Composição Corporal, Crescimento e Desenvolvimento Físico em Jovens de 11 a 13 Anos de Idade de Acordo com o Modelo de Capacidade/Carga Metabólica

Body Composition, Growth, and Physical Development in Young People Aged 11 to 13 Old According to the Metabolic Load Capacity Model

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Resumo

Introdução: À medida que os jovens passam pela fase dinâmica do desenvolvimento físico, a sua composição corporal passa por mudanças significativas, marcadas pela interação entre surtos de crescimento, flutuações hormonais e o desenvolvimento de estruturas musculares e ósseas, moldando coletivamente a base para o seu bem-estar geral.
Este estudo teve como objetivo comparar o desenvolvimento físico de acordo com as características da composição corporal do modelo de capacidade de carga, expresso pela relação entre massa magra (MM) e massa gorda (MG).

Métodos: A amostra foi composta por 580 participantes (283 meninas e 297 meninos) com idades entre 11 e 13 anos. As avaliações incluíram altura, índice de massa corporal (IMC), MM total, MG total, densidade mineral óssea do corpo inteiro menos a cabeça (DMO subtotal) determinada por absorciometria de raio X de dupla energia (DXA), velocidade do som na tíbia e rádio medida por ultrassom, maturidade somática por meio da idade do pico de velocidade de crescimento (PVA) e força de preensão avaliada com um dinamômetro. A amostra, separada por sexo, foi dividida em dois grupos de acordo com a relação MM/MG: grupo A com baixa MM/MG (- ≤ -1) e grupo B sem baixa MM/MG (- > -1). Para comparar esses grupos, as variáveis ósseas e a força de preensão foram padronizadas de acordo com o sexo e grupo etário (-) usando a amostra como referência.

Resultados: Em ambos os sexos, o grupo A apresentou um IMC mais elevado, índices de MM e MG mais elevados (-<0,001), uma idade mais precoce para o PVA (-<0,001) e menor resistência óssea tibial (-=0,001), sem diferenças na resistência óssea radial. No grupo A, também foi observada uma altura adulta prevista menor em meninas (-=0,024) e uma maior DMO subtotal em meninos (0,029) em comparação com o grupo B.

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Conclusão: Uma menor capacidade/carga metabólica em ambos os sexos está associada a um aumento no IMC e parece comprometer mais os membros inferiores do que os superiores, especialmente na mineralização esquelética, apesar de promover uma maturidade somática mais precoce.

Palavras-chave: Adiposidade; Composição Corporal; Crescimento; Criança; Índice de Massa Corporal

Abstract

Introduction: As young people undergo the dynamic phase of physical development, their body composition experiences significant changes, marked by the interplay of growth spurts, hormonal fluctuations, and the development of muscle and bone structures, collectively shaping the foundation for their overall well-being.
This study aimed to compare physical development according to body composition characteristics of the load-capacity model expressed through the ratio between lean body mass (LBM) and fat mass (FBM).

Methods: The sample consisted of 580 participants (283 girls and 297 boys) aged 11-13 years. The evaluations included height, body mass index (BMI), total LBM, total FBM, whole-body bone mineral density less head (WBLH BMD) determined by dual-energy x-ray absorptiometry (DXA), tibia and radius speed of sound (SoS) measured by ultrasound, somatic maturity through the age of peak height velocity (PHV), and handgrip strength evaluated with a dynamometer. The sample, separated by sex, was divided into two groups according to the LBM/FBM ratio: group A with low LBM/FBM (z-score ≤ -1) and group B without low LBM/FBM (z-score > -1). For comparison purposes between these groups, the bone variables and handgrip strength were standardized according to sex and age group (z-score) using the sample as a reference.

Results: In both sexes, group A revealed a higher BMI, LBM and FBM indexes (-<0.001), an earlier age at which PHV occurred (-<0.001) and lower tibial bone strength (-=0.001), with no differences in radial bone strength. In group A, a shorter predicted adult height was also observed in girls (-=0.024) and a higher WBLH BMD in boys (0.029) than in group B.

Conclusion: A lower metabolic capacity/load in both sexes is associated with increased BMI and seems to compromise the lower limbs more than the upper limbs, particularly in skeletal mineralization, despite promoting earlier somatic maturity.

