Description of Proximal Femoral Growth in Pediatric Patients Without Hip Disorders Using Tomography

Rodrigo Huertas Tafur,* Antonio J. Solano Noguera, María Fernanda García Rueda,# Helmuth R. Rashid Forero,** Martha L. Caicedo Gutiérrez#**

**School of Medicine, Universidad Nacional de Colombia, Bogota, Colombia.*
***School of Medicine, Universidad del Rosario, Bogota D.C., Colombia.*
#Department of Orthopedics and Traumatology, Roosevelt Institute, Bogota, Colombia.

ABSTRACT

Introduction: This study aims to perform a descriptive analysis of proximal femoral growth in a Latin-American population through femoral offset, neck-shaft angle, femoral neck length, and femoral head diameter evaluated through computed tomography in pediatric patients without hip pathology. **Materials and Methods:** Retrospective study evaluating CT images of the hips of healthy patients under 18 years. The following measurements were taken by a trained orthopedist: femoral offset, femoral neck length, femoral head diameter, and neck-shaft angle. **Results:** Femoral offset increases by 1.96 mm until age 12.5. From 12.5 to 16 years of age, it increases by 1.2 mm. A constant rise in the growth of the femoral neck length was found. The neck-shaft angle presented a progressive decrease until age 12. After that point, the curve flattened. An increase in femoral head diameter of 1.56 mm per year was observed until age 13 and then 0.62 mm per year. **Conclusions:** The measurements evaluated in this study are essential for the diagnosis, follow-up, and treatment approach in hip pathologies during growth. More extensive research is needed to define normal ranges that will serve as a baseline for anatomy restoration in hip joint preservation surgery.

Keywords: Femoral head; femoral neck; human development.
Level of Evidence: IV

Descripción del crecimiento del fémur proximal mediante tomografía en pacientes pediátricos sin enfermedad de cadera

RESUMEN

Objetivo: Describir el crecimiento femoral proximal en una población latinoamericana a través del desplazamiento femoral, el ángulo cervico-diafisario, la longitud del cuello femoral y el diámetro de la cabeza femoral evaluados con tomografía computarizada en pacientes pediátricos sin enfermedad de cadera. **Materiales y Métodos:** Estudio retrospectivo que evaluó imágenes de tomografía computarizada de caderas de pacientes sanos <18 años. Se tomaron las siguientes medidas: desplazamiento femoral, longitud del cuello femoral, diámetro de la cabeza femoral y ángulo cervico-diafisario. **Resultados:** El desplazamiento femoral aumenta 1,96 mm hasta los 12.5 años, y desde los 12.5 hasta los 16 años, aumenta 1,2 mm. Se constató un aumento lineal del crecimiento de la longitud del cuello femoral. El ángulo cervico-diafisario disminuyó progresivamente hasta los 12 años. A partir de ese momento, la curva se aplanó. Se observó un aumento anual del diámetro de la cabeza femoral de 1,56 mm hasta los 13 años y de 0,62 mm anuales, en adelante. **Conclusiones:** Las medidas descritas en este estudio son esenciales para el seguimiento, el diagnóstico o el abordaje conductual en múltiples cuadros articulares de cadera durante el crecimiento. Se expone la necesidad de realizar estudios más amplios para establecer rangos de normalidad en la población local con las herramientas tecnológicas disponibles, que fundamenten una referencia para la restauración de la anatomía en la cirugía de preservación.

Palabras clave: Cabeza femoral; cuello femoral; desarrollo humano.
Nivel de Evidencia: IV

Received on August 28th, 2023. Accepted after evaluation on July 4th, 2024 • Dr. RODRIGO HUERTAS TAFUR • rhuertast@unal.edu.co • https://orcid.org/0000-0003-3056-3296

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INTRODUCTION

The biomechanics of the hip are sensitive to the relationship between the elements of the Pauwels scale. During growth, maintaining the correct proportions of femoral neck length, femoral neck angulation, and the pelvic-trochanteric index is essential for achieving a limp-free gait in patients with stable, reduced hips. In skeletally mature individuals, the normal values for femoral offset, cervico-diaphyseal angle, and pelvic-trochanteric index are well-defined.[1] Although these relationships are valuable for planning proximal femoral osteotomies in the pediatric population, they have often been neglected due to the emphasis on improving femoral-acetabular congruence, ensuring sufficient femoral head coverage, and maintaining mobility through osteotomies that restore anatomy and joint relationships.[2]

