

Research article

Effects of Body Mass-Based Squat Training in Adolescent Boys

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Abstract

The purpose of this study was to determine the effects of body mass-based squat training on body composition, muscular strength and motor fitness in adolescent boys. Ninety-four boys (13.7 ± 0.6 yrs, 1.60 ± 0.09 m, 50.2 ± 9.6 kg) participated in this study and were randomly assigned to training ($n = 36$) or control ($n = 58$) groups. The training group completed body mass-based squat exercise training (100 reps/day, 45 sessions) for 8 weeks. Body composition and muscle thickness at the thigh anterior were determined by a bioelectrical impedance analyzer and ultrasound apparatus, respectively. Maximal voluntary knee extension strength and sprint velocity were measured using static myometer and non-motorized treadmill, respectively. Jump height was calculated using flight time during jumping, which was measured by a matswitch system. The 8-wk body mass-based squat training significantly decreased percent body fat (4.2%) and significantly increased the lean body mass (2.7%), muscle thickness (3.2%) and strength of the knee extensors (16.0%), compared to control group. The vertical jump height was also significantly improved by 3.4% through the intervention. The current results indicate that body mass-based squat training for 8 weeks is a feasible and effective method for improving body composition and muscular strength of the knee extensors, and jump performance in adolescent boys.

Key words: School-based training, force-generating capacity, motor fitness, adolescents.

Introduction

Resistance training with moderate- and high-loads is an effective method for improving body composition and muscular strength from childhood to adolescence (Behringer et al., 2010; Malina, 2006) and does not appear to adversely affect growth or cause any injuries when it is executed with proper technique (Malina, 2006). Prior studies (Faigenbaum et al., 2002; Lillegard et al., 1997; Lubans et al., 2010; Ozmun et al., 1994; Sailors and Berg, 1987; Velez et al., 2010; Weltman et al., 1986) have adopted supervised programs using training equipment which enables moderate to heavy resistance load. On the other hand, a body mass-based exercise such as a jump and squat can be performed without space or equipment concerns, and may not be too time demanding with large populations. Mackay and colleagues (Macdonald et al., 2008; MacKelvie et al., 2003; McKay et al., 2005; Naylor et al., 2006) have demonstrated that a 10- to 12-min body mass-based jump training improved bone mineral content, body composition and jump performances, and suggested that the body mass-based jump training increases physical activity opportunities throughout the school day

(Naylor et al., 2006).

Recently, we demonstrated that a body mass-based squat training program improved knee extension strength in elderly individuals (Nakamoto et al., 2012; Yoshitake et al., 2011). The body mass-based exercise adopted in the prior studies has some advantages in that it can be performed anywhere and for a short duration (approximately 15 min) with large populations. However, there is less information concerning the influence of body mass-based training on not only muscle strength but also body composition and motor fitness in adolescents. If body mass-based training can be a modality for improving body composition, muscle strength and motor fitness for adolescents, it could be a safe and convenient training method for inclusion in school physical education programs. Therefore, the present study aimed to determine the effects of body mass-based training on body composition, muscular strength and motor fitness in adolescent boys.

Methods

Participants

Ninety-four boys (13.7 ± 0.6 yrs at baseline) participated in this study. All participants were recruited from our pilot school. The physical characteristics of the participants were similar to the normative data of Japanese boys reported by the Ministry of Education, Culture, Sports, Science and Technology. The participants were divided into training ($n = 36$) and control ($n = 58$) groups. The events of the extracurricular activities in training group, in which participation in the current program was accepted prior to intervention, consisted of table tennis ($n = 12$) and volleyball ($n = 11$), track and field ($n = 5$), and Japanese archery ($n = 8$). Those in control group were baseball ($n = 24$), soccer ($n = 22$), swimming ($n = 5$) and kendo ($n = 3$). The number of times participating in a week and duration involved in their athletic activities in a day were 5.0 ± 2.0 days/week and 2.4 ± 0.9 h/day respectively. All participants involved in the activities had experienced competitions at a regional level.

This study was approved by the ethical committee of National Institute of Fitness and Sports in Kanoya (No. 10-3) and was consistent with their requirements for human experimentation. Prior to the experiment, all participants and their parents were informed of the purpose and procedures of this study and possible risks of the measurements beforehand. Written informed consent was obtained from each subject and their parents/legal guardians.

