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RESEARCH

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Physical fitness components are bone mineral density predictors in adulthood: cross-sectional study

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Abstract

Background Health-related physical fitness (HRPF) attributes are considered important markers beneficial to various health outcomes. However, the literature is divergent regarding HRPF and bone health in adulthood, especially due to the end of the second and beginning of the third decades of life when the peak bone mass period occurs.

Objective To analyze which HRPF variables are areal bone mineral density (aBMD) predictors in adult males and females.

Methods This study evaluated 137 healthy young adults aged 18–25 years (50% males). Dual-energy X-ray absorptiometry (DXA) was used to estimate fat mass and lean mass and aBMD, hand grip strength test, sit-ups test, flexibility test, lower limb muscle strength and 20-meter run were used to evaluate physical fitness. Multiple linear regression using the backward method was used to analyze bone mineral density predictors by sex.

Results HRPF indicators showed correlations from $R=0.28$ in the right femoral neck aBMD to $R=0.61$ in the upper limbs aBMD in males; in females, correlations from $R=0.27$ in total body aBMD to $R=0.68$ in the lower limbs aBMD were found. In males, body mass and HRPF indicators were aBMD predictors with HRPF indicators explaining variance from $R^2=0.214$ in the lumbar spine to $R^2=0.497$ in the upper limbs, and in females, with the exception of the lumbar spine, variance from $R^2=0.237$ in the right femoral neck aBMD to $R^2=0.442$ in the lower limbs aBMD was found.

Conclusion Health-related physical fitness components were able to predict aBMD in different anatomical regions in young adults, especially muscle strength and cardiorespiratory fitness indicators for males, while only lean mass and fat mass for females.

Keywords Bone density, Young adult, Body composition, Physical fitness

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Background

Osteoporosis is a systemic and silent disease characterized by low bone mineral density, bone tissue microarchitecture deterioration and reduced bone strength, which can cause increased bone fragility in adults and older adults [1, 2]. It is estimated that around 20% of the world's population has bone fragility after the age of 50 years [3, 4], making osteoporosis a serious public health problem [5–8].

There are several non-modifiable risk factors such as ethnicity, age, sex, early menopause, genetic factors and modifiable factors such as diet, alcohol and tobacco abuse and physical activity, which are important determinants for bone mass accumulation and maintenance or increase in areal bone mineral density (aBMD) [9, 10]. In addition, studies have shown that the mechanical adaptations arising from the practice of physical activity and exercise are capable of optimizing bone mass gains until gain peak is reached, mainly by the interaction between bone and muscle through muscle contraction [10–12].

In this way, the practice of physical activity and exercise contributes to peak bone mass [10]. Furthermore, these exposures have the potential to maintain or improve a variety of health-related physical fitness (HRPF) attributes such as strength, flexibility, cardiorespiratory fitness (CRF) and body composition [13], which in turn are considered important health markers due to their positive association with various health outcomes [14–16].

However, information in literature regarding associations between bone health indicators and HRPF points to a certain divergence in the adult population, since studies have observed positive associations between HRPF indicators such as body composition [17–19], strength [17, 20–22], CRF [23–25] and flexibility [24] and others showing no associations with body composition [26], strength [18] and CRF [27], not considering physical fitness components in isolation [21–23, 26–30].

Therefore, during adulthood, especially during the end of the second and beginning of the third decades of life, which is the period characterized by peak bone mass [31], prediction studies can bring important additional information on the relationship between bone health and health-related HRPF indicators. It should be noted that the practice of physical activity and exercise can increase bone mass, which is crucial to prevent bone diseases such as osteoporosis and fragility, especially in stages of life in which peak bone mass is relevant. Thus, the present study aims to analyze which HRPF variables are aBMD predictors in adult males and females. It was hypothesized that subjects with higher HRPF indicators have higher aBMD, especially in bone regions with greater body weight support.

Methods

Study design

This cross-sectional study is the result of part of the database of a longitudinal study entitled "Physical fitness and practice of sports in childhood and adolescence and biological and behavioral risk factors in adulthood: a 15-year longitudinal study". Initially, students aged 7–10 years were recruited from a school located in the city of Londrina (Paraná, Brazil), with mixed longitudinal design, annually followed between 2002 and 2006 (baseline). The follow-up occurred in 2016, and after the entire process of screening and searching for individuals, a final sample of 137 adults was evaluated and described in previous studies [32].