Keywords: Adiposity; Body Composition; Body Mass Index; Child; Growth

Introduction

Body composition assessment can be of added value in intercepting a developmental risk trajectory in pediatric ages. In addition to measurements of body mass, lean mass, or fat mass indexes (adjusted for height), it is important to analyze the relationship between lean mass and fat mass to assess homeostasis between metabolic capacity (muscle tissue) and metabolic load (adipose tissue). This model was proposed to study chronic disease in adulthood.[1]

Skeletal muscle is the most abundant tissue in the human body and has vital physiological functions, including posture, locomotion, and metabolic homeostasis. In skeletal muscle, 25% of ingested glucose is stored (or mobilized when needed as an energy source).[2] It is also in skeletal muscle that amino acids and triglycerides are stored. Muscle metabolism at rest determines considerable energy expenditure.[3]

It is known that the number of muscle fibers is established in embryonic and fetal life[4] After birth, muscle fibers increase in size rather than in number. Therefore, complications during pregnancy can affect future muscle development. Skeletal muscle mass and bone mineral density increase throughout childhood (slowly and proportionally to growth) and in adolescence (more quickly) starting to decrease around the age of 30.[5,6]

It was in 1964 that Forbes first described the sarcopenia phenotype in children. Sarcopenia results from decreased muscle mass and muscle strength, impacting health and motor performance. Several risk factors for sarcopenia include demographic factors [e.g., increasing age, female sex, and insufficient body mass index (BMI)]; medical conditions (e.g., chronic illness, malignancy, diabetes, and cognitive impairment); lifestyle and nutritional habits (e.g., physical inactivity, low protein intake, vitamin, or mineral deficiency).[7,8] The association of pediatric sarcopenia with medical conditions can be attributed to several factors, such as corticosteroid therapy, protein malabsorption or the presence of inflammatory cytokines and the insulin-like growth I (IGF-1).[9] Modifiable factors such as physical activity and nutrition are decisive for musculoskeletal

health.[10,11] However, in children, muscle mass gain is not synonymous with increased muscle strength, probably due to neuromuscular adaptations, unlike in adults.[12]

Sarcopenia contributes to greater cardiometabolic[13] and neurodevelopmental[14] risks because skeletal muscle tissue releases myokines that can cross the blood-brain barrier, promoting neurogenesis and synaptic plasticity.[15] and myokines are also essential for adequately developing bone tissue.[16] Several studies show associations between muscle volume and bone parameters such as mineral content, mineral density and bone area.[17,18] The optimal development of muscle mass and strength during childhood and adolescence is vital not only for bone growth and bone strength but also has beneficial effects in preventing cardiovascular disease, sarcopenia and osteoporosis in adulthood.[19,20]

Muscle mass is positively associated with body mass, where a greater or lesser muscle mass index (LBMI) generally results from a greater or lesser body mass index (BMI). However, a high BMI is associated with greater adiposity, presenting risks for short-term growth and development and long-term health. In this context, the metabolic load capacity index, the ratio between muscularity and adiposity, can be a promising marker for tracking possible risks. Therefore, this work aimed to compare growth and physical development among young people according to the metabolic capacity/load index.

Material and Methods

Participants

The sample consisted of 580 participants (283 girls and 297 boys) from 10 to 13 years old, attending 5th and 6th year grades, recruited from public schools. A trained group of evaluators evaluated all participants in May/June 2011. Informed consent was obtained from all guardians, and this study was approved by the FMH Research Ethics Council (CEI-FMH). General health status was assessed through a parental questionnaire (chronic illness, medication, and injuries/fractures) and confirmed in person at the Exercise and Health Laboratory of FMH, where all measurements were carried out. Chronic illnesses were reported in 11 participants with asthma, two participants with attention-deficit/hyperactivity disorder, one participant with unspecified thyroid disease, one participant with Kawasaki disease, one participant with 21-hydroxylase deficiency, one participant with epilepsy and one participant underwent appendectomy. Regarding bone fractures, they were reported in 37 participants (upper limb: 19; skull: five; remaining lower limb).

Anthropometry and Somatic Maturity

Body height and sitting height were measured with a stadiometer (Seca 770, Hamburg, Germany) to the nearest 0.1 cm and body mass with a scale (Seca Alpha model 770, Hamburg, Germany), to the nearest 0.1 kg, with subjects in underwear and without shoes. Body mass index (BMI) was calculated from the body mass/height ratio (kg/m^2). Somatic maturity was determined through the difference between chronological age and the age of peak height velocity (PHV) estimated by specific equations[21] from both a research perspective and youth sports stratification. A noninvasive, practical method predicting years from peak height velocity (a maturity offset value and expressed by the number of years of positive or negative deviation of the PHV.