As part of the development of femoral joint preservation surgery, which aims to maintain functionality and delay the onset of osteoarthritis in adulthood, several metrics have been described for the acetabulum and proximal femur. However, most of these metrics do not consider the restitution of the lever arms and soft tissue tension that ensure the stability of the hip joint, sometimes leading to changes in the length of the lower extremities. [2,3,5,6]

The averages and dispersion in joint relationship values during skeletal maturation, based on measurements obtained using the biplanar radiography method developed by EOS imaging™[7], have been published in a European population, where the median height and weight are higher than those in Latin America. In the absence of EOS imaging™[7] in Colombia, it is necessary to study age-adjusted normal values in the local population using available diagnostic imaging techniques.

This study describes the progression of proximal femur growth in a healthy pediatric population using computed tomography (CT) from 6 months to 17 years of age at Roosevelt Children's Orthopedic Institute in Bogota, Colombia.

MATERIALS AND METHODS

A retrospective study was conducted using hip CT scans obtained between 2014 and 2021 from Latin American patients under 18 years of age, with no history of surgery or neuromuscular, metabolic, or genetic disease. Images of healthy hips were obtained from patients with suspected infectious disease or avascular necrosis in the hip contralateral to the one used in this study. All images that met the inclusion criteria were included.

Demographic and clinical variables, such as sex, age, femoral offset, cervico-diaphyseal angle, femoral neck length, and femoral head diameter, were collected from the clinical records and the institution's image archive. All information was stored in REDCap®. Since CT does not allow direct evaluation of the cartilaginous component, measurements were taken using the technique described by Amador et al.,[9] which predicts the location of the femoral head center and its diameter without the use of MRI or ultrasound, ensuring accuracy and reproducibility.

In patients over 4 years old, femoral offset was measured as the orthogonal distance between the geometric center of the femoral head and the axis of the proximal femoral diaphysis (Figure 1).

In patients aged 4 years or younger, the method described by Amador et al. was used to locate the center of the femoral head. A secant line was drawn connecting the most distal points of the medial and lateral metaphyseal curvatures, and a perpendicular line was drawn from the center of this secant. The center of the femoral head is the point on this perpendicular line located at the distance from the metaphysis described by Amador et al., according to age.[9] The cervico-diaphyseal angle is the angle between the femoral neck axis and the femoral diaphyseal axis in all cases (Figure 2).[10]

The length of the neck corresponds to the distance from the center of the proximal femoral physis along the axis of the femoral neck to the axis of the diaphysis (Figure 3).

To calculate the diameter of the femoral head in children over 4 years old, the longest line within the circumference of the head that passes through the center was measured (Figure 4). In patients aged 4 years or younger, the diameter of the complete circumference was measured using the reference points described by Amador et al.[9]

Measurements were taken by an orthopedist trained in these techniques, following the specifications mentioned above. All measurements were conducted on the coronal slice of the CT scan, where the sphericity of the femoral head and the fovea capitis could be best appreciated.

