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Original Article

Radiographic study of tibiotalar alignment in normal ankles

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Abstract

Objective: Establish reference values for radiographic ankle measurements in healthy individuals. With these data, it will be possible to identify deviations from normality and assist in diagnosing and treating ankle osteoarthritis.

Methods: One hundred and fifty-six standard digital radiographs in physiological position with ankle weight-bearing in the anteroposterior (AP) and lateral incidences of 111 patients were evaluated. The parameters included in the AP incidence are the distal tibial articular surface angle, the talar tilt, and the talus center migration. The parameters in the lateral incidence are the sagittal distal tibial angle and the lateral position of the talus. Radiographic measurements were performed through inter- and intraobserver agreement, which was considered to have a significance level of 5%.

Results: There was good agreement between the measurements performed by different observers, establishing the reference values for each parameter.

Conclusion: All radiographic parameters tested showed excellent or good correlations to evaluate ankle alignment and should be considered together for a complete and adequate evaluation.

Level of Evidence IV; Therapeutic Studies; Case Series.

Keywords: Osteoarthritis; Ankle; Radiography.

Introduction

Ankle osteoarthritis can result from traumatic and clinical conditions that affect this joint. Unlike what occurs in the other weight-bearing joints of the lower limbs[1], in general, the occurrence of ankle osteoarthritis is secondary to fractures and ligament injuries[2], representing around 70% of cases[2]. Proper treatment of these injuries in the acute phase decreases the possibility of progression to complete joint degeneration. Among the causes of ankle arthrosis not associated with trauma, the most prevalent are rheumatoid arthritis (11.9%), neuropathic causes (4.9%), and primary arthrosis (7.2%)[2]. The degeneration of the tibiotarsal joint determines greater functional impairment compared to the degeneration of other joints, such as the hip or knee[1].

Two-thirds of patients with ankle osteoarthritis have an asymmetrical wear pattern. Because the ankle is part of a kinematic chain, intra-articular load distribution is not only influenced by the alignment of the tibiotalar joint itself but is highly dependent on extrinsic forces that are present due to the alignment of the distal end of the tibia and the subtalar joint, the medial spine of the foot, and soft tissue balance[1,3].

The altered morphology of the distal end of the tibia and its deviations in the sagittal and coronal planes are pointed out as important factors for mechanical overload of the ankle joint, which accelerates joint degeneration[1]. In addition, these changes also influence the prognosis after surgical procedures for treating symptomatic arthrosis, such as ankle arthroplasty and arthrodesis[4].

Study performed at the Hospital Israelita Albert Einstein, São Paulo, SP, Brazil.

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In the literature, several radiographic parameters can be found that define the normal relationship between the tibia and the talus[4-6], but their use in our environment is still not widespread. In addition, there is no significant population data on these parameters for the Brazilian population, which can make it difficult to accurately diagnose variations in normal alignment and, consequently, affect the treatment of ankle injuries.

The difficulties of standardization when positioning the patient to obtain adequate radiographic images are well known, which is essential for the reliable definition of radiographic parameters[6,7].

The objective of this study is to establish reference values for radiographic ankle measurements in healthy individuals. With these data, it will be possible to identify deviations from normality and assist in diagnosing and treating ankle osteoarthritis. It is understood that the knowledge of normal values helps diagnose patients with ankle pathologies and acts in the postoperative control, serving as a reference parameter.

Methods

This consecutive prospective study evaluated 156 standard digital radiographs in physiological position with ankle weight-bearing. The images, captured in anteroposterior (AP) and lateral incidences, were analyzed using the Carestream Vue Motion Image Viewer© system (Carestream Health) between August 2018 and July 2019, involving 111 patients. The study was approved by the Institutional Review Board and followed the ethical standards of our institution. All participants signed the informed consent form.

The radiographs were obtained following the rules established in the protocol of Tochigi et al.[8], according to which 15 cm of the distal tibial are included in the AP and lateral incidence while the patient is kept in monopodial support and the radiographic beam penetrates through the central point of the ankle joint in both positions.

The study included radiographs of both sexes, skeletally mature patients with no previous history of injuries capable of altering joint morphology.

Non-inclusion criteria include radiographs of patients with signs of congenital deformities, joint structural changes compatible with osteoarthritis, osteopenia or osteoporosis, patients with ankle fractures, operated or not, as well as patients with sequelae of fractures and major misalignments, in addition to other radiographic changes that potentially alter the local bone anatomy.