Body Composition

LBM and fat body mass (FBM) were evaluated through a whole-body DXA scan (QDR Explorer, Hologic, Waltham, MA, USA), after 3 hours fast. Separately, these markers were adjusted for body height (kg/m^2). Furthermore, LBM was also adjusted to FBM to express the metabolic capacity/load index, that is, the LBM/FBM ratio. An LBM/FBM ratio with a z-score ≤ - 1 was considered a risk marker for the relationship between capacity and metabolic load.

Bone Mineralization

Bone mineral density (BMD, g/cm^2) of the whole-body less head (WBLH) was assessed using a whole-body DXA scan (QDR Explorer; Hologic, Waltham, EUA). The speed of sound (m/s) of the radius and tibia was also evaluated using ultrasound (Sunlight Omnisense TM, BeamMed Ltd; Tel Aviv, Israel).

Musculoskeletal Fitness

The handgrip strength (Handgrip, kg), the maximum isometric contraction for 2 seconds, was assessed standing, twice in each hand, using a dynamometer (Jamar, Lafayette, IN, USA); the best result (kg) was used for data analysis.

Statistical Analysis

We conducted a detailed analysis to illustrate the distribution characteristics of the variables, presenting them as both the average and standard deviation or as a percentage (in the case of prevalence). T-tests were performed to compare variables between high-risk and low-risk groups, separately for boys and girls.

Prior to the comparison analyzes conducted with t-tests for independent samples, the variables were standardized (z-scores) according to the means and standard deviations (SD) of the

respective sex and age group (11, 12 and 13 years old) of the sample. To compare age, and the multiple indicators of maturity, body composition, physical development, growth, and physical activity depending on sex, lean mass/fat mass ratio groups, the use of Student t-test for two independent samples was considered. When the assumption of population normality was not validated, the non-parametric alternative of the Mann-Whitney test was chosen. All statistical analyzes were performed with IBM SPSS Statistics 28.0 (Chicago, IL). The level of significance was set at - ≤ 0.05.

Results

Descriptive statistics (means and standard deviations) for the variables of interest are summarized in Table 1 for girls and boys.

Twenty-six percent of girls and 24% of boys (Table 2) with a high-risk metabolic capacity/load index, that is, ≤ -1 SD revealed: an earlier age of peak height velocity (girls: 11.6 - 12.0 years -≤0.001; boys: 13.3 - 13.9 years -≤0.001), higher BMI, (girls: 24.2 - 18.6 kg/m^2 -≤0.001; boys: 24.5 - 18.0 kg/m^2, -≤0.001) FBMI (girls: 9.8 - 5.1, kg/m^2 -≤0.001; boys:9.4 - 4.0 kg/m^2 -≤0.00) and LBMI (girls: 13.6 - 12.8, -≤0.001; boys:14.3 - 13.3,-≤0.001; boys:), and lower tibial bone resistance (girls: -0.9- 0.2 SD -≤0.01; boys: -0.98 - 0.34 SD -≤0.001). There were no differences between group A and B regarding the handgrip strength for boys or girls.

In group A, girls evidenced a shorter adult estimated height (girls: 165.3 - 167.2 cm -=0.024), and boys had a higher WBLH BMD z-score (0.40 - 0.80, -=0.029) than in group B (Fig. 1). There were no differences in radius bone integrity in both sexes.

Table 1. Characterization of the sample: age, maturity, height, body composition and physical development.