Experimental design

A parallel control-intervention research design was used in this study. The training period was 8 weeks. The exercise used was a body mass-based squat movement at a pace of once every 2 s. We instructed the participants to squat until their thighs were parallel to floor. In a preliminary study using 16 young adults (9 males and 7 females), a training program with exercise style adopted here for 8 weeks (5-6 times/week) produced a significant gain in isometric maximal voluntary knee extension strength. In the training program, the participants were required to repeat the squat movement for 3 minutes at a pace of once every 2 s (<90 repetitions/session). By taking this result into account, we set the target number of repetitions per day for the squat movement of 100 repetitions/day and the participants were required to perform it after their school curriculum excluding holidays (4-6 days/week). The number of the performed training sessions was recorded in a notebook by the participants. The control group was asked to refrain from any resistance training and maintain their normal physical activities and nutrition behaviors throughout the intervention period.

Outcome measurements

The anthropometry, body composition, muscular strength, and motor fitness were determined before and after the intervention. The examiners performed outcome measurements as below, and were blinded to which groups (training group or control group) the participants belonged to.

Measurements of anthropometry and body composition: Body height was measured using a manual stadiometer to the nearest 0.1 cm. After cleaning their feet with a cloth soaked by alcohol, a bioelectrical impedance analyzer with leg-to-leg system (DC-320, Tanita, Japan) was used to determine body mass to the nearest 0.1 kg, and estimate percent body fat by using the input variables of body height and sex. The leg-to-leg system has a reliability for estimating body composition with 2.1% of coefficient of variation for inter-day measurement. (Nunez et al., 1997). Furthermore, this method has been adopted for determining the body composition for children (Sampei et al., 2008). Body mass index was calculated as mass (kg) divided by height squared (m^2). Lean body mass was calculated from percent body fat and body mass.

Measurements of muscle thickness at thigh anterior: Muscle thickness at the thigh anterior was measured by a B-mode ultrasound (Prosound 2, Aloka, Japan) with a linear scanner. During the measurement, the participants remained in a standing position with their arms and legs relaxed extended position. In accordance with a procedure described in an earlier study (Abe et al., 1994), the measurement site was precisely located and marked at the anterior surface in the middle of the femur length (the distance from the great trochanter of the femur to articular cleft between the femur and tibia condyles). A transducer with a 7.5 MHz scanning head was placed perpendicular to the underlying muscle and bone tissues. The scanning head was coated with water-soluble transmission gel, which provided acoustic contact without depressing the

dermal surface. The obtained ultrasonographic images were printed out by an echo copier. The muscle thickness of thigh anterior was measured as the distance between the fat-muscle tissue and muscle-bone interfaces. According to dimensional analysis (Asmussen and Heeb0Oll-Nielsen, 1955), muscle thickness was divided by the one-third power of lean body mass. The precision and linearity of the image reconstruction have been confirmed elsewhere (Kawakami et al., 1993). The one examiner performed the muscle thickness measurements throughout this study. In preliminary experiments, the examiner performed the repeatability test of the muscle thickness measurements on 3 separate day (>7 days) with 3 participants. The intraclass correlation coefficient for the muscle thickness measurement was ≥ 0.97 , satisfied the standard value of repeatability, ≥ 0.75 (Vincent, 1995). Measurement error was less than 1.0 mm. The coefficient of variation for the test-retest of the muscle thickness values was less than 5%.

Measurements of maximal knee extension strength

(KES): Maximal voluntary strength in knee extension was measured using a specially designed myometer (TAKEI, Niigata, Japan) in accordance with a procedure described in previous studies (Nakamoto et al., 2012; Yoshitake et al., 2011). The right leg was measured for all participants. The participants sat on the machine at 90 degree of hip and knee joint. The subject's hip was fixed by a non-elastic belt to prevent their hip from moving. The participants gradually exerted muscle force from rest to maximum in 3 to 4 seconds and then sustained at maximum for approximately 2 s. Participants performed at least two trials with a 2-min rest between trials. If the difference in the measured score of the two trials was $>10\%$, an additional trial was performed. The highest value for the trials was used for analysis. The KES was divided by body mass $^{2/3}$ (KES/BM).

