Investigating the Deformation Parameters of PVC Fitness Balls in Relation to the Height and Body Mass Index of the Users

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The aim of the study was to measure the goniometric differences of the knee and hip joints and the changes regarding the features of fitness balls by taking into consideration its circumference and the vertical and horizontal diameters under the action of the body weight. The outcomes of the study have resulted in the creation of a table with reference values regarding the size of fitness balls in relation to the height and body mass index of the subjects.

Keywords: PVC ball, goniometry, somatometry, health, fitness

Plastic materials have been widely used in physical, kinetoprophylactic and therapeutical activities, as well as in the manufacturing of certain materials, equipment, devices, clothes and accessories for exercise and sports facilities [1,2]. Fitness balls are manufactured of 100.0% polyvinyl chloride (PVC), non-phthalate, with anti-slip and anti-burst characteristics. Considering the thickness of the material variable strength and stability is provided [3]. From a mechanical point of view, fitballs must have the same properties as plastics, namely: elasticity, stiffness, anti-burst and tension [4-8].

The fitness ball, also known as the Swiss-ball, is used in three major categories of human activities: physical therapy, sports and recreational activities and lucrative work that requires work performed in a seated position.

Invented in 1963 by an Italian plastic manufacturer Aquilino Cosani [9], the Swiss ball was later used by many physiotherapists for therapeutic purposes, such as functional recovery and rehabilitation, proven by numerous scientific studies [10]. The sanogenic benefits of using fitness balls are: mitigation and prevention of muscle pain in the coxofemoral and knee joints, as well as the joints of the vertebral column, postural control, and correction, rehabilitation of certain physical deficiencies, post-operative rehabilitation and cardiorespiratory improvement [11-15]. During sports and recreational activities, the fitball is used in most exquisite workout programs due to postural and movement adaptations to the elasticity and relative instability of the ball that allow differential activation of muscle groups without increasing the total weight, causing the tonification of the muscles of the trunk, postural correction, improvement in flexibility, muscle strength and optimization of body coordination and ideomotricity [16-18]. Due to its ergonomic and biomechanical characteristics, many people use the fitness ball to replace the traditional chair for postural correction and toning [19-21].

Fitball can also be used in the treatment of certain physical health problems (physical exercise for health), depending on the age of the patient. It is important to enhance these activities so as to be recreational, fun and, in the same extent, useful. The technical specifications and the use of Decathlon fitness balls, also called fitballs, are insufficient because the diameter of the balls is related only to subjects' height. We believe that a thorough analysis of the correct upright sitting position, regarding the anthropometric and goniometric parameters with reference to the level of deformation of the fitness ball parameters, will allow the creation of a table through which we will be able to correlate users' choice in selecting the size of the balls in relation to their height and BMI.

The aim of the research was to highlight the postural angular differences in the upright sitting position and the deformation (vertical and horizontal diameter, circumference) of fitness balls under the action of the body weight in relation to the height and the BMI of the subjects in order to develop accurate and detailed technical specifications necessary in choosing fitballs.

Experimental part

Materials and methods

The study was conducted between October - November 2017 and aimed to evaluate a sample of 1,607 adult subjects divided into 4 subgroups according to their BMI reference values, as follows: 433 underweight subjects in subgroup 1 with BMI below 18.49, 499 normal weight subjects in subgroup 2 with BMI between 18.5 - 24.49, 419 overweight subjects in subgroup 3 with BMI between 24.5-29.99 and 256 obese (class I) subjects in subgroup 4 with BMI over 30. The sample consisted of 958 women (59.61%) and 649 men (40.38%) with a mean age of 31.23 years. The subjects voluntarily agreed to participate in the study and were recruited from the University of Medicine and Pharmacy, Tirgu Mures, from 8 Fitness centers from Targu Mures and Brasov and 3 Recovery centers from Targu Mures. The tests were conducted on the basis of the ethical principles on human subjects in accordance with the 2008 Helsinki Declaration. The height (cm) and the weight (kg) of each subject was measured using an electronic scale. The BMI calculation formula was:

$$BMI = \text{weight (kg)} / \text{height (cm)}\ 2 \quad (1)$$

With the help of a goniometer, the angles of the knee and hip joint were measured as well. The circumference of the fitness ball was measured using a 3 m body circumference measurement band while for the measurement of the vertical and horizontal diameters a 3 m glass fiber tape roulette was used.