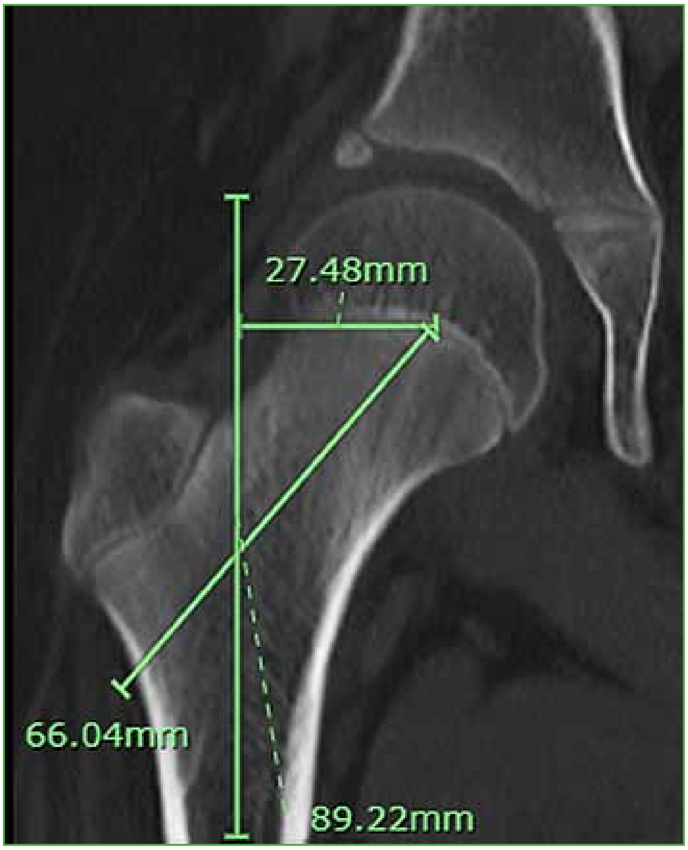

Figure 1. Lateral femoral offset. Distance from the center of rotation of the femoral head to the diaphyseal anatomical axis of the femur. In this case, it is 27.48 mm.

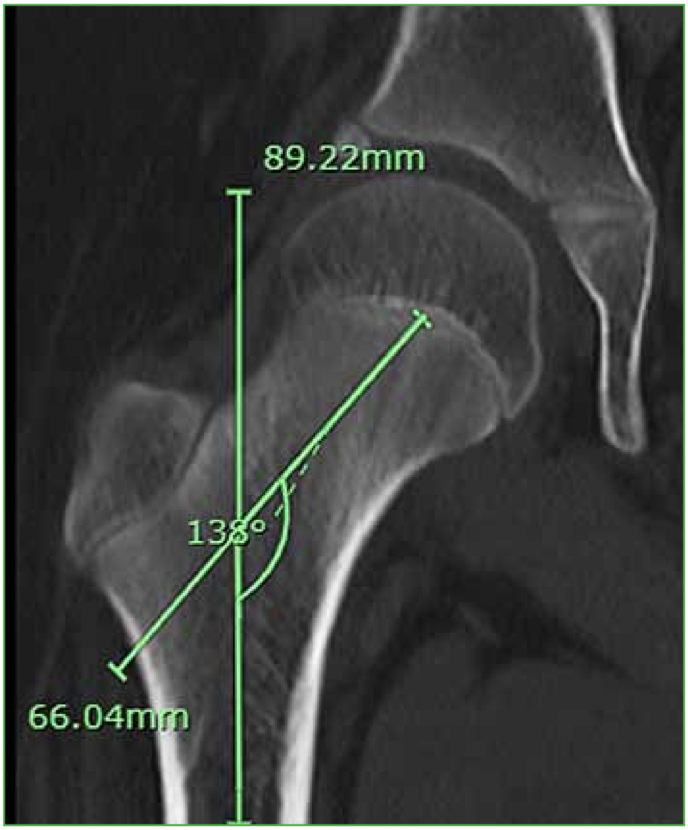

Figure 2. Cervico-diaphyseal angle. Angle formed between the anatomical axis of the femoral neck and the diaphyseal anatomical axis of the femur. In this case, it is 138°.

