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Muscle Function in Saudi Children and Adolescents: Relationship to Anthropometric Characteristics During Growth

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The main purpose of the present study was to determine isokinetic strength and endurance, isometric strength, and anaerobic power for untrained healthy Saudi children and adolescents. The secondary purpose was to evaluate the effects of age in relation to anthropometric characteristics on strength and anaerobic performances. Forty-four (untrained) 11- to 19-year-old boys were grouped by age: 11–13 years, 14–16 years, and 17–19 years. All participants underwent anthropometric measurements, a flexibility test, a vertical jump test, a grip strength test, isokinetic strength measurements (Cybex Norm), and a Wingate anaerobic power test. One-way ANOVA results indicated age-related increases in muscle strength and power. High correlation coefficients that were found among age and strength and anaerobic power indices almost disappeared when fat-free mass (FFM) was controlled for, indicating that the amount of variance in these indices that was explained by age is mostly shared by FFM. In addition, stepwise linear regression models indicated that FFM was the main predictor of strength and power performances. Thus, FFM was the best scaling variable for body size when comparing these age groups of Saudis. Until wide-range normal representative values for isokinetic strength and anaerobic power for Saudi children and adolescents are available, the present study's results can serve as a reference for these indices.

In almost all daily tasks, games, or sports events children are involved in short bursts of intense exercise (33). Indeed, strength and anaerobic power are two important components related to daily life. Strength testing of children is performed routinely by rehabilitation therapists to assess the extent of muscle disability and to diagnose the rate of recovery from injury. In addition, it is used by physical educators to evaluate student performance, by coaches to monitor effectiveness of training and to select athletes for sports teams, and by researchers to identify both the determinants and trainability of strength during childhood (11). Thus, it is important for strength-test administrators to be equipped with knowledge of the normal age variations in strength and the factors attributable to that variation that can both influence and confound interpretation of strength results (11,18). Although factors that control the age variations in muscle strength are of great interest, from

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a physiological perspective, much is still unknown about the factors that contribute to the observed age-associated differences in isokinetic strength (18). Age, height, weight, percent body fat, and limb circumference are all factors that correlate with strength and can be used to account for some of the variability in strength and anaerobic power between participants (18,21,34).

Muscle function is usually assessed under isokinetic, isotonic, or isometric conditions (22). Because maximal force is applied during all phases of the movement at a constant velocity, isokinetic assessment has been primarily recommended for strength testing (13,18). The isokinetic mode is also safe to use with children (18). In fact, isokinetic dynamometry is currently regarded as the most valid tool for muscle-function assessment (22). It allows quantification of a variety of muscle-function indices such as peak and average torque, joint angle of peak torque, work, power, and reciprocal and bilateral muscle ratios. Research on isokinetic parameters in children is very limited (9,22), and less is known about the quantitative isokinetic measurement of children's strength (29). Data concerning the age trend in the flexors:extensors strength ratio are limited internationally (23) and nonexistent nationally. The fact that there are no isokinetic strength data on Saudi children and adolescents adds to the significance of the present study.

The development of anaerobic power during growth and maturation is an important matter. Indeed, most of the activities that children and adolescents participate in involve bursts of energy expenditure that primarily depend on anaerobic energy-production mechanisms (26). The most popular anaerobic test is the Wingate anaerobic test (36). Indeed, this test has been examined more extensively than any other anaerobic performance test for several pediatric populations and found to be valid and reliable (35). Representative values in children are available worldwide (20); however, normal values for untrained healthy Saudi children and adolescents are yet to be determined.

It is unfortunate that there is no published information about normal values of isokinetic strength and endurance and anaerobic power or information on the relationship between anthropometric measures and these strength and anaerobic-power indices during growth for Saudi children and adolescents. These issues underline the rationale for the present study.

Therefore, the main purpose of the present study was to determine isokinetic strength and endurance, isometric strength, and anaerobic power for untrained healthy Saudi children and adolescents. The secondary purpose was to evaluate the effects of age in relation to anthropometric characteristics on strength and anaerobic performances.