Radiographs performed outside the technical standard described above were not included.

Radiographic measurements

On the AP incidence, the distal tibial articular surface angle (Figure 1), the talar tilt (Figure 2), and the talus center migration (Figure 3) were measured.

Figure 1. The distal tibial articular surface angle, determined by the measurement between the long tibial axis and the line tangent to the distal tibial articular surface.

Figure 2. The talar tilt, determined by the measurement between the line that touches the distal tibial articular surface and another that touches the surface of the talar dome in the AP incidence.

The distal tibial articular surface angle on AP incidence was determined by the measurement between the long tibial axis and the line tangent to the distal tibial articular surface(7). The medial distal tibial angle to the long tibial axis was considered(7,9).

The long tibial axis on AP incidence was determined from the center of the circle tangent to the medial and lateral cortices 10 cm proximal to the ankle joint and the center of another circle tangent to the three cortices of the distal tibial metaphysis, as shown by Ahn et al.(9). The line connecting both centers is the long tibial axis on AP incidence.

The talar tilt angle was determined by the measurement between the line that touches the distal tibial articular surface and another that touches the surface of the talar dome on the AP incidence(7).

The talus center migration was determined as the shortest distance between the talus center and the long tibial axis(9,10). Medial displacements were considered positive, and lateral displacements were considered negative(9).

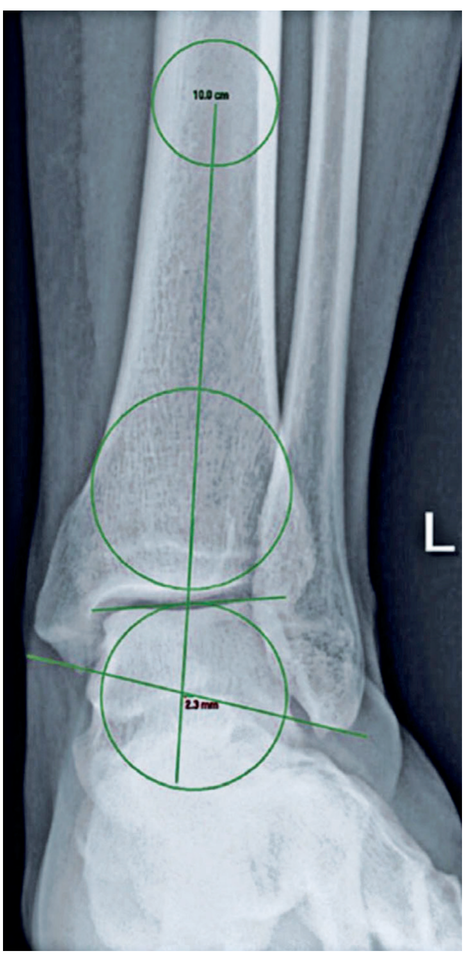

Figure 3. The talus center migration, the shortest distance from the talus center to the long tibial axis.

The center of the talus in the AP incidence corresponds to the center of a circle that touches the midpoint of the talar dome (which in the AP incidence is seen as a plateau) and, at the same time, coincides with one of the points that make up the line that touches inferiorly both tibial and fibular malleolus(9,10).

On lateral incidence radiographs, the lateral distal tibial articular surface (Figure 4), the lateral position of the talus (Figure 5), and the tibiotalar ratio (Figure 6) were measured.

The lateral distal tibial articular surface angle is formed between the long tibial axis and the distal tibial articular surface (Figure 6), determined by a line tangent to the articular surface on the lateral incidence.

The long tibial axis on lateral incidence was determined from the center of a circle fitted to the anterior and posterior cuts of the tibia located 10 cm above the ankle joint, and the center of another circle also fitted to the anterior and posterior tibial cortices 5 cm above the ankle joint; the line intersecting the center of both these circles is considered as the long tibial axis (Figure 5).

The lateral position of the talus is defined as the distance measured perpendicularly between the line of the long tibial axis and the talus center rotation. The center rotation is defined as the center of a circle fitted to the talar dome (Figure 5). Displacements to the anterior side of the long tibial axis were considered positive, and displacements to the posterior side were considered negative (Figure 5).