Measurement of sprint velocity: As described in the previous studies (Funato et al., 2001; Yanagiya et al., 2003), the sprint velocity was measured by a non-motorized treadmill to avoid the influence of the difference in measurement environment on sprint performance. The treadmill was specially designed (D-08011d, Takeikiki, Niigata, Japan) and consisted of a low friction belt, a small flywheel, a handlebar and a rotary encoder. The participants gripped a handlebar in front of them keeping both arms straight and in a horizontal position during running. The height of the handlebar was adjusted to the position of the horizontally straightened arms when each subject ran on the belt. The participants were required to start with standing position at rest and then to accelerate the belt as quickly as possible up to the highest velocity of the belt which was maintained for a few seconds. Participants performed at least 2 trials with 2-min rest between trials.

Electrical signals from the encoder were amplified and fed into a personal computer via an A/D converter (ADA16-8/2(CB)L, CONTEC, Japan) at a rate of 100 Hz. The pulses produced by the pulse generator were converted to the displacement of the belt by multiplying by a predetermined conversion factor. The instantaneous velocity of the belt was determined by differentiating the

horizontal displacement of the belt. The sprint velocity was defined as the mean value of the six steps included maximal sprint velocity. The highest value between trials was used for analysis.

In a preliminary experiment, we confirmed whether the sprint velocity measured by the non-motorized treadmill is feasible as index of that on the ground. As the result, the internal consistency between the methods for sprint velocity was 0.87, indicating that the reliability of the two assessments is acceptable (≥ 0.70) (Bland and Altman, 1997).

Measurement of jump height: The participants were in a standing position, and performed a counter movement jump as high as possible. The position of the jumper on the mat was the same for takeoff and in landing. When jumping, the participants kept their hands on their hips and jumped vertically on a matswitch platform. The height of vertical jump was calculated from the following equation. (Bosco et al., 1983).

$$\text{Jump height (cm)} = g \times t^2 \times 8^{-1}$$

where g is acceleration due to gravity (9.81 m/s^2) and t is the time of the flight of the jump (s). The t taken from takeoff to ground contact was measured by a matswitch system (Multi Jump Tester, DKH, Japan).

The participants completed 3 trials with a rest interval of 1 min between the trials. The highest value for the three trials was used for analysis.

Assessment of sexual maturation

Prior to the intervention, the self-assessment of stage of pubic hair based on the criteria of Tanner (Tanner, 1962) was assessed for all participants. The stage consists of 5 classes. This method has been shown to have good validity for the assessment of secondary sex characteristics for Asian children (Duke et al., 1980). To reduce embarrassment, each participant went into a room by himself to complete the self-assessment anonymously (Gurd and Klentrou, 2003). Once completed, the self assessment was placed in a closed box. Eighty six of 94 boys (92%) completed the self-assessment.

Statistical analysis

Descriptive data are presented as means \pm SDs. The normality of the independent variables was tested by Kolmogorov-Smirnov test, indicating that all variables were confirmed normal distributions by the test. Group differ-

ences at baseline were tested using an unpaired t-test. A paired t-test was used to test the significance of changes in all independent variables for both groups. We used an unpaired t-test to test the significance of the difference between the two groups in the relative changes in all variables. Statistical significance was set at $p < 0.05$. All data analyses were conducted using a statistical software package (SPSS 19.0 for windows, IBM, Japan).

Results

At baseline, no significant difference was found in each of the independent variables between the training and control groups. There was no significant difference in maturity status between the training and control groups (3.5 ± 1.4 vs. 3.6 ± 1.2). In the training group, training frequency and volume per day were 4.4 ± 0.8 days/week and 99.6 ± 1.3 repetitions/day.