Methods

Participants

Forty-four (untrained) 11- to 19-year-old boys volunteered to participate in this study. The participants were grouped together by chronological age: 11–13 years (G1), 14–16 years (G2), and 17–19 years (G3). The physical characteristics of the participants in each age group are presented in Table 1. All participants were students from one of three local schools. Age was obtained for each student from the school records. All participants were healthy and they had no history of musculoskeletal disease or knee joint surgery. They were not involved in any specific physical training program beyond their school physical education curriculum activities. The project was approved by an institutional review board, the children and their parents were informed about the nature of this project, and parental written consent was obtained.

Preliminary Measurements

Body weight (kg) and height (cm) were measured using a Seca digital scale, calibrated against known weights to ensure its validity and reliability. Body-mass index was calculated by the following equation: weight (kg)/[height $(m)^2$]. Subscapular, triceps, thigh, and calf skinfolds were measured using Harpenden calipers. Percentage body fat was estimated by age-specific regression equations and fat-free mass (FFM) was calculated accordingly (24). The circumference of the midthigh, distal thigh, and calf were measured from the right side. Leg length was measured from the head of the trochanter to lateral malleolus. All leg girths and lengths were measured to the nearest 0.1 cm using a flexible steel tape, calibrated in centimeters with millimeter gradations. All measurements were taken from the right side according to known procedures (14).

Testing Procedures

All tests were preceded by a proper warm-up and equipment familiarization. In addition, verbal encouragement was standardized between participants and across age groups. Each participant made one visit to the exercise physiology laboratory to do the tests, starting with the anthropometric measurements. Then participants performed a flexibility test, followed by a vertical jump test and a grip strength test. After a proper warm-up, the participants underwent isokinetic strength measurements on a dynamometer, and then rested for at least 30 min before performing the Wingate anaerobic-power test. Owing to the fact that laboratory equipment such as the isokinetic is scarce, the vertical-jump and grip-strength tests were selected for the purpose of comparison with available strength data internationally and locally.

Flexibility Test. A sit-and-reach test was performed by the participants according to known procedures (31). The participants were each given three trials, and the best value was used as the test score.

Vertical Jump. Height of the vertical jump was determined in the laboratory using a measuring board (Taki & Company, LTD, Japan). Participants were required to jump vertically as high as they could according to known procedures (1). The participants were given three trials, and the best value was used as the test score.

Isometric Grip Strength. Each participant performed a hand grip isometric strength test using a dynamometer according to known procedures (1). Each participant performed three trials using the dominant hand, with 2 min rest between trials. The best score was recorded for each participant.

Isokinetic Strength Measurements. In preparation for the measurements, a standardized intermittent warm-up was provided. The participants then stretched their quadriceps and hamstrings. Using an isokinetic dynamometer (Cybex Norm, CYBEX International, Inc.), knee extensor and flexor peak torque in Newton-meters (the highest torque value seen from all points in the range of motion) and reciprocal muscle ratio (flexors/extensors × 100) were recorded at angular velocities of 60, 180, and 300°/s during knee concentric muscle actions for the dominant leg (the preferred kicking leg). Participants were tested in the seated position with their backs fully supported and trunk and thigh stabilizer straps secured. The mechanical axis of rotation of the lever arm was aligned to the axis of rotation of the knee being tested. The resistance pad at the end of the level arm was strapped to the distal part of the tibia. The dynamometer's software allowed for gravity correction. This was done before testing and while the participants were relaxed; their legs were allowed to fall under gravity over the full range of movement at a standard angular velocity, where angle-specific torque values generated by the passive flexion of the leg and the weight of the lever arm were subsequently used by the dynamometer's software to perform the gravity correction over the full range of movement. Participants were instructed to grip the sides of the seat during testing. All participants performed submaximal and maximal effort warm-ups on the unit before the actual test. The test procedure consisted of four consecutive maximal extension-flexion repetitions at each velocity, performed with a 1-min rest between velocities. The highest torque at each velocity was recorded. Then participants rested for 5 min before performing a 30-repetitions endurance test. An endurance ratio was then calculated by dividing the work done in the last 50% of the set by the work done in the first 50% of the set and multiplying by 100 (15). Order of trial velocities were randomized in a counter-balanced design. The participants were verbally encouraged to produce maximal effort. After testing, the participants completed a 2-min cool-down period on the cycle.