Participants and sample size

This study had final sample of 137 healthy young adults that conducted bone densitometry (DXA) measurement, on which (50% males), aged 22.3±1.7 years, an explanatory power of 0.85 was obtained (f2=0.20; 1-β=0.85; α=0.05). This sample obtained explanatory power of 0.85 (f2=0.20; 1-β=0.85; α=0.05). The study was conducted in accordance with the National Health Council resolution (466/2012) and was approved by the Research Ethics Committee of the local university (Proc. 1.340.735/2015). All participants signed an informed consent form. As inclusion criteria, young adults should (i) not be injured or physically limited (e.g., asthma); (ii) have completed the same muscular fitness indicators battery in addition to dual energy x-ray absorptiometry (DXA), and the frequent use of medication to treat any disease that could interfere with the study variables was adopted as exclusion criterion.

Anthropometry

Anthropometry was assessed according to procedures described by Gordon, Chumlea and Roche [33]. Body mass was measured on a digital platform scale with precision of 0.05 kg. Harpenden portable stadiometer with 0.1 cm precision was used to measure height. Subsequently, body mass index (BMI) was calculated and expressed in kg/m^2.

Dual energy X-Ray absorptiometry (DXA)

DXA was used to estimate fat mass (FM) and lean mass (LM) in kilograms and aBMD in g/cm^2. Participants were positioned on the table in supine position with body aligned along with the central axis. A single certified technician performed scans using DXA (Lunar DPX-MD+, GE Lunar Corporation, 726 Heartland Trail, Madison, WI 53717−1915 USA). Data were obtained using the software recommended by the manufacturer (Software: enCORE version 4.00.145). Scans allowed body composition and aBMD calculations for total body, lumbar spine (L1-L4), upper limbs, lower limbs, right femoral neck. The equipment was previously calibrated according to the manufacturer. Full body scan was performed with participants in supine position and aligned, holding still for approximately 15 to 20 min. For the lumbar region, individuals were also positioned in dorsal decubitus, with legs placed on a block forming a 90-degree angle in relation to the table, with the intention of straightening the lumbar spine. For the proximal femur examination, for keeping participant positioned in dorsal decubitus, a triangular support was used to immobilize the lower limbs after internal rotation and adequate positioning of the femur, in order to capture the femoral neck region of interest.

Physical fitness

Considering the proposed objectives and for the HRPF assessment, three muscular strength/endurance tests were used, the abdominal muscle endurance test (Sit-ups test), the upper limb strength test (Hand grip strength test) and lower limb strength (Lower limb muscle strength test); flexibility test (sit-and-reach test) and cardiorespiratory endurance test (20 m Shuttle-run test).

The hand grip strength test (HS), which measures strength, was performed according to procedures described by Soares, Sessa [34], using Jamar Hydraulic Dynamometer (Sammons and Preston Scientific Industries Inc.) with precision of 1 kgf. Three measurements were performed in the dominant hand and the best score was used for analysis. Sit-ups test to assess abdominal muscle endurance, required a mat and a stopwatch. With participants in dorsal decubitus, hips and knees flexed, feet soles facing the ground, arms crossing the thorax, hands supported on shoulders, the evaluator was holding the feet of participants who were instructed to perform the maximum number of trunk elevation including a contact of the forearms with the thighs and return to the initial position, the test was performed only once for a period of 60 s and the total number of repetitions was used in the analyses. With participants in the supine position, hips and knees flexed, feet soles facing the ground, arms crossed on the chest, hands resting on the shoulders, the evaluator held the feet of participants who were instructed to perform the maximum number of trunk elevations, including contact of the forearms with the thighs and return to the starting position, the test was performed only once for a period of 60 s and the total number of repetitions was used in the analyses.