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Procedure

The test was performed in a sitting position with the back in a vertical and straight posture, and the angles formed at the level of the ankle, knee and coxa-should be as close as possible to 90° in order to achieve a correct position (between the thigh and trunk). The purpose of the study was to assess these angles and the deviations from the correct value of maintaining a 90° upright sitting position. We considered that a deviation of ± 10° from the 90° reference value at the level of the knee and hip joints was tolerable, so the values between 80° - 100° were considered to be within normal limits. The goniometric deviations from these values reflected in the deformation values of the ball under the body weight were the benchmarks for indicating the correct ball size relative to subjects' height and BMI. The size of the ball was selected by taking into account the subjects' height and the usage specifications of the ball, thus: for subjects with a height up to 165 cm a small ball with 55 cm in diameter is recommended, for subjects with a height between 165-185 cm a medium ball with 65 cm in diameter is suggested, and for subjects with a height of 185 cm a ball with a diameter of 75 cm is recommended. In order to carry out the experiment we have chosen to use the Decathlon balls which were inflated, according to the manufacturer's specifications for the following diameters: small ball at 55 cm, medium ball at 65 cm, large ball at 75 cm. The goniometric evaluation and the deformation parameters of the fitness balls were performed by asking subjects to sit on the center of the ball, in a straight position by maintaining their heads in a neutral position, their hands resting on the ball, with their legs open (at a distance equal to the width of their shoulders) and by keeping both their feet on the ground. The correct position on the ball involves a straight angles (90°) between the trunk and thigh (hip joint) nad between the thigh and the calf (knee joint).

Statistical analysis

The results of the research were processed in SPSS 20., by calculating the statistical indicators: arithmetic mean (X), standard deviation (SD), one sample t- Student test; One-Sample Kolmogorov-Smirnov Z test (ZKS). The statistical significance threshold considered to be relevant for the research was $p < 0.05$. The investigated parameters were reported by indicating X ± SD.

Results and discussions

The goniometric evaluation of the 433 subjects from the 4 subgroups in relation to the ascending BMI reference value (subgroup 1 underweight versus subgroup 2 normal weight, subgroup 2 normal weight versus subgroup 3 overweight and subgroup 3 overweight versus subgroup 4 representing the obese subjects) revealed the following differences for the knee joint (°):7.91 / 13.59 / 9.01 and for the hip joint (°): 8.61 / 9.38 / 13.13. The assessment of the characteristics of the ball under body weight pressure, between the 4 subgroups in an ascending BMI order, highlighted the following differences for: horizontal diameter (cm): 1.87 /0.74 / 0.73, vertical diameter (cm): 1.65 / 0.69 / 0.64 and circumference (cm): 2.76 / 2.84 / 1.67. The ZKS values for all the assessed parameters revealed that the distribution is normal, the results being statistically significant for $p < 0.05$. The t-Student test values are statistically significant for $p < 0.05$, the null hypothesis is rejected (table 1).

The sample with a height of 165 to 175 cm comprised 499 subjects and the goniometric evaluation recorded the following differences between the 4 subgroups for the knee joint (°): 6.37 / 3.42 / 2.33, and for the hip joint (°): 6.88 / 2.02 / 1.77. The evaluation of the deformation of the fitball under the pressure of the subjects' body weight presented the following differences between the 4 subgroups (differences between subgroups 1-2, subgroups 2-3, subgroups 3-4): horizontal diameter (cm): 2.88 / 2.55 / 0.54, vertical diameter (cm): 0.67 / 0.81 / 1.16, circumference (cm): 3.16 / 1.46 / 2.47. The sample consisting of 419 subjects with a height between 175 - 185 cm registered the following differences with reference to the goniometric evaluation between the 4 subgroups (in ascending order of the BMI): for the knee joint (°): 10.21 / 14.48 / 5.21 and for the hip joint (°):13.23 / 11.72 / 4.86. Under the action of the body weight the fitballs suffered statistically significant deformations for $p < 0.05$, thus between the 4 subgroups the differences were the following: horizontal diameter (cm): 1.2 / 4.26 / 2.25, vertical diameter (cm): 2.67 / 5.20 / 2.17 and circumference (cm): 0.80 / 1.23 / 0.72 (table 2).