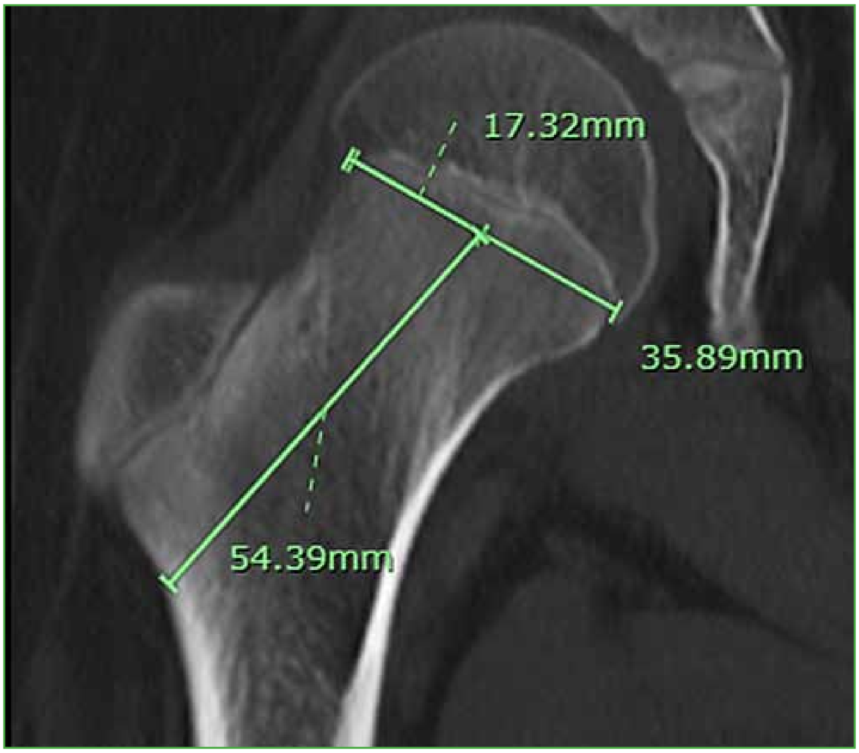

Figure 3. Femoral neck length. Distance from the center of the fissure line of the proximal femur to the lateral cortex of the intertrochanteric region, passing through the axis of the femoral neck. In this case, it is 54.39 mm.

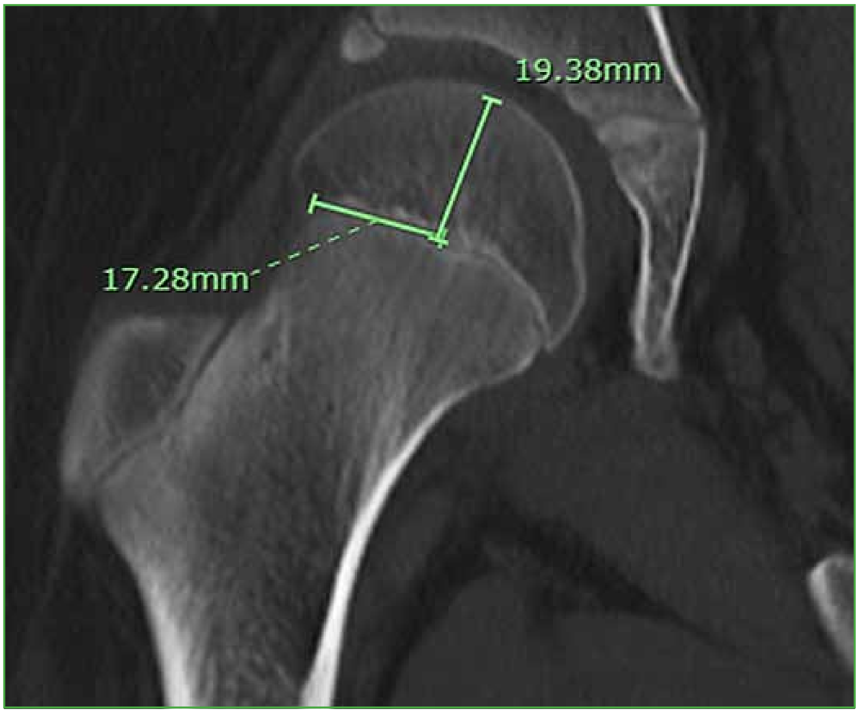

Figure 4. Femoral head radius. Its measurement is adjusted for age. In children aged >4, the longest line contained in the circumference of the femoral head passing through the center of rotation was measured. In children aged <4, the circumference was completed using the technique described by Amador et al. In this case, it is 19.38 mm.

Statistical analysis

Absolute and relative frequencies were calculated for qualitative variables, and scatter plots were created for each variable of interest according to age. The trend was established in these graphs, with smoothing added as necessary to regularize the curve in the cervico-diaphyseal angle graph. The growth rate for each parameter was determined by calculating the change in slope.