Descriptive data on anthropometry and body composition in both groups are summarized in Table 1. After the intervention period, body height and mass significantly increased in both groups without significant group differences in the relative changes. Lean body mass significantly increased in both groups ($p < 0.01$), and the relative change was higher in the training group than in the control group (2.7% vs. 2.0%, $p = 0.026$). Percent body fat for the training group significantly decreased ($p < 0.01$) by 4.2%, whereas that for the control group did not. Body mass index did not significantly change in both groups. Thigh circumference significantly increased in both groups ($p < 0.01$), and the relative change was higher in the training group than in the control group (1.6% vs. 0.7%, $p = 0.008$). Muscle thickness at thigh anterior and its relative to lean body mass $^{1/3}$ were significantly increased by 3.2% and 2.3% in the training group ($p < 0.05$), whereas not in the control group.

Table 2 presents descriptive data on KES, sprint velocity and jump height in both groups. KES and KES/BM significantly increased in both groups ($p < 0.01$), but the relative changes were higher in the training group than in the control group (KES, 16% vs. 8%, $p = 0.014$; KES/BM, 15% vs. 7%, $p < 0.01$). Sprint velocity did not change in the training group, but it significantly increased in the control group. On the other hand, jump height significantly increased in the training group ($p = 0.042$), but not in the control group.

Table 1. Descriptive data on anthropometry in adolescent boys. Data are means (\pm SD).

	Training group (n = 36)			Control group (n = 58)		
	Pre	Post	%	Pre	Post	%
Chronological age (yrs)	13.6 (.6)	13.7 (.6)		13.8 (.5)	14.0 (.5)	
Body height (m)	1.58 (.09)	1.59 (.09) *	.7	1.61 (.09)	1.61 (.08) *	.6
Body mass (kg)	49.3 (10.5)	50.1 (10.3) *	1.6	50.8 (9.0)	51.5 (8.8) *	1.6
BMI ($\text{kg}\cdot\text{m}^{-2}$)	19.5 (2.7)	19.5 (2.7)	.2	19.6 (2.5)	19.7 (2.3)	.4
Percent body fat (%)	17.5 (7.5)	16.7 (7.1) *	-4.2	16.9 (7.0)	16.6 (6.4)	.0
Lean body mass (kg)	40.1 (6.2)	41.2 (6.2) *	2.7	41.8 (5.4)	42.6 (5.5) *	2.0 #
Thigh circumstance (cm)	45.8 (4.9)	46.6 (4.9) *	1.6	46.7 (4.2)	46.9 (4.1) *	.7 #
MT _{QF} (cm)	4.52 (.60)	4.66 (.62) *	3.2	4.74 (.49)	4.76 (.50)	.5 #
MT _{QF} /LBM (cm/kg $^{1/3}$)	1.32 (.13)	1.35 (.14) *	2.3	1.37 (.12)	1.36 (.12)	-.1 #

*, Significance change between Pre and Post ($p < 0.05$) #, Significance difference in relative change before intervention ($p < 0.05$) BMI, body mass index; MT_{QF}, muscle thickness of anterior of thigh; LBM, lean body mass. %, relative change from the initial value at Pre.

Table 2. Descriptive data on knee extension strength and motor fitness in adolescent boys. Data are means (\pm SD).

	Training group (n = 36)			Control group (n = 58)		
	Pre	Post	%	Pre	Post	%
KES (kg)	41.6 (11.2)	47.9 (12.6) *	16.0	44.7 (10.1)	48.0 (11.1) *	8.1 #
KES/BM (kg/kg ^{2/3})	3.08 (.59)	3.51 (.64) *	14.8	3.25 (.53)	3.46 (.57) *	7.0 #
Sprint velocity (m/s)	5.21 (.80)	5.18 (.83)	-.5	5.17 (.59)	5.32 (.67) *	2.9 #
Jump height (cm)	32.1 (6.0)	33.1 (6.5) *	3.4	31.6 (5.4)	31.9 (5.1)	1.8

* Significance change between Pre and Post ($p < 0.05$). # Significance difference in relative change before intervention ($p < 0.05$). KES, knee extension strength; BM, body mass; %, relative change from the initial value at Pre.