Table 1

THE RESULTS OF THE GONIOMETRIC EVALUATION AND THE DEFORMATION CHARACTERISTICS OF A 55 cm DIAMETER BALL FOR SUBJECTS WITH A HEIGHT OF 155-165 cm IN RELATION TO THE BMI REFERENCE VALUES (DESCRIPTIVE-STATISTIC)

Ball	H (cm)	Subgroups (1-4)	Statistical indicators	Somatic evaluation		Goniometric evaluation		Evaluation of ball characteristics		
		BMI / n		Height (cm)	BMI	Knee (°)	Hip (°)	Horizontal diameter (cm)	Vertical diameter (cm)	Ball circumference (cm)
Small ball (55cm)	155-165	< 18.49 / 108	X±SD	161.162± 2.411	17.509± .710	103.861± 6.237	102. 888± 5.811	56.026± 3.641	45.746± 11.044	191.811± 1.123
			t	694.427*	255.995*	194.185*	209.288*	159.878*	43.987*	1774.729*
			ZKS	2.564*	2.927*	1.862*	1.759*	2.161*	2.091*	2.112*
		18.5-24.9 /144	X±SD	159.331± 4.027	21.088± 2.180	95.951± 6.708	94.270± 4.526	57.893± 2.932	44.096± 1.054	194.572± 1.672
			t	474.738*	116.055*	171.648*	249.897*	236.891*	490.250*	1395.683*
			ZKS	2.086*	2.262*	1.582*	1.849*	2.133*	2.072*	1.372*
		25.-29.9 / 125	X±SD	161.955± 3.941	27.317± 1.162	82.360± 5.751	84.892± 5.264	58.639± 1.019	43.408± .527	197.419± .951
			t	459.350*	262.831*	129.771*	150.406*	643.379*	941.386*	2319.614*
			ZKS	4.344*	1.555*	2.484*	2.427*	2.039*	3.592*	2.876*
		> 30 / 56	X±SD	159.955± 2.308	31.397± .790	73.358± .723	71.762± .567	59.364± .388	42.767± .047	199.085± .280
			t	518.487*	297.323*	758.692*	945.809*	1144.355*	7108.985*	5310.595*
			ZKS	2.270*	2.323*	1.705*	2.097*	2.448*	3.225*	1.809*

H- subjects' height, BMI – body mass index, n – number of subjects, X – arithmetic mean, SD = standard deviation, T – student test, ZKS - Kolmogorov-Smirnov Z test, * statistically significant for $p<0.05$.

Table 2

THE RESULTS OF THE GONIOMETRIC EVALUATION AND THE DEFORMATION CHARACTERISTICS OF A 65 cm DIAMETER BALL FOR SUBJECTS WITH A HEIGHT OF 165-185 cm IN RELATION TO THE BMI REFERENCE VALUES (DESCRIPTIVE-STATISTIC)