	Girls n=249	Boys n=237	*p*
Age, y	11.4 ± 0.6	11.5 ±0.6	0.016
Peak height velocity, y	11.9 ± 0.5	13.8 ±0.6	<0.001
Maturity offset, y	-0.04 ±0.68	-1.77 ±0.67	<0.001
Height, cm	153.3 ±7.6	150.4 ±8.0	0.007
Predicted adult height, cm	166.9 ±5.1	178.7 ±6.2	<0.001
Body mass, kg	45.7 ±9.9	43.6 ±10.8	0.024
BMI, kg/m^2	19.6 ±3.4	19.1 ±3.5	0.127
Fat mass, kg	13.8 ±5.8	11.3 ±6.3	<0.001
Fat mass, %	29.5 ±6.9	24.8 ±7.8	<0.001
FBMI, kg/m^2	5.9 ±2.4	4.9±2.5	<0.001
Lean mass, Kg	30.1 ±5.1	30.8 ±5.7	0.148
LBMI, kg/m^2	13.0 ± 1.4	13.5±1.5	<0.001
LBM/FBM	2.5 ± 0.8	3.3 ± 1.3	<0.001
Radial-US, m/s	3780 ±92	3776 ±97	0.666
Tibial-US, m/s	3679 ±116	3644 ±117	0.002
WBLH BMD, g/cm^2	0.754 ±0.077	0.749 ±0.069	0.386
Handgrip strength, kg	22.6 ±4.6	23.4 ±5.0	0.060

BMI, body mass index; FBMI, fat body mass index; LBMI, lean body mass index; WBLH, whole body less head; BMD, bone mineral density; US, ultrasound

Table 2. Age, maturity, height, body composition and physical development according to the metabolic capacity/load index (lean body mass/fat body mass).

	GIRLS			BOYS		
	LBM/FBM (z-score ≤ -1) A (n=46)	**LBM/FBM (z-score > -1) B (n=203)**	***p***	**LBM/FBM (z-score ≤ -1) A (n=42)**	**LBM/FBM (z-score > -1) B (n=195)**	***p***
Peak height velocity, y	11.6 ± 0.5	12.0 ± 0.4	0.001	13.3 ± 0.4	13.9 ± 0.4	<0.001
Predicted adult height, cm	165.3 ± 4.0	167.2 ± 5.2	0.024	179.4 ± 6.1	178.6 ± 6.2	0.453
BMI (kg/m^2)	24.2 ± 2.9	18.6 ± 2.5	<0.001	24.5 ± 3.9	18.0 ± 2.1	<0.001
Fat mass, %	40.2 ± 3.5	29.7 ± 4.9	<0.001	37.7 ± 4.3	21.9 ± 5.0	<0.001
FBMI, kg/m^2	9.8 ± 1.9	5.1 ±1.4	<0.001	9.4 ± 2.4	4.0 ± 1.2	<0.001
LBMI, kg/m^2	13.6 ± 1.4	12.8 ± 1.4	<0.001	14.3 ± 1.7	13.3 ± 1.3	<0.001
LBM/FBM	1.41 ± 0.19	2.67 ± 0.63	<0.001	3.65 ± 1.14	1.59 ± 0.28	<0.001
Radial-US, SD	0.19 ± 1.2	-0-18±1.04	0.064	0.13 ±1.41	0.01± 1.04	0.649
Tibial-US, SD	-0.89 ± 1.23	0.24 ± 0.92	0.001	-0.98 ± 1.37	0.34 ± 1.03	<0.001
WBLH BMD, SD	0.16 ± 0.80	-0.05 ± 1.04	0.513	0.40 ± 1.11	-0.8 ± 0.94	0.029
Handgrip strength, SD	0.20 ± 1.16	-0.05 ± 0.96	0.127	0.23 ± 1.11	-0.07 ± 0.95	0.080

BMI, body mass index; FBMI, fat body mass index; LBMI, lean body mass index; WBLH, whole body less head; BMD, bone mineral density; US, ultrasound; SD, standard deviation.