The total number of repetitions performed on a single trial was recorded. Lower limb muscle strength (LLMS) was determined using isokinetic dynamometer, resulting from reciprocal concentric muscle actions of knee flexion and extension performed on a calibrated dynamometer (Biodex System 3, Shirley, NY, USA) at angular speed of $60^{\circ}\cdot s^{-1}$. Subjects performed a 10-minutes warm-up of light jogging and 1 min of static stretching of hamstring and quadriceps muscles, and the equipment was adjusted for each subject following the manufacturer's guidelines. A series of three measurements was performed and the highest knee flexion and extension value of the right leg was used for the average value, expressed in Nm. For flexibility, the sit-and-reach test (SR) was used to measure forward trunk flexion, which consists of the individual in a sitting position trying to reach with the hands the greatest possible distance in relation to the initial position. Individuals were instructed to perform the test three times and the greatest distance measured in centimeters (cm) was used for analysis [35]. As an indicator of cardiorespiratory fitness, the 20 m Shuttle-run test was performed [36]. To estimate oxygen uptake (VO_2max) in milliliters of oxygen consumed per kilogram of body mass per minute (ml/kg/min), the equation proposed by the authors of the test was used: $VO_2max = -24.4 + 6.0$ (speed in km/h achieved in the test).

Data quality control

Regarding data quality control, the muscular fitness indicators of 25 randomly selected young adults (six females), after an interval of 7 days, were analyzed. Intraclass correlation coefficients for intra-observer reliability were: body mass (ICC = 0.99), height (ICC = 0.99), HS (ICC = 0.98), sit-ups (ICC = 0.90) and VO_{2max} (ICC = 0.98).

Statistical analysis

Data are described as mean and standard deviation. The Shapiro-Wilk test was applied to evaluate data normality. Descriptive statistics of the sample were summarized in Table 1, and the independent t-test was used for comparison between sexes. Pearson's Correlation Coefficient [37] was applied to observe the relationship between body size and HRPF with aBMD by sex, adjusted for chronological age. Multiple linear regression using the backward method was used to analyze aBMD predictors by sex and adjusted for chronological age. Data were analyzed using SPSS version 25.0. The significance level adopted was 5%.

Results

Table 1 presents body size, HRPF and aBMD descriptive data of different areas by sex. In the body size indicators, males presented greater body mass (20.7%), height (6.7%), body mass index (9%) and lean mass (33.8%); in HRPF indicators, only HS presented difference in favor of males (41.8%). In aBMD indicators, only lumbar spine did not present any difference between males and females ($p = 0.162$).

Table 2 presents correlations between body size, physical fitness and aBMD stratified by sex. For males, aBMD indicators showed weak to moderate positive correlations

Table 1 – Descriptive statistics and comparisons between males and females

Variables	Unit	Males (*n* = 69)	Females (*n* = 68)	t	*p*
Chronological age	years	22.4 ± 1.7	22.2 ± 1.7	0.554	0.587
Body mass	kg	76.1 ± 10.6	60.3 ± 10.7	8.694	**< 0.001**
Height	cm	176.5 ± 6.0	164.6 ± 6.7	10.991	**< 0.001**
Body mass index	kg/m^2	24.40 ± 2.9	22.21 ± 3.4	4.032	**< 0.001**
Fat mass	kg	17.2 ± 8.2	20.9 ± 7.6	-1.601	0.208
Fat mass	%	22.0 ± 8.11	33.8 ± 7,3	-8.990	**< 0.001**
Lean mass	kg	57.1 ± 6.8	37.8 ± 4.8	5.576	**0.018**
Lean mass	%	75.8 ± 9.3	63.6 ± 8.1	8.217	**< 0.001**
HS	kgf	49.7 ± 8.8	28.9 ± 5.6	4.784	**0.030**
LLMS extension	Nm	224.2 ± 41.4	144.7 ± 36.0	2.104	0.149
LLMS flexion	Nm	119.8 ± 21.7	69.9 ± 18.5	0.796	0.374
SR test	cm	30.9 ± 8.1	34.6 ± 8.0	-2.728	**0.007**
Sit-ups test	repeats	47.6 ± 5.4	37.3 ± 10.3	0.041	0.840
VO_{2max}	(ml/kg/min)	45.2 ± 5.4	34.6 ± 4.6	0.542	0.463
Bone mineral density					
Total body	g/cm^2	1.269 ± 0.091	1.167 ± 0.074	7.268	**< 0.001**
Lumbar spine	g/cm^2	1.205 ± 0.135	1.174 ± 0.123	1.406	0.162
Upper limbs	g/cm^2	0.945 ± 0.092	0.795 ± 0.049	11.974	**< 0.001**
Lower limbs	g/cm^2	1.430 ± 0.122	1.203 ± 0.095	12.146	**< 0.001**
Right femoral neck	g/cm^2	1.165 ± 0.184	1.038 ± 0.124	4.773	**< 0.001**