Discussion

The main findings of this study were that the 8-wk body mass-based squat exercise training in adolescent boys : 1) decreased percent body fat, 2) increased lean body mass, muscle thickness and strength of the knee extensors, and 3) improved vertical jump height. These results indicate that a body mass-based squat training for 8 weeks is a feasible and effective method for improving body composition, the strength capability of the knee extensors and jump performance in adolescent boys. As a practical application, the body mass-based squat exercise training (100 repetitions/day, <10 min/day) can be conducted easily with large populations in terms of no special equipment and facilities. The number of inactive and obese youth has increased markedly over last two decades (Ogden et al., 2010), and it has links with the occurrence of diabetes, heart disease and hypertension (James, 2004). Individuals who develop a routine of participating in physical activities that can be easily carried into adulthood may be more likely to become active adults (Corbin, 2002). Taken together, these findings suggest that the body mass-based squat training is feasible training method for adolescents, which could be easily added in to school-based physical education programs for adolescent boys.

The changes in body height and mass in the training group were similar to those in the control group. This is consistent with the finding of Malina (2006) in which similar changes in body size were found, regardless of participation in training. In addition, the observed gains in body height and mass are comparable to those in the earlier studies which have examined the effect of resistance training in adolescents (body height, 0.7-2.2 cm; body mass, 0.6-1.1 kg) (Lubans et al., 2010; Vrijens, 1978). The training group showed a significant decrease in percent body fat, indicating that the body mass-based squat exercise training can improve body composition. The observed changes in percent body fat are similar to those reported in supervised resistance training with free weight, machine and elastic tube (Lubans et al., 2010; Velez et al., 2010).

At baseline, the thigh girth and muscle thickness at the thigh anterior were comparable to the findings of Kanehisa et al. (2003). These variables were increased by the current training and the training-induced gains were greater in the training group than in the control group. These results are consistent with the findings of Vrijens (1978) in that the girth and muscle cross-sectional area of thigh were increased by high intensive resistance training.

The training group showed a significant improvement in muscle strength. The gains in knee extension

strength (16%) and its relative to body mass (15%) were relatively lower than those observed in prior studies with supervised modality using free weight and machine (19-35%) (Faigenbaum et al., 1999; 2002; 2007a; Lubans et al., 2010; Sailors and Berg, 1987), whereas comparable for those with body mass-based exercise training for elderly individuals (9-22%) (Aniansson and Gustafsson, 1981; Kubo et al., 2003; Nakamoto et al., 2012; Yoshitake et al., 2011). For the knee extensors in young and elderly individuals, muscular activity level during body mass-based squat exercise is associated with muscle strength per body mass (Fujita et al., 2011). Knee extension strength per body mass in adolescents increases across age (De Ste Croix et al., 2002). Taken together, it is reasonable to assume that muscular activity levels during the squat exercise are relatively higher in adolescent boys, and so it would appear to be a sufficient overload for improving knee extension strength. However, Behringer et al. (2010) pointed out that training-induced effects in adolescents are attributed to more training duration as well as frequency than training intensity. As the content of the training program used in this study, the duration was short (8 weeks), the frequency was higher (4.4 ± 0.8 days/week) compared to that used in the earlier studies (2-3 days/week) (Faigenbaum et al., 1999; 2002; 2007a; Lubans et al., 2010; Sailors and Berg, 1987). Hence, it seems that relatively high training frequency would be needed to improve muscular strength through body mass-based squat training.

The vertical jump height significantly improved through the intervention. Earlier findings regarding the effect of resistance training on motor fitness are very unclear (Faigenbaum et al., 2002; 2007a; 2007b; Lillegard et al., 1997; Weeks and Beck, 2012; Weltman et al., 1986). Weltman et al. (1986) demonstrated that resistance training including squat jump exercise increased vertical jump, but not standing long jump. Faigenbaum et al. (2007b) showed that, in adolescent boys, a greater gain in sprint velocity was obtained in the combined training of plyometric and resistance exercises, as compared to only resistance training. Considering these findings, it seems that the improvement in jump performance may be affected by the specificity of the squat exercise which is performed due to force-production to vertical direction.