Wingate Test. In preparation for the test, participants were given a warm-up that consisted of 3 min of pedaling on a cycle ergometer (Monark), interspersed with two all-out sprints each lasting 5 s so that participants could get a feel for the actual test. Participants then rested for 5 min. Before the start of each test, the seat was adjusted according to the height of the participants with a slight knee bend. Toe clips were used to enable exertion of force on the pedal during both knee flexion and knee extension (20). All participants were given a standardized instruction to pedal as fast as possible from the beginning of the test and to maintain maximal speed throughout the 30-s period. With the command start, participants pedaled as fast as possible without resistance on an ergometer (Monark, model 824 E), with hanging weights lifted until they reached their maximal speed (in about 3–4 s). The predetermined load (0.075 kp/kg body mass) was then applied to start the 30-s test. This was done to overcome the inertial and frictional resistance of the flywheel and to shorten the acceleration phase (20). Pedal revolution counts were sensed by photoelectric cells fed into a microcomputer. This microcomputer generated an online analysis of power and calculated peak and mean power using software (Cranlea & company, Sp-6 Wingate power testing software, USA). Verbal encouragement was standardized. For a cool-down, participants pedaled for 2 min against a light resistance immediately following the test. Peak power is considered to be the highest mechanical power produced during any 5-s period (typically in the first few seconds) and mean power as the average power sustained throughout the 30-s period.

Data Analysis. An SPSS statistical package was used to analyze the data. Descriptive statistics were computed for each age group separately. Analysis of variance (ANOVA) was used to test for differences among age groups in anthropometric, strength, endurance, and anaerobic-power variables. This was done within the acknowledged limitations of small numbers in Group 3. Post hoc tests were performed using the Bonferroni procedure, and Pearson correlation coefficients and partial correlation coefficients were used to further evaluate the association between anthropometric and strength, endurance, and anaerobic-power variables. Stepwise linear-regression models were performed to predict the strength, endurance, and anaerobic-power variables from age and the anthropometric variables. Level of significant was set at ≤ .05, and, with multiple tests, Type I error was controlled for using the Bonferroni procedure.

Results

Table 1 presents means ± standard deviation (*SD*) of anthropometric and flexibility of the participants by age groups (G1, G2, and G3). In addition, this table shows the results of the ANOVA and post hoc tests using Bonferroni procedure. Statistically significant differences among the age groups were evident in all variables except in triceps and calf skinfolds (see Table 1). Table 2 represents means (± *SD*) and the results of ANOVA and post hoc tests for all the isokinetic strength and endurance and isometric strength variables by age groups. Most of the variables were statistically significant among the age groups (see Table 2). In addition, there were statistically significant differences among the three groups in peak and mean anaerobic power and distance of vertical jump, as indicated by the results of ANOVA and post hoc tests presented on Table 3.

Results of Pearson correlation coefficients between anthropometric variables and strength and anaerobic power indices are presented in Table 4. Noticeably high coefficients can be found between FFM and the isokinetic strength and anaerobic-power indices. This was also true among age or body weight and these indices (see Table 4). Therefore, to evaluate the relationship between age and strength, endurance, and anaerobic-power indices while eliminating the effects of some potentially confounding variables, partial correlation coefficients were conducted, controlling for selected anthropometric variables (as indicated in Table 5). The strong relationship found between age and isokinetic strength and anaerobic power almost disappeared when FFM was controlled for, indicating that the amount of variance in isokinetic-strength and anaerobic-power indices that was explained by age is mostly shared by FFM. Thus, to find which of these anthropometric variables (presented in Table 4) can predict strength and anaerobic-power performances, stepwise linear-regression models were conducted. Results of these runs revealed the following prediction equations:

Table 1 Anthropometrics and Flexibility By Age Group (*M* ± *SD*)