RESULTS

Forty patients were included (mean age: 9 years; range: 6 months to 18 years). Femoral offset shows linear growth over time, with a trend of increasing approximately 1.96 mm per year until 12.5 years of age, followed by a flattening of the curve and an increase in offset of 1.2 mm between 12.5 and 16 years of age (Figure 5). Regarding femoral neck length, the growth trend remains constant at a rate of 1.95 mm per year (Figure 6).

For the measurement of the cervico-diaphyseal angle, a smoothing factor of 0.6 was applied. A progressive decrease of 1.16° per year was observed from birth to 10 years of age. This rate continues to decrease by 0.88° per year between 10 and 12 years of age, followed by a flattening of the curve between 12 and 16 years of age, with a decrease of 0.09° per year (Figure 7). The femoral head diameter increases 1.56 mm per year during the first 13 years of life, with a slower growth of 0.62 mm per year thereafter (Figure 8).

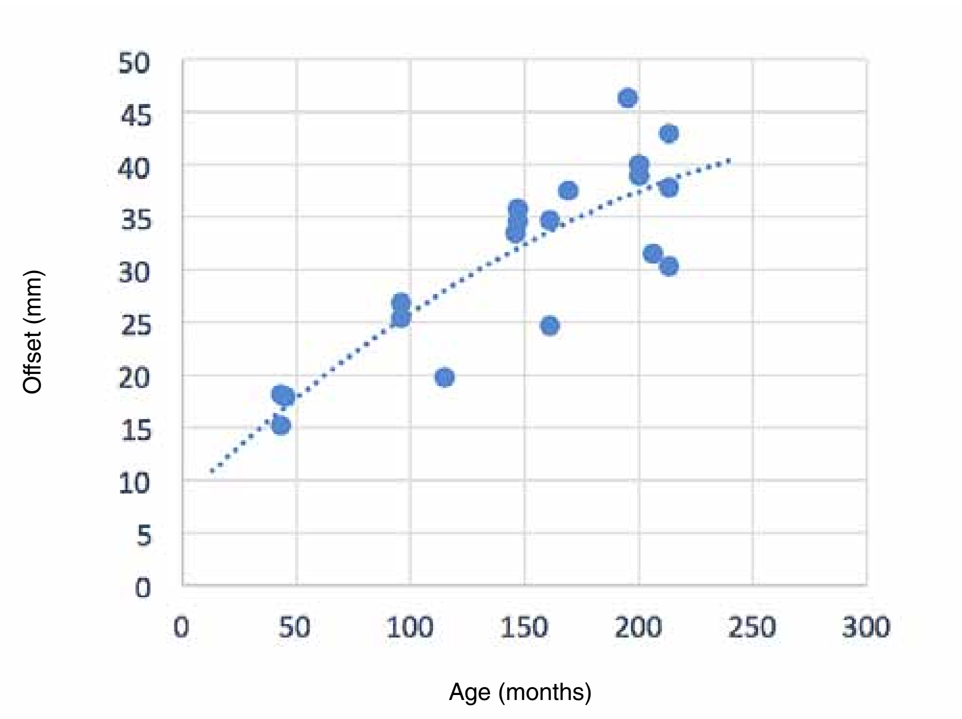

Figure 5. Femoral offset (mm) vs. age in months.