We should comment on some limitations of the present study. Firstly, the current data was analyzed, regardless of the events of the after-school activities in which the subjects participated. Hence, there is a possibility that the current findings might have been influenced by event-related differences in the after-school sports activities. However, the initial values in the measured variables for the training group did not significantly differ

from the control group. Furthermore, regular participation in sport training during puberty and the adolescent spurt do not appear to influence on body size attained in boys (Malina and Bielicki, 1996; Malina et al., 1997). Considering these findings, it is likely that the effect of event-related difference in the training-induced change might be less for the current results. Secondly, the current findings were obtained from only adolescent boys. Weeks and Beck (2012) have demonstrated that, for adolescents, the execution of body mass-based jump training in school produced sex- and maturity-related differences in the training-induced changes for lean body mass and jump performances. Unfortunately, we did not have the relevant data, and further investigations are needed to clarify this point.

Conclusion

In summary, the current results indicate that body mass-based squat training for 8 weeks is a feasible and effective method for improving body composition and muscular strength of the knee extensors, and jump performance in adolescent boys.

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References

- Abe, T., Kondo, M., Kawakami, Y. and Fukunaga, T. (1994) Prediction equations for body composition of Japanese adults by B-mode ultrasound. *American Journal of Human Biology* **6**(2), 161-170.
- Aniansson, A. and Gustafsson, E. (1981) Physical training in elderly men with special reference to quadriceps muscle strength and morphology. *Clinical Physiology* **1**(1), 87-98.
- Asmussen, E. and Heeboll-Nielsen, K. (1955) A dimensional analysis of physical performance and growth in boys. *Journal of Applied Physiology* **7**(6), 593-603.
- Behringer, M., Vom Heede, A., Yue, Z. and Mester, J. (2010) Effects of resistance training in children and adolescents: a meta-analysis. *Pediatrics* **126**(5), e1199-1210.
- Bland, J.M. and Altman, D.G. (1997) Statistics notes: Cronbach's alpha. *British Medical Journal* **314**, 572.
- Bosco, C., Luhtanen, P. and Komi, P.V. (1983) A simple method for measurement of mechanical power in jumping. *European Journal of Applied Physiology and Occupational Physiology* **50**(2), 273-282.
- Corbin, C.B. (2002) Physical Activity for Everyone: What every physical educator should know about promoting lifelong physical activity. *Journal of Teaching in Physical Education* **21**(2), 128-144.
- De Ste Croix, M.B., Armstrong, N., Welsman, J.R. and Sharpe, P. (2002) Longitudinal changes in isokinetic leg strength in 10-14-year-olds. *Annals of Human Biology* **29**(1), 50-62.
- Duke, P.M., Litt, I.F. and Gross, R.T. (1980) Adolescents' self-assessment of sexual maturation. *Pediatrics* **66**(6), 918-920.
- Faigenbaum, A.D., McFarland, J.E., Johnson, L., Kang, J., Bloom, J., Ratamess, N.A. and Hoffman, J.R. (2007a) Preliminary evaluation of an after-school resistance training program for improving physical fitness in middle school-age boys. *Perceptual and Motor Skills* **104**(2), 407-415.
- Faigenbaum, A.D., McFarland, J.E., Keiper, F.B., Tevlin, W., Ratamess, N.A., Kang, J., Hoffman, J.R. (2007b) Effects of a short-term plyometric and resistance training program on fitness performance in boys age 12 to 15 years. *Journal of Sports Science and Medicine* **6**, 519-525.
- Faigenbaum, A.D., Milliken, L.A., Loud, R.L., Burak, B.T., Doherty, C.L. and Westcott, W.L. (2002) Comparison of 1 and 2 days per week of strength training in children. *Research Quarterly for Exercise and Sport* **73**(4), 416-424.
- Faigenbaum, A.D., Westcott, W.L., Loud, R.L. and Long, C. (1999) The effects of different resistance training protocols on muscular strength and endurance development in children. *Pediatrics* **104**(1), e5.
