
Email: paulvm_89@yahoo.com
ORCID https://orcid.org/0000-0001-6459-9823

Stalin Santiago Celi Simbaña, Doctor from the Central University of Ecuador (Ecuador, 2017). The patient was a postgraduate doctor in imaging from the International University of Ecuador, Guayaquil, Ecuador.
Email: ssantiago.celi19@gmail.com
ORCID https://orcid.org/0000-0003-2091-9295.

Paola González, is a graduate imaging doctor at the International University of Ecuador, Guayaquil-Ecuador.
Email: pao217 @hotmail.com
ORCID https://orcid.org/0009-0009-9806-278X.

Carmen Matilde Navas Palma, Doctor from the University of Guayaquil (Ecuador, 2015). Master in Occupational Safety and Health from the Universidad del Pacífico, Business School (Ecuador, 2022). Postgraduate medical doctor in Imaging from the International University of Ecuador, Guayaquil-Ecuador.
Email: carmennavas.p@gmail.com
ORCID https://orcid.org/0000-0002-7749-1392 .

Jean Carlos Galló Valverde, Doctor from the University of Guayaquil (Ecuador, 2018). Postgraduate doctor in Imaging from the International University of Ecuador, Guayaquil-Ecuador.
Email: medjeangallo@gmail.com
ORCID https://orcid.org/0000-0002-3709-3947.

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Correspondence: Carlos Jacinto Valle Ochoa. Mail: drcvalleo@hotmail.com
Address: Coronel 2301 and Azuay. Orthopedics and Traumatology Service, Alcívar Hospital, Guayaquil, Ecuador. Telephone: (5934) 3720100.