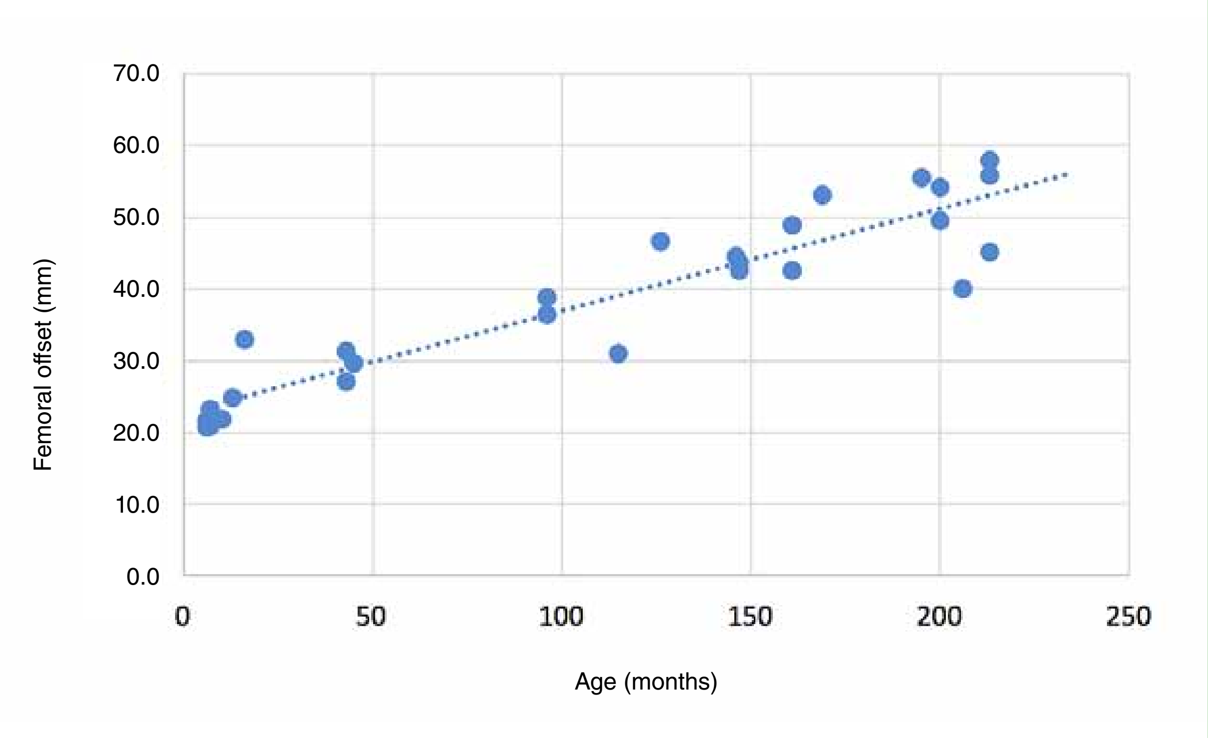

Figure 6. Femoral neck length (mm) vs. age in months.