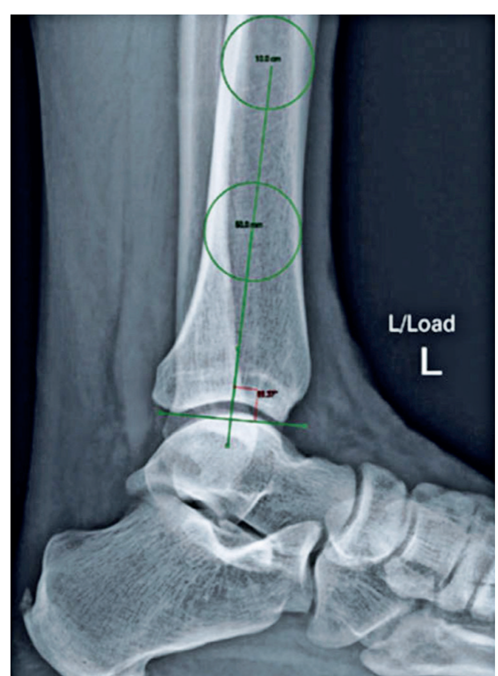

Figure 4. The lateral distal tibial articular surface, formed between the long tibial axis and the line of the distal tibial articular surface.

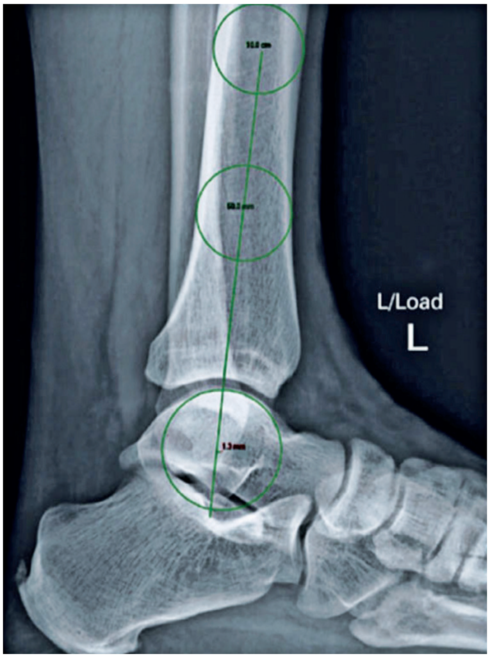

Figure 5. The lateral talus position, defined as the distance measured perpendicularly between the line of the long tibial axis and the talus center rotation.

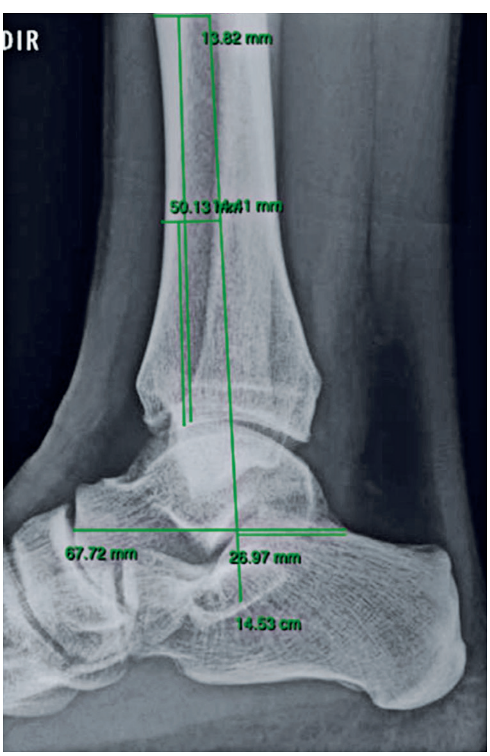

Figure 6. The tibiotalar ratio, the ratio of the intersection of the distal tibial axis line with the long talus axis.

The tibiotalar ratio uses as a reference the intersection of the distal tibial axis line with the long talus axis (Figure 6). The ratio is calculated between the total length of the talus and the distance at which the long tibial axis intersects with the talus axis (Figure 6).

Two orthopedists with different degrees and professional experience participated in these measurements: one trainee in medicine and surgery of the ankle and foot (R4) and one specialist in the ankle and foot with 25 years of experience. The evaluators performed the measurements independently and at two different times with an interval of one month.

Data analysis

The intraclass correlation coefficient (ICC) was used to measure the agreement between the measurements obtained by the two observers, separately by moments, and between the measurements obtained in the two moments, separately by the observer. As this is a method used for independent observations, patients with bilateral radiographs had one of them randomly drawn. The coefficients were followed by their respective 95% confidence intervals, and the data were represented in scatter plots and Bland-Altman plots. The measurement means were estimated by adjusting mixed linear models contemplating the dependence between the measurements obtained in the same patient.