Variable	G1 (*n* = 18)	G2 (*n* = 18)	G3 (*n* = 8)	ANOVA (*F*)	Bonferroni
Age (years)	12.3 ± 0.5	15.3 ± 0.4	18.4 ± 0.7	385.2**	1 ≠ 2, 1 ≠ 3, 2 ≠ 3
Body weight (kg)	38.1 ± 5.7	44.9 ± 5.0	68.7 ± 12.2	53.4**	1 ≠ 2, 1 ≠ 3, 2 ≠ 3
Body height (cm)	144.4 ± 3.3	156.2 ± 5.5	173.0 ± 6.4	96.3**	1 ≠ 2, 1 ≠ 3, 2 ≠ 3
Body-mass index	18.3 ± 2.8	18.4 ± 1.4	22.0 ± 4.1	9.3**	1 ≠ 3, 2 ≠ 3
Skinfold (mm)					
subscapular	8.1 ± 4.0	7.5 ± 2.1	13.6 ± 8.4	5.3**	1 ≠ 3, 2 ≠ 3
triceps	11.1 ± 3.9	8.4 ± 2.9	10.8 ± 5.4	2.7	NS
calf	13.1 ± 5.5	9.9 ± 3.1	14.1 ± 6.0	2.8	NS
thigh	16.6 ± 5.5	12.0 ± 3.4	17.6 ± 8.3	4.4*	1 ≠ 2, 2 ≠ 3
Body fat (%)	18.1 ± 6.3	13.6 ± 4.3	17.6 ± 8.7	2.7	NS
Leg circumference (cm)					
Midthigh	41.8 ± 4.6	43.6 ± 2.6	52.5 ± 4.4	22.1**	1 ≠ 3, 2 ≠ 3
Distal thigh	33.2 ± 4.0	33.9 ± 1.7	40.5 ± 2.5	18.3**	1 ≠ 3, 2 ≠ 3
Calf	29.3 ± 2.7	30.9 ± 1.3	36.9 ± 3.9	25.8**	1 ≠ 3, 2 ≠ 3
Leg length (cm)	70.9 ± 3.2	76.7 ± 3.2	83.3 ± 5.0	28.9**	1 ≠ 2, 1 ≠ 3, 2 ≠ 3
Flexibility (cm)	22.4 ± 3.7	22.5 ± 9.7	35.4 ± 10.7	8.6**	1 ≠ 3, 2 ≠ 3

Note. G1 = 11–13 years old; G2 = 14–16 years old; G3 = 17–19 years old; NS = not significant.

*Significant at ≤ 05. ** Significant at ≤ .01.

Table 2 Dominant Leg Isokinetic Strength and Endurance and Isometric Strength By Age Group (*M* ± *SD*)