Ball	H (cm)	Subgroups (1-4) BMI / n	Statistical indicators	Somatic evaluation		Goniometric evaluation		Evaluation of ball characteristics		
				Height (cm)	BMI	Knee (°)	Hip (°)	Horizontal diameter (cm)	Vertical diameter (cm)	Ball circumference (cm)
Medium ball (65cm)	165-175	< 18.49 / 136	X±SD	170.735± 1.858	17.656± .402	106.985± 2.394	104.014± 6.111	61.497± 3.453	54.355± 3.235	210.614± 2.474
			t	1071.143*	511.471*	521.073*	192.762*	207.680*	195.903*	40.600*
			ZKS	4.433*	1.747*	2.891*	2.652*	3.785*	5.082*	5.854*
		18.5-24.9 /152	X±SD	171.375± 2.513c	20.547± 2.44119	99.618± 7.896	98.131± 5.334	64.307± 1.756	53.686± 4.647	213.773± 2.982
			t	840.534*	103.774*	152.409*	217.543*	492.613*	326.648*	883.713*
			ZKS	5.428*	4.528*	4.055*	4.608*	4.917*	2.866*	3.427*
		25.-29.9 / 127	X±SD	170.241± 1.137	26.771± 1.012	96.196± 7.084	96.110± 6.516	66.092± 1.654	52.878± 2.033	215.239± 4.146
			t	1687.256*	298.044*	153.020*	166.212*	412.512*	135.023*	593.117*
			ZKS	2.667*	2.785*	1.917*	1.352*	5.086*	3.318*	4.146*
		> 30 / 84	X±SD	170.423± 2.579	30.735± .595	93.869± 3.935	94.345± 2.131	67.465± 1.984	51.177± 2.165	217.702± 1.839
			t	605.438*	473.124*	218.602*	405.728*	311.506*	216.621*	1084.476*
			ZKS	1.775*	1.571*	2.229*	2.032*	2.526*	2.111*	2.380*
	175-185	< 18.49 / 102	X±SD	183.379± 2.083	17.531± 2.124	103.125± 2.657	104.241±5 .715	72.132± 2.873	56.879± 3.083	217.672± 2.349
			t	791.841*	157.409*	178.876*	132.256*	381.547*	152.261*	417.811*
			ZKS	3.481*	4,142*	2.544*	2.431*	2.279*	3.302*	2.582*
		18.5-24.9 /159	X±SD	180.339± 2.773	21.883± 2.098	92.911± 11.260	91.018± 14.461	70.937± 9.733	54.200± 14.747	218.471± 19.958
			t	819.808*	131.470*	104.041*	79.361*	91.902*	50.616*	144.346*
			ZKS	4.064*	3.396*	4.379*	5.783*	4.801*	4.367*	5.750*
		25.-29.9 / 86	X±SD	182.581± 3.266*	28.618± 1.276*	78.430± 3.906	79.290± 4.311	66.679± .789	49.004± .282	219.704± .103
			t	518.356*	207.885*	186.191*	170.565*	782.923*	1606.945*	1960.950*
			ZKS	3.695*	3.145*	1.648*	2.093*	3.731*	3.984*	3.077*
		> 30 / 72	X±SD	183.477± .757	30.817± .415	73.222± 1.484	74.430± 1.852	64.420± .176	46.833± .282	220.422± .38354
			t	2054.147*	628.597*	418.561*	340.927*	3092.200*	1405.000*	4876.499*
			ZKS	3.651*	3.322*	1.801*	1.732*	4.523*	4.523*	3.550*

H- subjects' height, BMI – body mass index, n – number of subjects, X – arithmetic mean, SD = standard deviation, T – student test, ZKS - Kolmogorov-Smirnov Z test, * statistically significant for p<0.05.

Table 3

THE RESULTS OF THE GONIOMETRIC EVALUATION AND THE DEFORMATION CHARACTERISTICS OF A 75 cm DIAMETER BALL FOR SUBJECTS WITH A HEIGHT OF 185-195 cm IN RELATION TO THE BMI REFERENCE VALUES (DESCRIPTIVE- STATISTIC)

Ball	H (cm)	Subgroups (1-4) BMI / n	Statistical ndicators	Somatic evaluation		Goniometric evaluation		Evaluation of ball characteristics		
				Height (cm)	Height (cm)	Knee (°)	Hip (°)	Horizontal diameter (cm)	Vertical diameter (cm)	Ball circumference (cm)
Large ball (75cm)	185-195	< 18.49 / 64	X±SD	186.164± .976	17.620±.6 25	115.384± 9.254	116.046± 9.743	81.968± 1.007	67.798± 17.780	257.862± 34.252
			t	1525.744*	225.207*	99.742*	95.282*	818.209*	738.277*	53.220*
			ZKS	1.659*	1.382*	2.554*	2.312*	25610*	2.780*	2.780*
		18.5-24.9 /77	X±SD	187.194± 2.257	22.423± 1.252	96.909± 6.645	97.584± 4.540	84.189± 5.242	60.424± 3.107	265.289± 2.342
			t	727.651*	157.159*	127.962*	188.599*	140.920*	170.635*	993.894*
			ZKS	1.754*	1.532*	1.970*	1.839*	2.038*	1.613*	2.360*
		25.-29.9 / 62	X±SD	187.677± 2.298	26.546± .989	86.645± 3.041	87.451± 3.237	86.146± .430	57.229± .842	267.580± 1.397
			t	643.050*	211.279*	224.332*	212.695*	1538.450	534.680*	1502.240*
			ZKS	2.888*	2.286*	1.754*	1.800*	3.054*	1.924*	2.286*
		> 30 / 53	X±SD	187.755± 1.037	30.794± .424	75.534± 2.538	76.953± 3.039	88.725± .392	54.879± .563	270.179± .726
			t	1186.998*	475.235*	195.103*	166.044*	1433.146*	638.272*	2437.365*
			ZKS	1.906*	1.616*	1.843*	1.936*	2.077*	2.251*	2.190*