Results

One hundred and seventy radiographs of normal ankles were selected and included in the database. Excluding images not suitable for the study as described in the non-inclusion criteria and, after the analysis, excluding possible typing and measurement errors, the final study sample included 156 radiographs from 111 different patients. Results are shown in Table 1.

The ICC values obtained were calculated to compare the measurements obtained by the two observers separately per moment and between the measurements obtained in the two moments separately per observer. It was observed that the concordances between the moments per observer are greater than between the observers per moment (Table 2).

Table 1. Estimated mean values and 95% confidence intervals for measurements obtained on ankle radiographs (111 patients)

Radiographic measurements	Estimated mean value (95%CI)
Anteroposterior incidence	
TAS (°)	90.98 (90.57; 91.38)
TT(°)	0.82 (0.73; 0.91)
TCM (mm)	-0.47 (-0.66; -0.28)
Lateral incidence	
TAS (°)	85.63 (85.16; 86.10)
Lateral talus position (mm)	1.10 (0.84; 1.35)
TTR	36.07 (35.56; 36.58)

95%CI: 95% confidence intervals; AP: anteroposterior; TAS: distal tibial articular surface angle; TT: talar tilt; TCM: talus center migration; TTR: tibiotalar ratio.

The values less than 0.2 represent low agreement, between 0.21 and 0.40 weak, between 0.41 and 0.60 moderate, between 0.61 and 0.80 good, and from 0.81 to 1.00 very good agreement.

Considering the distal tibial articular angle, no significant difference was observed by the same observer at two different times. The value of this angle was 90.98°.

Considering the talar tilt, there was a difference in the measurements of the same observer at different times (intraobserver), but there were little significant variations, approximately 1°.

In the comparative analysis between observers (interobserver), discrete variations were also observed, approximately 1°.

In the analysis of the talus migration center of each observer individually (intraobserver), a small variation in the measurements of observer B compared to observer A was noticed.

Considering the two observers (interobserver), a difference between them was noticed.

Regarding the lateral position of the talus and the lateral distal tibial articular surface, similar characteristics of the other evaluations were observed, in which the results of observer A vary more compared to observer B, but without very discrepant values. In the evaluation between the observers, a difference between the measurements obtained between the observers was noticed.

Finally, the evaluation of the tibiotalar axis showed excellent agreement between the measurements of observer A, good agreement between the observers in the first measurement, and low agreement between the measurement of observer B and between the observers in the second measurement.

Discussion

The ankle joint alignment determines its normal physiology. The disturbance of this alignment generates an anomalous distribution of loads across the joint surfaces and accelerates their wear, which culminates in degenerative joint disease. This occurs mainly after fractures and ligament injuries that can cause changes in alignment and instability. Degenerative changes associated with previous trauma, even if properly treated, can progress to degenerative disease due to trauma-related chondral injury, and arthrosis can cause secondary changes in alignment, as in other joints.

Positioning the lower limb at the time of obtaining the radiographs is essential for properly identifying the parameters. Poorly positioned limbs lead to difficulty in determining the center migration (AP incidence) and the talus center rotation (lateral incidence)[6,11], making it impossible to study joint alignment properly. The standardization of radiographic images allows the reproduction of the parameters used safely. They are also indispensable in determining the reduction quality after treating ankle fractures and in procedures for realignment (joint revision procedures) or joint ankle replacement[4,10].

The radiographic parameters on the AP incidence are the long distal tibial axis, distal tibial articular line, talar dome articular line, and talus center migration. On the lateral incidence, the parameters are the long distal tibial axis, the tibial articular surface, the talus center rotation, and the long talus axis. The definition of the long tibial axis in the lateral incidence is divergent in the literature. Tochigi et al.[6] define the long tibial axis as a line that crosses the middle of the distance between the anterior and posterior tibial cortices at 5 and 10 cm proximal to the articular surface. Barg et al.[12] define it as the line from the center of a circle in the proximal tibia, the undefined distance, to the center of a tangent circle on the anterior, posterior cortices, and articular surface. The definition of the long tibial axis in the lateral incidence used in our present study was suggested by Tochigi et al.[6] because it is easily reproducible, has less influence on anatomical deformities of the distal tibial metaphysis, and has relevance in the literature.