Variable	G1 (*n* = 18)	G2 (*n* = 18)	G3 (*n* = 8)	ANOVA (*F*)	Bonferroni
Peak torque (Nm)					
60°/s extension	70.7 ± 10.8	103.4 ± 19.5	173.5 ± 41.5	58.5**	1 ≠ 2, 1 ≠ 3, 2 ≠ 3
60°/s flexion	45.1 ± 7.4	62.8 ± 18.9	97.1 ± 26.4	25.8**	1 ≠ 2, 1 ≠ 3, 2 ≠ 3
180°/s extension	48.0 ± 9.4	75.7 ± 14.4	132.6 ± 9.6	79.5**	1 ≠ 2, 1 ≠ 3, 2 ≠ 3
180°/s flexion	33.2 ± 6.9	48.9 ± 9.6	74.1 ± 14.8	49.0**	1 ≠ 2, 1 ≠ 3, 2 ≠ 3
300°/s extension	34.1 ± 6.8	51.7 ± 8.9	98.0 ± 20.5	91.7**	1 ≠ 2, 1 ≠ 3, 2 ≠ 3
300°/s flexion	23.1 ± 6.3	32.8 ± 8.3	54.5 ± 13.6	35.9**	1 ≠ 2, 1 ≠ 3, 2 ≠ 3
Angle of Peak torque					
60°/s extension	73.6 ± 7.2	69.1 ± 8.3	68.9 ± 4.5	1.3	NS
60°/s flexion	41.6 ± 14.6	29.1 ± 11.5	31.3 ± 12.6	4.3*	1 ≠ 2
180°/s extension	75.4 ± 9.1	69.4 ± 7.9	65.4 ± 8.5	4.5	NS
180°/s flexion	42.2 ± 11.2	36.1 ± 8.9	39.0 ± 8.4	1.7	NS
300°/s extension	82.1 ± 7.0	72.0 ± 6.7	66.9 ± 8.1	15.7**	1 ≠ 2, 1 ≠ 3
300°/s flexion	44.9 ± 9.7	39.3 ± 6.9	40.0 ± 8.9	2.2	NS
Reciprocal muscle ratio					
60°/s	64.4 ± 9.4	60.2 ± 11.3	56.4 ± 13.1	1.6	NS
180°/s	69.4 ± 8.7	65.0 ± 7.8	56.4 ± 7.0	7.2**	1 ≠ 3
300°/s	68.0 ± 15.4	63.4 ± 11.6	56.0 ± 10.6	2.3	NS
Endurance ratio					
180°/s extension	77.7 ± 10.1	70.6 ± 9.1	61.9 ± 6.2	8.4**	1 ≠ 3
180°/s flexion	73.0 ± 10.1	66.7 ± 10.1	53.7 ± 9.4	10.4**	1 ≠ 3, 2 ≠ 3
Grip strength (kg)	17.0 ± 2.3	22.5 ± 9.7	35.4 ± 10.7	70.3**	1 ≠ 2, 1 ≠ 3, 2 ≠ 3

Note. G1 = 11–13 years old; G2 = 14–16 years old; G3 = 17–19 years old; NS = not significant.

*Significant at ≤ .05. **Significant at ≤ .01.

Table 3 Anaerobic Power Characteristics By Age Group (*M* ± *SD*)

Variable	G1 (*n* = 18)	G2 (*n* = 18)	G3 (*n* = 8)	ANOVA (*F*)	Bonferroni
Vertical jump (cm)	32.2 ± 4.0	42.4 ± 7.0	51.5 ± 11.3	23.4*	1 ≠ 2, 1 ≠ 3, 2 ≠ 3
Wingate peak power (W)	275.9 ± 44.1	369.1 ± 74.0	605.8 ± 83.7	49.9*	1 ≠ 2, 1 ≠ 3, 2 ≠ 3
Wingate peak power (W/kg)	7.4 ± 1.1	8.3 ± 1.5	10.5 ± 0.5	11.6*	1 ≠ 3, 2 ≠ 3
Wingate mean power (W)	171.4 ± 23.0	242.1 ± 56.4	393.0 ± 40.7	49.9*	1 ≠ 2, 1 ≠ 3, 2 ≠ 3
Wingate mean power (W/kg)	4.6 ± 0.7	5.4 ± 1.1	6.8 ± 0.6	12.1*	1 ≠ 3, 2 ≠ 3

Note. G1 = 11–13 years old; G2 = 14–16 years old; G3 = 17–19 years old.

*Significant at ≤ .01.

Table 4 Pearson Correlation Coefficients Between Anthropometric Variables and Strength and Anaerobic Power Indices