H- subjects' height, BMI – body mass index, n – number of subjects, X – arithmetic mean, SD = standard deviation, T – student test, ZKS - Kolmogorov-Smirnov Z test, * statistically significant for p<0.05.

Table 2. highlights the ZKS values for all assessed parameters, which show that the distribution is normal, the results being statistically significant for p <0.05 and the null hypothesis is rejected

Table 3. emphasizes the t and ZKS values for all assessed parameters by which the null hypothesis is rejected as the distribution is normal but the results were highly statistically significant for p <0.05. Among the 4 subgroups (subgroups

155-165	Very small ball (45 cm)	Small ball (55 cm)	Small ball (55 cm)	Medium ball (65 cm)
165-175	Small ball (55 cm)	Medium ball (65 cm)	Medium ball (65 cm)	Medium ball (65 cm)
175-185	Small ball (55 cm)	Medium ball (65 cm)	Medium ball (65 cm)	Large ball (75 cm)
185 -195	Medium ball (65 cm)	Large ball (75 cm)	Large ball (75 cm)	Large ball (85 cm)

Table 4
TABLE PROPOSAL REPRESENTING THE REFERENCE VALUES OF FITBALL DIMENSIONS ACCORDING TO SUBJECTS' BMI AND HEIGHT

1-2, subgroups 2-3, subgroups 3-4), the goniometric evaluation revealed the following differences: for the knee joint (°):18.48 / 10.26 / 11.11 and for the hip joint (°): 18.46 / 10.13 / 10.50. The ball suffered statistically significant deformations for $p < 0.05$ exerted by the subjects' body weight, so between the 4 subgroups the following differences were recorded for: horizontal diameter (cm): 2.22 / 1.96 / 2.58, vertical diameter (cm): 7.37 / 3.20 / 2.35 and circumference (cm): 7.42 / 2.30 / 2.59.

In order to achieve the desired results and not to develop side effects especially in patients with various diseases, the recommendation of performing physical exercises, in these situations, must be very precise. From this perspective, these results are useful for all those who use the fitball, but it is mandatory to be applied by specialists who use it for health related physical activities (for therapeutic or prophylactic purposes) with their patients. The prescribed exercises should be strictly personalized (taking into account the state of health, personal, family and anthropometric data, exercise capacity, laboratory tests, ECG, etc. of the subjects) and their safety of is completed by the data of this study. The detailed description and the type of the prescribed physical exercise should be based on scientifically proven data for their assessment in precise conditions. Fitballs must be specifically used for the prescribed exercise according to the data presented in the study.

Conclusions

The correct choice of the balls in relation to the height and BMI of the subjects is a very important factor in maintaining a healthy lifestyle, streamlining physical effort and postural optimization by using them in an upright sitting position. The results of the research reveal that by correlating subjects' height with their BMI, the criteria for choosing fitness balls are different and optimal compared to the specifications recommended by the manufacturers which highlight subjects' height in relation to the diameter of the balls as the only criteria to be taken into account when it comes to choosing them. The validation of the goniometric changes and the characteristics of the fitness balls as a result of the investigation performed on 1,607 adult subjects allowed us to create a table with reference values in choosing the size of the balls relative to subjects' height and BMI, a table that we would like to propose to the manufacturers (table 4).

Fitness balls manufactured of 100.0% polyvinyl chloride (PVA) under the action of the body weight in the upright sitting position suffer significant changes in the vertical and horizontal diameters and the circumference in relation to the height and weight of the subjects. Many specialists who want to be creative in indicating physical activity as a lifestyle will certainly use the results of our evidence-based indications.

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Manuscript received: 18,.05.2017