Note: HS = hand grip strength test; LLMS = lower limb muscle strength; SR = sit-and-reach test

Table 2 – Correlation of body size and physical fitness and areal bone mineral density indicators by sex

Variables	aBMD (g/cm)				
	Total body	Lumbar spine	Upper limbs	Lower limbs	Right femoral neck
Male (*n* = 69)					
Body mass (kg)	0.48**	ns	0.42**	0.28*	0.32**
Height (cm)	ns	ns	0.31**	ns	ns
Body mass index (kg/m^2)	0.45**	ns	0.29*	0.26*	0.28*
Fat mass (kg)	ns	ns	ns	ns	ns
Lean mass (kg)	0.45**	0.33**	0.57**	0.32**	0.35**
HS (kgf)	0.36**	ns	0.53**	ns	ns
LLMS extension (Nm)	0.65**	0.42**	0.62**	0.50**	0.47**
LLMS flexion (Nm)	0.56**	0.36**	0.61**	0.46**	0.40**
Sit-ups test (repeats)	0.39**	0.43**	0.44**	0.39**	ns
VO_2max (ml/kg/min)	0.32**	0.36**	ns	0.41**	0.28*
SR test (cm)	ns	ns	ns	ns	ns
Female (*n* = 68)					
Body mass (kg)	0.62**	0.52**	0.59**	0.68**	0.31**
Height (cm)	0.35**	ns	0.29*	0.43**	0.25*
Body mass index (kg/m^2)	0.53**	0.51**	0.53**	0.54*	ns
Fat mass (kg)	0.56**	0.49**	0.60**	0.61**	0.33**
Lean mass (kg)	0.59**	0.35**	0.46**	0.59**	ns
HS (kgf)	0.27*	ns	0.37**	0.34**	ns
LLMS extension (Nm)	0.47**	0.35**	0.47**	0.52**	ns
LLMS flexion (Nm)	0.45**	0.33**	0.45**	0.51**	ns
Sit-ups test (repeats)	ns	ns	ns	ns	-0.33**
VO_2max (ml/kg/min)	ns	ns	ns	ns	ns
SR test (cm)	ns	ns	ns	ns	ns

Note: HS = hand grip strength test; LLMS = lower limb muscle strength; SR = sit-and-reach test; * = <0.05; ** = $P < 0.01$; ns = not significant; adjusted by chronological age with body composition (R=0.26 to 0.57) and HRPF (R=0.28 to 0.62), except for FM and flexibility (P>0.05). In females, aBMD indicators showed weak to moderate positive correlations with body composition (R=0.25 to 0.68) and HRPF (R=0.27 to 0.47), except for flexibility and VO_2max (P>0.05), and the sit-up test, which showed moderate negative relationship with right femoral neck (R = -0.33).

Table 3 presents body size and HRPF aBMD predictors stratified by sex. In males, body mass and HRPF indicators were aBMD predictors. Total body aBMD was predicted by body mass, LLMS extension and VO_2max (R^2 = 0.547), upper limb aBMD by body mass, HS, LLMS extension and the sit-up test (R^2 = 0.571), and lower limbs aBMD by LLMS extension and VO_2max (R^2 = 0.370) and right femoral neck aBMD was predicted by LLMS extension and VO_2max (R^2 = 0.254). Lumbar spine aBMD was only estimated by VO_2max fitness indicator (R^2 = 0.283). In females, only FM and LM body size indicators presented total body (R^2 = 0.476), upper limbs (R^2 = 0.465) and lower limbs aBMD as predictor (R^2 = 0.517). Body mass was predictive only of right femoral neck (R^2 = 0.294).