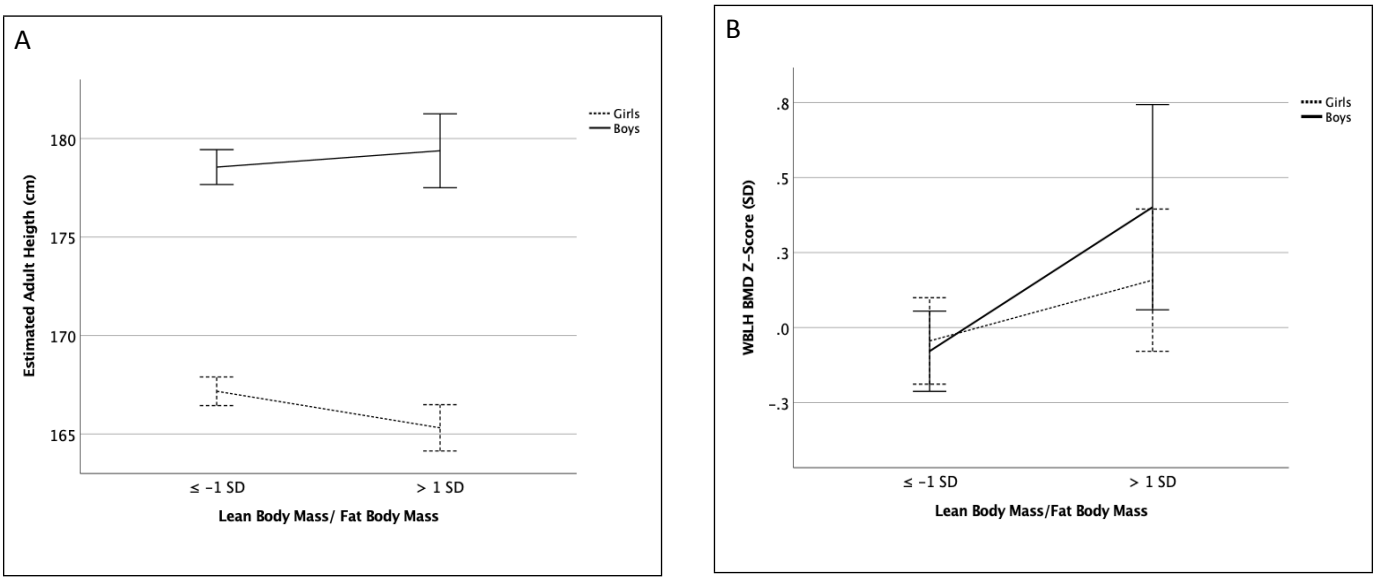

Figure 1. Estimated adult height (A) and WBLH BMD (B) according to the metabolic capacity/load index (≤-1 vs > -1 SD) in boys and girls.

Discussion

This study's main objective was to compare growth and physical development expressed through somatic maturity, BMI, LBMI, FBMI, WBLH BMD, bone integrity and handgrip strength of apparently healthy children according to the risk of low metabolic capacity relative to metabolic load.[22] The metabolic capacity/load model expressed through the LBM/FBM ratio, respectively, was used to identify participants at risk.[23] The metabolic capacity refers to the organs and tissues that maintain homeostasis. The metabolic load is represented by other body components, influenced mainly by lifestyle (food intake, sedentary behavior) that collectively challenge the maintenance of homeostasis.[24]

Orsso and colleagues (2019) suggested a metabolic load--capacity index to discriminate metabolic dysregulation emerging during childhood, leading to compromised health in adulthood or earlier. Several studies have investigated body composition in children and adolescents and confirmed that a low muscle mass relative to fat mass increases the risk of disease in this age group.[25,26] The metabolic capacity/load index is also a risk marker for sarcopenic obesity, a condition identified in the adult population when both conditions are present, according to defined criteria.[27-29]

About ~18% of the participants formed group A, which was considered at risk, meaning they had a body composition with an imbalance between capacity (low) and load (high).

As mentioned in the methodology, to identify participants at risk, reference values from the sample itself (mean and standard deviation) were used, meaning that it is not possible to compare the prevalence of risk between different studies. This type of imbalance in body composition denotes risk of sarcopenic obesity - defined as excessive fat mass in the presence of reduced lean mass.[29,30] There has been a notable rise in childhood and adolescent obesity due to the imprisonment of children's psychomotor development.[31] Indeed, caution is crucial because relying solely on body mass as the criterion for obesity might lead to an oversight. For instance, a child might not appear obese due to low lean body mass. This association, known as sarcopenic obesity, is considered more detrimental than obesity or sarcopenia alone, underlining the importance of comprehensive assessment beyond just body mass.[32,33]

The BMI in the risk group (group A) was higher in both sexes, but in girls, due to hormonal pressure, a more pronounced FBMI was observed than in boys. After the peak height velocity, boys tend to experience a greater increase in muscle mass than girls,[34] who acquire more fat mass. Overweight and obesity have been linked to an earlier onset of puberty, particularly in girls[35,36] a lower age at which peak height velocity occurs and a smaller magnitude of the growth spurt in both sexes.[37] Conversely, in slender children of both sexes, the age of peak height velocity occurs later compared to those with excess body fat.[38] Hormones like estrogens, androgens, growth hormone, and insulin-like growth factor 1 are pivotal in shaping growth and fat, lean and bone mass accrual. Before puberty, body composition alterations occur gradually and in tandem with overall body growth.[39,40]