In the AP incidence, Ahn et al.[9] use the same tangent circle in the distal tibial cortices, as Barg et al.[12] suggested, but with a proximal point defined at 10 cm proximal. The criterion for determining the long tibial axis used in our study was that suggested by Ahn et al.[9]. We consider this easily reproducible and reliable since it has as reference a proximal

Table 2. Intraclass correlation coefficients (ICC) and 95% confidence intervals for the agreement between measurements obtained on ankle radiographs at two time points by two observers (111 patients)

Radiographic measurements	Measure 1 x Measure 2		Observer A x Observer B	
	Observer A	Observer B	Measure 1	Measure 2
Anteroposterior incidence				
TAS (°)	0.93 (0.90; 0.95)	0.98 (0.97; 0.99)	0.65 (0.48; 0.76)	0.61 (0.43; 0.73)
TT (°)	0.75 (0.63; 0.83)	0.89 (0.82; 0.93)	0.72 (0.78; 0.53)	0.66 (0.57; 0.68)
TCM (mm)	0.63 (0.46; 0.74)	0.92 (0.88; 0.94)	0.60 (-0.06; 0.81)	0.62 (0.51; 0.69)
Lateral incidence				
TAS (°)	0.93 (0.90; 0.95)	0.98 (0.97; 0.99)	0.75 (0.44; 0.86)	0.75 (0.49; 0.86)
TTR	0.84 (0.70; 0.90)	0.99 (0.98; 0.99)	0.52 (0.22; 0.70)	0.45 (0.20; 0.62)

TAS: distal tibial articular surface angle; TT: talar tilt; TCM: talus center migration; TTR: tibiotalar ratio.

point defined at 10 cm from the articular surface, different from what Barg et al.[12] suggest in which they defined the distance from which the reference should be considered.

Specifically for the distal tibial joint angle, we noticed some variability, but similar between observers, maintaining very good and good intra- and interobserver coincidence, respectively. The observed differences were very small. This radiographic parameter allows a specific assessment of the distal tibial articular surface alignment in relation to the distal tibial metaphysis.

The talar tilt and the medial distal tibial angle in normal ankles are taken in the literature as 0º (± 1º) (in the evaluation of 24 patients)[13] and 89º (87º-91º)[14]. Among the patients evaluated in our study, the mean value for the talar tilt was 0.82º, and the medial distal tibial angle was 90.98º, thus coinciding with the literature. The talar tilt on the AP incidence allows us to evaluate the congruence of the distal tibial with the talar dome, which must be properly positioned within the mortise. For this measurement, the interobserver correlation was good and excellent, and the intraobserver correlation was good, showing that it is a good way to evaluate the tibial talar alignment in the ankle joint.

The long tibial axis alignment with the talus center (evaluation of the talus center migration) measured on ankle radiography in the AP incidence was developed to measure the degree of talus migration inside the mortise[9,10]. The lateral position of the talus allows for the classification of the talus as medial, neutral, or lateral[5].

The interobserver agreement was moderate and good, and we attributed this variation to differences in experience with radiographic images among the participants. However, the variability between the two observers was small, remaining within values considered normal in the literature[4,10]. Interestingly, the intraobserver variation was substantially lower in the second assessment (good in the first and excellent in the second measurement). This may indicate the need for training to perform complex measurements. The values for talus center migration described by Yi et al.[4] are 0.4 mm, ranging from 2.1 mm to -1.4 mm, considering 73 radiographs of skeletally mature individuals without deformities or lower limb axis deviations. In the initial study by Ahn et al.[10], the value was 3.5mm, ranging from 1.9 to 5.2 mm. However, as this study focused on alignment after supramalleolar osteotomy in 18 ankles with focal medial osteoarthritis, secondary deviations due to joint wear must be considered. In the present study, the normal value was -0.47 mm.

In the evaluation of the distal tibial articular surface angle, it is noted that there was less variation in the measurements of observer B compared to A. However, the differences remain within acceptable limits (between ± 3º). According to the literature, the lateral distal tibial angle is considered normal 80º[15]. The population studied in our study was 85.63º.

In the lateral incidence evaluation, in the talus lateral position, Tochigi et al. [6] observed a normal value of 33.4 ± 3.3%, which does not contrast with our results, in which the value found was 36.07 (ranging from 35.56 to 36.58). Obtaining such a reference allows positional evaluation in the axial incidence of the tibiotalar joint, with less interference from the position of the joint in flexion or extension. In the literature, the normal range of the talus lateral position for normal ankles ranges from -0.8076 mm to 3.1496 mm, with a mean of 1.17 mm in the series by Veljkovic et al.[5] with 82 ankles. Magerkurth et al.[16], in a series of 52 patients without ankle pathologies, have the talus center position 1.6 mm anterior to the anatomical tibial axis as normality. Our results are in accordance with these values, with a mean of 1.10 mm.