Variable	PT60	PT180	PT300	IEE	PP	MP	VJ	GS
Age (years)	.87**	.89**	.89**	–.59**	.83**	.84**	.74**	.84**
Body weight (kg)	.84**	.92**	.90**	–.54**	.86**	.81**	.60**	.76**
Height (cm)	.81**	.84**	.83**	–.59	.80**	.80**	.69**	.81**
Body-mass index	.58**	.69**	.66**	–.34	.47**	.38*	.31*	.49*
Leg length (cm)	.78**	.75**	.72**	–.42**	.73**	.71**	.53**	.73**
Leg circumference (cm)								
midthigh	.68**	.78**	.75**	–.52**	.70**	.67**	.45**	.62**
distal thigh	.63**	.72**	.70**	–.45**	.60**	.51**	.35**	.62**
calf	.72**	.82**	.80**	–.45**	.68**	.59**	.52**	.66*
Skinfold (mm)								
subscapular	.23	.42**	.39**	–.22	.20	.12	.03	.15
triceps	–.03	.06	.10	.04	–.29	–.39*	–.31*	–.05
calf	.09	.14	.15	.03	–.23	–.25	–.18	.09
thigh	–.01	.08	.10	–.01	–.28	–.32*	–.24	.04
Sum of 4 skinfolds	–.03	.08	.10	–.02	–.19	–.23	–.30	.00
Body fat (%)	–.15	.00	.00	.02	–.23	–.33*	–.39**	–.17
Fat-free mass	.91**	.96**	.93**	–.58**	.92**	.91**	.66**	.86**

Note. PT60 = angular velocities of 60°/s; PT180 = angular velocities of 180°/s; PT300 = angular velocities of 300°/s; IEE = isokinetic extension endurance; PP = peak power on the Wingate test; MP = mean power on the Wingate test; VJ = vertical jump; GS = isometric grip strength.

*Significant at ≤ .05. **Significant at ≤ .01.

Table 5 Partial Correlation Coefficients Between Age and Strength and Anaerobic Power Indices Controlling for Selected Anthropometric Variables

Variable Controlled	PT60	PT180	PT300	IEE	PP	MP	VJ	GS
Body weight (kg)	.85**	.58**	.51**	–.14	.37*	.48**	.58**	.54**
Height (cm)	.60**	.58**	.49**	–.15	.42**	.44**	.31	.53**
Body-mass index	.87**	.89**	.86**	–.50**	.81**	.81**	.73**	.83**
Leg length (cm)	.67**	.73**	.68**	–.44**	.60**	.64**	.56**	.67**
Leg circumference (cm)								
Midthigh	.79**	.82**	.77**	–.31**	.69**	.71**	.64**	.75**
Distal thigh	.83**	.85**	.82**	–.41*	.75**	.77**	.71*	.78*
Calf	.80**	.80**	.76	–.38	.66**	.73**	.65**	.75**
Skinfold (mm)								
Subscapular	.88**	.90**	.87**	–.53**	.82**	.83**	.75**	.85**
Triceps	.87**	.89**	.88**	–.54**	.81**	.81**	.66**	.83**
Calf	.87**	.90**	.88**	–.54**	.82**	.82**	.69**	.85**
Thigh	.87**	.90**	.88**	–.56**	.82**	.81**	.67**	.84**
Sum of 4 skinfolds	.88**	.90**	.88**	–.55**	.83**	.82**	.70**	.85**
Body fat (%)	.87**	.89**	.88**	–.56**	.82**	.82**	.68**	.84**
Fat-free mass	.15	.07	.11	–.01	–.23	–.06	.24	.16

Note. PT60 = angular velocities of 60°/s; PT180 = angular velocities of 180°/s; PT300 = angular velocities of 300°/s; IEE = isokinetic extension endurance; PP = peak power on the Wingate test; MP = mean power on the Wingate test; VJ = vertical jump; GS = isometric grip strength.

*Significant at ≤ .05. **Significant at ≤ .01.

$$\text{Extension peak torque at } 60°/\text{s} = 5.2\ (\text{FFM}) - 4.1\ (\text{calf girth}) + 27.7$$
$$F_{(2,\,39)} = 124.6,\ P = .000,\ R = .93,\ R^2 = .87,\ \text{SEE} = 14.2$$

$$\text{Extension peak torque at } 180°/\text{s} = 3.3\ (\text{FFM}) - 54.4$$
$$F_{(1,\,40)} = 473.4,\ P = .000,\ R = .96,\ R^2 = .92,\ \text{SEE} = 8.4$$

$$\text{Extension peak torque at } 300°/\text{s} = 2.4\ (\text{FFM}) - 38.5$$
$$F_{(1,\,40)} = 260.7,\ P = .000,\ R = .93,\ R^2 = .87,\ \text{SEE} = 8.0$$