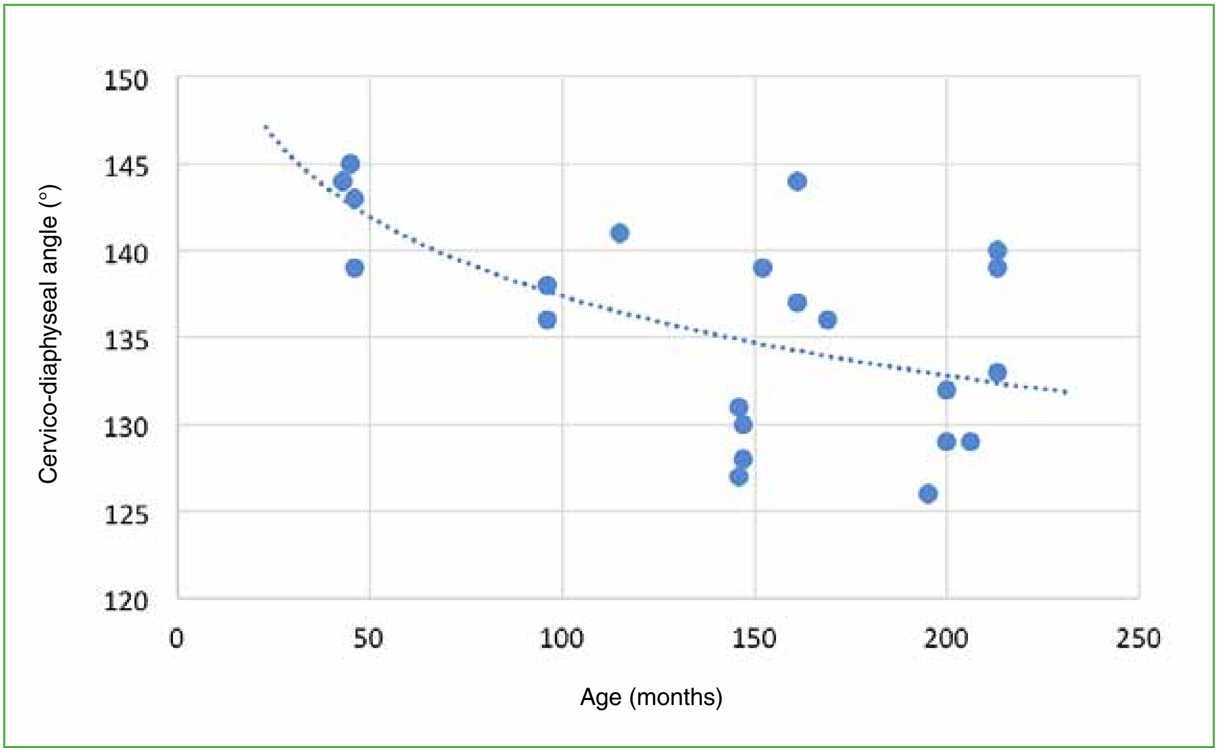

Figure 7. Cervico-diaphyseal angle (°) vs. age in months.

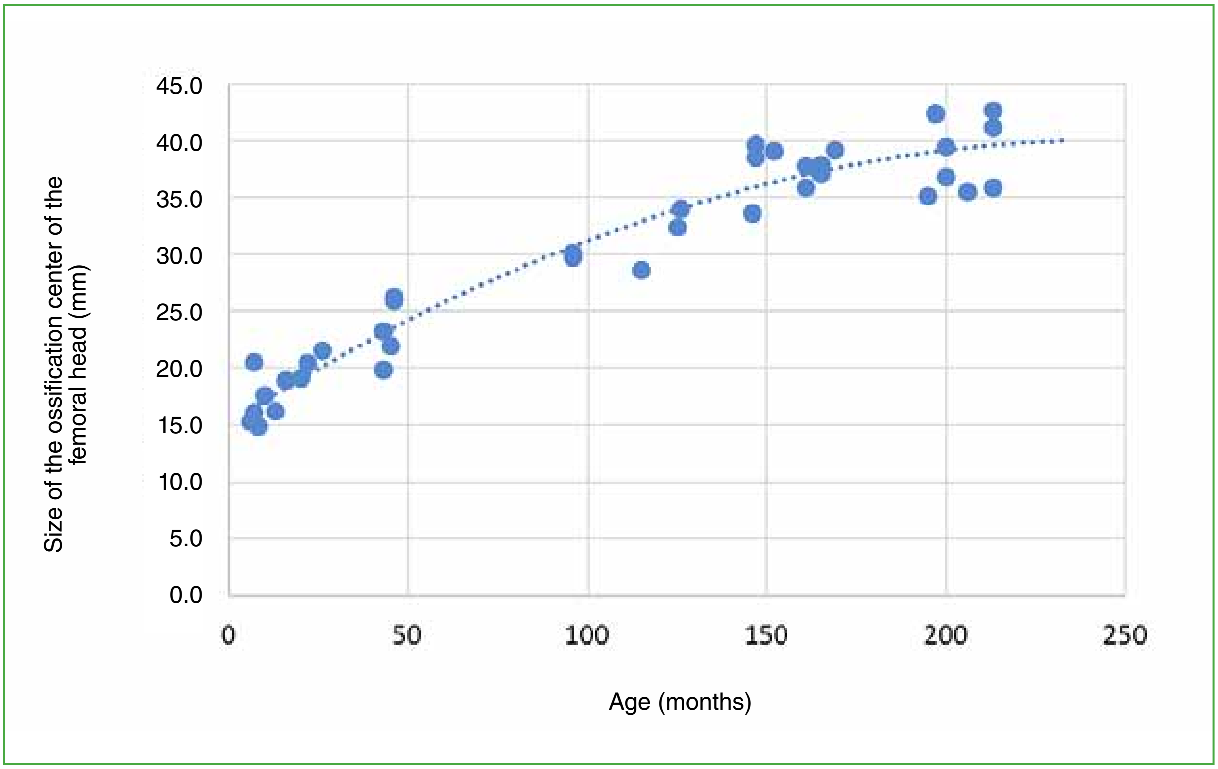

Figure 8. Size of the ossification center of the femoral head (mm) vs. age in months.