Discussion

The aim of this study was to analyze which health-related fitness variables are aBMD predictors in adulthood. The main finding was that in males, HRPF indicators such as body mass, muscular strength (LLMS and HS), resistance (sit-ups) and CRF were able to predict aBMD in different anatomical regions. While for females, only body composition indicators, lean mass and fat mass, were the main aBMD predictors. These results suggest that different HRPF components predict aBMD distinctly in both sexes.

In the case of males, positive associations between aBMD in different anatomical regions were also found in other studies with muscle strength and endurance [21, 24], body mass [38], and CRF [24, 38]. Muscle strength, especially LLMS extension, seem to be the most predictive aBMD components in all body regions, with the exception of the lumbar spine. Since it is a movement that primarily uses the quadriceps femoral muscle, which originates above and below the quadriceps joint, LLMS appears to play an indirect role in different anatomical regions [39]. In relation to sit-ups, unexpectedly it was shown to be associated with aBMD upper limbs. This fact may be related, em partes, to the interaction between bone and muscle, which through mechanical stimuli generated by muscle contraction would provide greater aBMD in males [40]. Regarding CRF, although a limited number of studies were identified with the age range of the present study, similar results were observed in the literature [38, 41]. Regarding abdominal exercises, it was unexpectedly associated with upper limbs aBMD. This fact may be related, at least in part, to the interaction between bone and muscle, which through mechanical stimuli generated by muscle contraction would provide

Table 3 – Significant areal bone mineral density predictors stratified by sex

Variables	Predictors	B	*p*	VIF	R^2	Adjusted R^2	*p*
	Male (*n*=69)						
aBMD Total body	Body mass	0.002	0.028	1.824	0.547	0.468	< 0.001
	LLMS extension	0.001	< 0.001	1.760			
	VO_2max	0.005	0.001	1.192			
aBMD Lumbar spine	VO_2max	0.005	< 0.001	1.017	0.283	0.214	0.002
aBMD Upper limbs	Body mass	0.003	0.016	1.601	0.571	0.497	< 0.001
	HS	0.003	0.011	1.347			
	LLMS extension	0.001	0.005	1.617			
	Sit-ups test	0.002	0.022	1.212			
aBMD Lower limbs	LLMS extension	0.001	0.001	1.017	0.370	0.351	< 0.001
	VO_2max	0.008	0.003	1.017			
aBMD Right femoral neck	LLMS extension	0.002	0.001	1.436	0.276	0.254	< 0.001
	VO_2max	0.011	0.004	1.436			
	Female (*n*=68)						
aBMD Total body	Fat mass	0.004	< 0.001	1.250	0.476	0.394	< 0.001
	Lean mass	0.007	< 0.001	1.250			
aBMD Upper limbs	Fat mass	0.003	< 0.001	1.250	0.465	0.382	< 0.001
	Lean mass	0.003	0.019	1.250			
aBMD Lower limbs	Fat mass	0.005	< 0.001	1.250	0.517	0.442	< 0.001
	Lean mass	0.008	< 0.001	1.250			
aBMD Right femoral neck	Body mass	0.006	< 0.001	1.034	0.294	0.237	0.001

Note: aBMD=areal bone mineral density; HS=hand grip strength test; LLMS=lower limb muscle strength; adjusted by chronological age greater aBMD in males [40]. Regarding CRF, although a limited number of studies with the age group of the present study were identified, similar results were observed in literature [38, 41]. In addition, Lee, Kim and Kang [23] observed that high CRF was able to attenuate BMD loss and reduce the risk of low BMD in adults over the age of 50 years.

The association between LLMS, HS, sit-ups and CRF with aBMD in different anatomical regions, are in agreement with the mechanotransduction hypothesis that through osteocytes respond to forces at cellular levels with signals that are relayed throughout the bone tissue network through gap junction channels and by the release of chemical messengers that act on neighboring cells [42, 43]. The association between LLMS, HS, sit-ups and CRF with aBMD in different anatomical regions is in accordance with the mechanotransduction hypothesis, which, through osteocytes, respond to forces at cellular levels with signals that are retransmitted throughout the bone tissue network, through gap junction channels and by the release of chemical messengers that act on neighboring cells.