$$\text{Endurance ratio at } 180°/\text{s} = -.71\ (\text{FFM}) + 99.1$$
$$F_{(1,\,40)} = 19.9,\ P = .000,\ R = .58,\ R^2 = .33,\ \text{SEE} = 8.7$$

$$\text{Wingate peak power} = 14.1\ (\text{FFM}) - 162.1$$
$$F_{(1,\,36)} = 206.8,\ P = .000,\ R = .92,\ R^2 = .85,\ \text{SEE} = 48.3$$

$$\text{Wingate mean power} = 9.3\ (\text{FFM}) - 109.8$$
$$F_{(1,\,36)} = 167.9,\ P = .000,\ R = .91,\ R^2 = .82,\ \text{SEE} = 35.2$$

$$\text{Grip strength} = .69\ (\text{FFM}) + .49\ (\text{Thigh skinfold}) + 1.78\ (\text{age in years}) - 1.04\ (\text{Subscapular skinfold}) - 27.8$$
$$F_{(4,\,37)} = 50.1,\ P = .000,\ R = .92,\ R^2 = .84,\ \text{SEE} = 3.6$$

$$\text{Vertical jump distance} = 2.6\ (\text{age in years}) - 1.0\ (\text{Triceps skinfold}) + 11.3$$
$$F_{(2,\,39)} = 32.03,\ P = .000,\ R = .79,\ R^2 = .62,\ \text{SEE} = 5.7$$

Discussion

The physical and physiological characteristics of the participants in the present study are comparable to locally reported counterparts (3,4,5,6,25). Saudi boys, however, have lower values for height and weight than Western boys, which is in agreement with previously reported data (3,5).

Peak torque in the present study was higher in knee extensors than knee flexors. This is in agreement with what has been accepted as typical for children and adults (19) and might reflect the differences in muscle size and function of these two muscle groups (9). It is normal for extension and flexion peak torques to drop with increasing velocity (13), which is evident in the present study for all age groups and for both the extension and flexion concentric muscle actions (see Table 2). In fact, this drop increased in magnitude with age in the present study (ranges from about 48% to 56% for extension and from 51% to 56% for flexion). These drops in extension and flexion peak torque with increasing velocity are similar to results of Saudi adults. Al-angari and Al-Hazzaa (2) reported a range of reduction from 48% in the flexion of the right leg to 51% in extension of the left leg. In addition, the present results indicate that isokinetic peak torque increased with age at all angular velocities (see Table 2). This is in agreement with previously reported longitudinal (17) and cross-sectional data (16,32).

In addition, hamstring:quadriceps (H:Q) ratio did not increase with increasing test speeds, which is considered normal (13) when gravity is corrected. This was true for all age groups (see Table 2). Although the optimal values for H:Q ratios for the muscles around the knee joint are controversial, studies investigating the H:Q ratio suggest that it should be 50–80%, depending on test velocity (13). The H:Q ratios for all age groups and for all test velocities fall within this expected range. For the endurance ratio, it decreased with increasing age. This was significant between G1 and G3 in all the extension and flexion concentric muscle actions. It is unfortunate that the limited number of studies in the area of muscular endurance in children does not permit general conclusions on muscle-fatigue characteristics in children (9).

Indeed, differences in testing procedure, especially velocities of movement, types of devices used, and age, made the comparison of isokinetic results of the present study with available data very difficult. This is especially true because isokinetic-strength and -endurance data for children and adolescents are scarce. In fact, the present study was the first to report data on isokinetic strength and anaerobic power for Saudi children and adolescents. Therefore, a comparison of data locally is not possible. In addition, limited studies match the comprehensive nature of the protocols used in the present study.

On the other hand, the grip-strength test is one of the most common methods of measuring isometric strength in children. In the present study, isometric strength measured by grip strength in kilograms increased with age (see Table 2). This is in agreement with the literature (7,10,11,19). Results of grip strength for G1 fall above the 70th percentile, compared with local counterparts (4). In a study conducted in the Riyadh area, grip strength was 26.67 ± 6.95 kg for Saudi boys age 15 years (6), compared with 22.5 ± 9.7 kg for G2 in the present study. There were slight differences in age between the participants of the present study and the latter one, as well as differences in testing procedures. For G3, unfortunately, no local data are available for comparison.