DISCUSSION

The aim of this study was to characterize the growth of the proximal femur in terms of anatomical parameters evaluated in CT scans of healthy hips from 40 Latin American pediatric patients. Previous studies have focused on describing the femoroacetabular relationship and establishing cut-off points for certain ages to facilitate decision-making, using reference points such as the center-edge angle (Wiberg) and the acetabular index, among others.[11,12] This approach does not allow for an exact or dynamic evaluation over time of the effect that femoral anatomy has on the lever arm of the hip, but it does indirectly infer alterations in the femoroacetabular relations, which are the basis for surgical interventions. An exception to this is the study published by Novais et al.,[13] which reports the median and dispersion of the acetabular index and the acetabular depth ratio from birth to 17 years of age. In the case of the femur, the analysis of femoral growth using the EOS system[7] in the Hungarian population has been described.

As described by Pauwels,[2,14] hip biomechanics are strongly influenced by the length of the lever arms of its components. This influence is evident in pediatric patients with conditions that modify these relationships, such as Perthes disease, hip dysplasia, or the sequelae of septic arthritis.

It is challenging to obtain femoral growth measurements in the population under 4 years of age. To address this, Amador et al.[9] described a reproducible method based on cadaveric dissections and radiographs, which allows for locating the center of the femoral head and its circumference when ossification is incomplete. In 1981, Wientroub et al.[10] described the normal hip development of the infant population using plain radiographs, but they did not refer to the calculation of the femoral head center in patients without femoral head ossification. As a complement to this review, in 2012, Monazzam et al.[15] demonstrated the possibility of extrapolating results from radiographic measurements to CT.

As shown in Figures 5-8, there is a relationship between the parameters evaluated and the age of the patients. The averages of the measurements at 5 and 15 years were calculated and compared with the results of Szuper et al.,[7] which is the only published study that establishes reference values for the anatomical parameters of normality of the proximal femur in the pediatric population.

In our population, the offset increased with age, from an average of 20 mm at 5 years to 37 mm at 15 years (6 mm and 3 mm less, respectively, than in the Szuper et al. population). Femoral neck length averaged 33 mm at age 5 years and 49 mm at age 15 years (1 mm and 1.5 mm less, respectively, than in the Szuper et al. population). Femoral head size was also smaller than in the comparison population, with averages of 24.6 mm at 5 years and 38.2 mm at 15 years (4 mm and 5.5 mm smaller, respectively). These differences may be related to a lower average height in our population from birth to adulthood compared to the Hungarian population. The gap found decreases progressively due to a higher rate of increase in femoral head offset and size.

In addition, the cervico-diaphyseal angle decreased with age, averaging 141.5° at 5 years and 133.8° at 15 years (differences of 11.1° and 5.8°, respectively). Although genetic differences in our population prevent direct extrapolation to other populations, the trends of increase or decrease in measurements in this study were similar to those published by other authors.[5,7]

The main limitation of this study is the size of the population sample, which allows us to show trends but is insufficient to determine the medians and percentiles required for a growth and development curve. The selection of a convenience sample limits the extrapolation of the findings to the general population.

When comparing our population with that of Szuper et al.,[7] a difference in the values of each variable for the same age groups is evident, highlighting the need to establish reference values for each population, as they cannot be universally extrapolated.

CONCLUSIONS

The measurements of the proximal femur described in this study provide valuable information and growth trends in Hispanic minors using imaging available in Colombia. These findings should be considered for the diagnosis, follow-up, and surgical planning of proximal femur alterations, aiming to restore anatomy to the normal values specific to the Latin American pediatric population. Expanding the studied sample is necessary to develop growth charts and guide treatment with appropriate instrumentation for this population.

Conflict of interest: The authors declare no conflicts of interest.

A. J. Solano Noguera ORCID ID: https://orcid.org/0000-0002-9749-2624
M. F. García Rueda ORCID ID: https://orcid.org/0000-0001-9173-1121
H. R. Rashid Forero ORCID ID: https://orcid.org/0000-0002-7869-2583
M. L. Caicedo Gutiérrez ORCID ID: https://orcid.org/0000-0002-0802-765X

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