Regarding females, muscle strength and resistance, flexibility and CRF indicators were not aBMD predictors. These results differ from other cross-sectional and longitudinal studies. For example, in a sample of Iranian women, positive associations were found between upper and lower limb strength with lumbar spine and femoral neck aBMD [20]. A 20-year longitudinal study indicated that muscle strength was aBMD predictor in different anatomical regions between adolescence and adulthood [44]. Similarly, Bailey et al. [45] observed that muscle strength and body composition were aBMD predictors in regions such as femoral neck, upper neck, lower neck, and trochanter. In fact, muscle strength and endurance indicators appear to play an important role in bone health; in some ways, the divergent results found for females appear to be related to insufficient mechanical stimuli in the sample, which may not reach the thresholds necessary to generate aBMD gains [46].

In the case of CRF, the literature has pointed to divergences between results, with studies showing association with lumbar spine and femoral neck aBMD [47] and in other anatomical regions [38]. In contrast, Tucker et al. [48] pointed out that high CRF is not enough to protect females from losing hip aBMD over time, regardless of age and menopausal status.

On the other hand, LM, FM and body mass were able to predict aBMD in different anatomical body regions. This result is similar to other studies that showed positive associations between LM [28, 29, 49] and FM [29]. Possible explanations for associations between aBMD and fat mass and LM may be related with physiological and mechanical factors. Physiological factors are related to FM, which through leptin secretion and the indirect effect of insulin could increase the action of osteoblasts and reduce osteoclasts [50, 51]. Regarding mechanical factors, the mechanosensation and transduction theory would explain the association of LM with aBMD, since bone tissue deformation caused by muscle action would generate hydrostatic and fluid flow changes in bone tissues, activating the action of osteocytes and the signaling of osteoclasts and osteoblasts [52]. However, the positive association between FM and aBMD in females should be analyzed with caution, since studies have pointed out the negative effect of FM on aBMD in obese individuals [28, 53], mainly via low-grade chronic inflammation processes, increasing cytokine concentrations and osteoclast activity [53, 54].

HRPF appears to influence bone mass gain differently in males and females. A possible explanation could be the hormonal differences between sexes that occur from adolescence. In males, testosterone promotes an increase in muscle mass and consequently in muscle strength and endurance, while in females, estrogen affects the location and amount of body fat. In addition, estrogen inhibits bone modeling, directly affecting osteoblastic activity and bone repair [55]. Due to this difference, females would need a mechanical stimulus with longer duration and greater intensity to obtain bone response similar to that of males [21, 56].

This study has advanced in analyzing various HRPF components (body composition, muscle strength and endurance, flexibility and cardiorespiratory fitness) in young adults of both sexes, especially in this age group, as a shortage of studies has been identified for this age range, furthermore, analyzing aBMD of various anatomical body regions and body composition by DXA and LLMS estimation by isokinetic dynamometer, especially in this age group, as a shortage of studies including this age group was observed, in addition, it analyzed aBMD of several anatomical regions of the body and body composition through DXA and the estimation of LLMS through isokinetic dynamometer.

Limitations include the cross-sectional design that does not establish a cause-effect relationship, lack of control of information on physical activity, diet, and consumption of alcoholic beverages, tobacco and hormones. Thus, future studies should carry out longitudinal analyses, taking into account possible confounding factors for a better understanding of the different HRPF indicators in adulthood.

Conclusion

Health-related physical fitness components were able to predict aBMD in different anatomical regions in young adults, especially muscle strength and CRF indicators in males, while only lean mass and fat mass in females.

Abbreviations

HRPF Health	related physical fitness
aBMD	Areal bone mineral density
DXA	Dual-energy X-ray absorptiometry
CRF	Cardiorespiratory fitness
BMI	Body mass index
FM	Fat mass
LM	Lean mass
HS	Handgrip strengths
LLMS	Lower limb muscle strength

Supplementary Information

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Supplementary Material 1

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Author contributions

Conceptualization: JCC and MCMF. Data curation: JCC and CCLB. Formal analysis: JCC, RGC and MCB. Writing – original draft. JCC, MCMF, ABG and LFCCC. Writing – review & editing: ERVR. All authors reviewed the manuscript.

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Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The study was conducted in accordance with the National Health Council resolution (466/2012) and was approved by the Research Ethics Committee of of State University of Londrina, Paraná, Brazil (Proc. 1.340.735/2015). All participants signed an informed consent form.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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