Two tests of anaerobic power performance of Saudi children were used in the present study. Results indicated that there was an increased vertical jump distance with age, which is in agreement with locally reported data (7). Values of distance of vertical jump were close to what has been reported locally for G1 (8). Comparison was not possible for G2 and G3, however, because of lack of available data locally.

Second, results of anaerobic power measured by the Wingate test also are in agreement with reported data in the literature (26,36). Both absolute peak power and mean power increased with age. Negligible differences in age-related trends were observed, however, for data expressed relative to body mass (see Table 3). In fact, the differences between G1 and G2 in peak power and mean power were reduced when results were expressed per unit of body mass, an age trend that is in agreement with the literature (30). Martin and Malina (26) stated that peak power generally increases with age from middle childhood into adolescence, and differences between age groups in peak power per unit body mass are greatly reduced. Recent findings, however, reported a significant increase of anaerobic power in absolute and relative values with chronological age, which could possibly be a result of the need to account for the potential changes to braking forces during growth (33).

Flexibility is related to anaerobic performance, and this is because muscular efficiency is optimal when the appropriate range of motion is available (12). Results of flexibility tests in the present study indicated that all age groups barely fall within the healthy fitness zone (28). Specifically, all groups were below the 50th percentile, compared with American boys of the same ages (31). Values of flexibility in the present study compare favorably with locally reported data for the same age (6).

There are many important factors in the objective evaluation of strength in the pediatric population (35). Of critical importance to the present study are anthropometric characteristics and, to a lesser extent, age. It is well known that size matters in human performance, that is, larger people are stronger, more powerful, and have greater maximum anaerobic power. In the present study, body weight, height, and leg length all significantly increased with chronological age. This increase of body size was paralleled by an increase in strength and anaerobic-power indices across age groups. Body weight, for example, increased by about 44% when G1 and G3 were compared. In addition, dominant leg isokinetic extension peak torque increased by about 59% when the same comparisons were made between G1 and G2. In fact, age has been found to exert an independent effect on strength development (18). This is true in the present study, especially because high correlation coefficients were found among body weight, height, leg length, and FFM, strength, and anaerobic power (see Table 4). Although chronological age was highly correlated with strength and anaerobic power, this relationship almost disappeared when, for example, FFM was controlled for (see Table 5). In this case, chronological age is a nonsignificant explanatory variable when FFM is controlled for. In fact, this result is reinforced by longitudinal research that used multilevel modeling and found that age is a nonexplanatory variable once stature and mass are accounted for in 10- to 14-year-old children (17). In the present study, FFM consistently explained most of the variance of the strength and anaerobic-power indices, as indicated by the high multiple-regression coefficients. This high percentage of variance explained by FFM is in agreement with what has been reported in the literature (34). This is not surprising because skeletal muscle is the tissue responsible for force generation, and one might predict a strong association between muscle mass and muscle force during growth (11).

This leads to the importance of scaling for body size when one compares different age groups of children and adolescents. One should be cautious, however, about the fact that the valid use of FFM as a scaling variable relies on the assumption that total FFM increases with age at the same rate as regional muscle cross-sectional area (of course, of the muscle group that produced the force) (18). In the present study, cross-sectional area was not measured; however, leg circumference increased at about the same rate as FFM. In addition, strength increases coincided with changes in FFM across age groups. Furthermore, a previous study (27) that used an identical age range (11–19 years) found that lean body mass seemed to be the best reference factor for normalization of maximal anaerobic power.

In conclusion, until wide-range normal representative values for isokinetic strength and endurance and anaerobic power for Saudi children and adolescents are available, the present study results can serve as a reference for these indices for the specified age groups. In addition, the present study introduces FFM as the best scaling variable for body size when comparing different age groups of Saudi children and adolescents.

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