The dysregulation between metabolic capacity and metabolic load seems to affect growth, with an earlier peak in PHV also conditioning a lower estimated adult stature in girls. The typical progression of growth and maturation relies on the available energy levels and the regulation of energy balance.[41] Consequently, energy intake and expenditure disparity can significantly influence these developmental processes. The proportion of adipose tissue observed in children and adolescents has demonstrated an inverse correlation with both sexual maturation (initiation of hypothalamic-pituitary-gonadal axis functioning, onset of secondary sex characteristics) and somatic maturation (age of peak height velocity and intensity of growth spurt).[35-38,41]

As for bone mass, the results showed differences between the groups regarding the lower limbs, namely lower strength in the tibia of the group with lower metabolic capacity (low lean mass) with no differences concerning the radius in the upper limbs. These data suggest that fat mass and lean mass may have differential relations to bone strength at weight-bearing vs non-weight-bearing bone in children and adolescents.[42] It may explain, in part, why obese children appear to be at greater risk of fracture, suggesting that the accumulation of fat mass represents an increased mechanical load on the skeleton and that bone resistance is not developed in proportion to body size.[43] The risk is more evident in the lower limbs than the upper limbs in both sexes despite a more significant mechanical load associated with a higher BMI in risk participants. These participants may also be less active in weight-bearing physical activities that require active locomotion. From a mechanical point of view, muscle contraction associated with physical activity is more relevant to the bone than the passive support of body mass.[44] Lean mass has a strong positive association between lean mass of the limbs and bone strength in both boys and girls, due to periosteal expansion, thicker cortex and optimized trabecular bone structure.[42] But other studies demonstrate that fat-bone has a weaker association during growth.[43] Evidence suggests that adipose tissue may increase secretion of citokines, estrogens, adiponectin that could mediate positive/negative effects in the bone.[45] Other known fact is that increased body fat exacerbates sarcopenia via lipotoxicity to myocytes.[28]

In summary, a risk metabolic capacity/load index is unfavorable to growth and physical development in both boys and girls. We used absolute handgrip to assess physical development like several pediatric studies have used measures of muscle mass or muscle function (e.g., appendicular muscle mass and handgrip strength) to identify sarcopenic children. However, there is no consensus on the definition of pediatric sarcopenia: Collins defined their sarcopenic population as those with a brachial circumference 15% below the study population's average[46]; Steffl used a predetermined muscle-fat ratio of two SD below the mean in patients with BMI from the 1st tertile to define sarcopenia[47]; Mager defined sarcopenia as a skeletal muscle z-score < -2 SD measured by dual-energy X-ray absorptiometry (DXA),[48] and Rezende measured skeletal muscle mass and handgrip strength, identifying sarcopenia in those with below-average values in both variables.[49] Handgrip strength is a non-invasive, portable, and low-cost test that can assess upper limb muscle strength (and correlates with overall muscle strength between 8 and 20 years old and can be used as a health predictor).[50-53]

We consider the lack of diversity and the short-term observational design a limitation. On the other hand, the information retrieved from almost 600 participants can be considered a strength. Also, we used DXA to assess the body composition, a reference for diagnosing sarcopenia and sarcopenic obesity.

Conclusion

A low metabolic capacity/load in both sexes expressed through LBM/FBM Z score ≤ -1 appears to compromise the

lower limbs' skeletal mineralization despite promoting earlier somatic maturity. Girls who are at risk are expected to have a shorter adult height. Low metabolic capacity/load is more evident in boys and girls with increased BMI for their age.

Responsabilidades Éticas

Conflitos de Interesse: Os autores declaram a inexistência de conflitos de interesse na realização do presente trabalho.

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Confidencialidade dos Dados: Os autores declaram ter seguido os protocolos da sua instituição acerca da publicação dos dados de doentes.

Proteção de Pessoas e Animais: Os autores declaram que os procedimentos seguidos estavam de acordo com os regulamentos estabelecidos pela Comissão de Ética responsável e de acordo com a Declaração de Helsínquia revista em 2013 e da Associação Médica Mundial.

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Ethical Disclosures

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Confidentiality of Data: The authors declare that they have followed the protocols of their work center on the publication of data from patients.

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Declaração de Contribuição

MM: Escrita do artigo
FB: Revisão do artigo

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