In the tibiotalar ratio, the intraobserver coefficients were excellent, but the interobserver coefficients were weak in both measurements. This alignment parameter suffers interference from the presence of stretching or degenerative changes in the posterior portion of the talus, making it difficult to standardize the parameters for determining the long talus axis due to the final measurement. This parameter showed the poorest interobserver agreement among the radiographic measurements, reflecting the challenges associated with its evaluation.

There are several options for the surgical treatment of patients with ankle arthrosis: osteophyte resection and synovectomy, arthrodiastasis, supramalleolar osteotomies for ankle realignment, fresh cadaver osteochondral allograft, ankle arthrodesis, and total ankle arthroplasty[17]. Regardless of the chosen method, reestablishing ankle alignment is essential, as failure to do so compromises the outcome of the procedure[4]. This shows the importance of defining normal parameters.

The main limitations faced in our study are related to the parameters adopted, the sample, and the body segment studied.

Other parameters for measuring radiographic alignment, also described in the literature, can contribute to the study of the ankle joint, such as using the mechanical axis of the lower limbs, unlike the parameters used in the current study. Another technical limitation concerns the radiographic parameters used to define the lateral talus position. Due to its irregular shape, alignment with the radiographic cassette can be unsatisfactory (ideally, the ankle should be positioned with both malleoli overlapping). Consequently, determining the talus center rotation using a circle tangent to the articular surface may be compromised, leading to measurement variability.

Another limitation is related to the sample. This study was performed in a single center with a specific population, so extending the data to the Brazilian population may not portray reality.

The various parameters created and tested in other countries need to be validated for our population since there may be substantial variations in the normality values given the ethnic differences of each nationality.

Benevides et al.[18] propose that a minimal radiographic evaluation of the tibiotalar alignment should include the following parameters in the AP incidence: the distal tibial joint angle, the talar tilt, and the talus center migration. The lateral incidence should include lateral distal tibial angle and lateral talar station. Our study complements this proposal, bringing together all the tested parameters that are interesting for evaluating ankle alignment and should be considered to allow a complete and adequate evaluation. In the lateral incidence, the talus position under the distal tibial, the lateral talus position proved to be easier to assess and less influenced by degenerative changes in the subtalar joint than the tibiotalar ratio.

Conclusions

The reference values for normal weight-bearing radiographic measurements for the studied population, which show excellent or good inter- and intraobserver correlations for the AP incidence, were the distal tibial articular angle between 90.57° and 91.38°, the talar tilt between 0.73° and 0.91°, and the alignment between the long tibial axis and the talus center between -0.66 and -0.28°. For the lateral incidence were the distal tibial articular angle between 85.16° and 86.10° and the lateral talus position between 0.84 mm and 1.35 mm.

It is understood that knowledge of these normal values, which show good correlation, helps diagnose patients with ankle pathologies and plays a role in postoperative control, serving as a reference parameter.

Authors' contributions: Each author contributed individually and significantly to the development of this article: PCB *(https://orcid.org/0000-0002-4209-0564) Conceived and planned the activities that led to the study, interpreted the results of the study, participated in the review process, data collection, bibliographic review, survey of the medical records, approved the final version, wrote the article; CMM *(https://orcid.org/0009-0001-5071-9764) Interpreted the results of the study, participated in the review process, bibliographic review, approved the final version; PJF *(https://orcid.org/0000-0003-1296-6665) Interpreted the results of the study, participated in the review process, bibliographic review, formatting of the article, approved the final version; CASN *(https://orcid.org/0000-0002-9286-1750), and JFMA *(https://orcid.org/0000-0002-7664-2064), and ALGS *(https://orcid.org/0000-0002-6672-1869), and ASOJ *(https://orcid.org/0000-0002-7348-4697), and GBBS *(https://orcid.org/0000-0001-9004-3909), and RAM *(https://orcid.org/0000-0002-7830-8318) Interpreted the results of the study, participated in the review process, approved the final version; MPP *(https://orcid.org/0000-0003-0325-8050) Interpreted the results of the study, participated in the review process, data collection, wrote the article, participated in the review process, approved the final version.. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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