- Fujita, E., Kanehisa, H., Yoshitake, Y., Fukunaga, T. and Nishizono, H. (2011) Association between knee extensor strength and EMG activities during squat movement. *Medicine and Science in Sports and Exercise* **43**(12), 2328-2334.
- Funato, K., Yanagiya, T. and Fukunaga, T. (2001) Ergometry for estimation of mechanical power output in sprinting in humans using a newly developed self-driven treadmill. *European Journal of Applied Physiology* **84**(3), 169-173.
- Gurd, B. and Klentrou, P. (2003) Physical and pubertal development in young male gymnasts. *Journal of Applied Physiology* **95**(3), 1011-1015.
- James, P.T. (2004) Obesity: the worldwide epidemic. *Clinics in Dermatology* **22**(4), 276-280.
- Kanehisa, H., Abe, T. and Fukunaga, T. (2003) Growth trends of dynamic strength in adolescent boys. A 2-year follow-up survey. *The Journal of Sports Medicine and Physical Fitness*, **43**(4), 459-464.
- Kawakami, Y., Abe, T., and Fukunaga, T. (1993) Muscle-fiber pennation angles are greater in hypertrophied than in normal muscles. *Journal of Applied Physiology* **74**(6), 2740-2744.
- Kubo, K., Kanehisa, H., Miyatani, M., Tachi, M. and Fukunaga, T. (2003) Effect of low-load resistance training on the tendon properties in middle-aged and elderly women. *Acta Physiologica Scandinavica* **178**(1), 25-32.
- Lillegard, W.A., Brown, E.W., Wilson, D.J., Henderson, R. and Lewis, E. (1997) Efficacy of strength training in prepubescent to early postpubescent males and females: effects of gender and maturity. *Pediatric Rehabilitation* **1**(3), 147-157.
- Lubans, D.R., Sheaman, C. and Callister, R. (2010) Exercise adherence and intervention effects of two school-based resistance training programs for adolescents. *Preventive Medicine* **50**(1-2), 56-62.
- Macdonald, H.M., Kontulainen, S.A., Petit, M.A., Beck, T.J., Khan, K.M. and McKay, H.A. (2008) Does a novel school-based physical activity model benefit femoral neck bone strength in pre- and early pubertal children? *Osteoporosis International* **19**(10), 1445-1456.
- MacKelvie, K.J., Khan, K.M., Petit, M.A., Janssen, P.A. and McKay, H.A. (2003) A school-based exercise intervention elicits substantial bone health benefits: a 2-year randomized controlled trial in girls. *Pediatrics* **112**(6 Pt 1), e447.
- Malina, R.M. (2006) Weight training in youth-growth, maturation, and safety: an evidence-based review. *Clinical Journal of Sport Medicine* **16**(6), 478-487.
- Malina, R.M. and Bielicki, T. (1996) Retrospective longitudinal growth study of boys and girls active in sport. *Acta Paediatrica* **85**(5), 570-576.
- Malina, R.M., Woynarowska, B., Bielicki, T., Beunen, G., Ewold, D., Geithner, C.A., Huang, Y.C. and Rogers, D.M. (1997) Prospective and retrospective longitudinal studies of the growth, maturation, and fitness of Polish youth active in sport. *International Journal of Sports Medicine* **18**(Suppl 3), S179-185.
- McKay, H.A., MacLean, L., Petit, M., MacKelvie-O'Brien, K., Janssen, P., Beck, T. and Khan, K.M.. (2005) "Bounce at the Bell": a novel program of short bouts of exercise improves proximal femur bone mass in early pubertal children. *British Journal of Sports Medicine* **39**(8), 521-526.
- Nakamoto, H., Yoshitake, Y., Takai, Y., Kanehisa, H., Kitamura, T., Kawanishi, M. and Mori, S. (2012) Knee extensor strength is associated with Mini-Mental State Examination scores in elderly men. *European Journal of Applied Physiology* **112**(5), 1945-1953.
- Naylor, P.J., Macdonald, H.M., Zebedee, J.A., Reed, K.E. and McKay, H.A. (2006) Lessons learned from Action Schools! BC--an 'active school' model to promote physical activity in elementary schools. *Journal of Science and Medicine in Sport* **9**(5), 413-423.
- Nunez, C., Gallagher, D., Visser, M., Pi-Sunyer, F.X., Wang, Z. and Heymsfield, S.B. (1997) Bioimpedance analysis: evaluation of leg-to-leg system based on pressure contact footpad electrodes. *Medicine and Science in Sports and Exercise* **29**(4), 524-531.
- Ogden, C.L., Carroll, M.D., Curtin, L.R., Lamb, M.M. and Flegal, K.M. (2010) Prevalence of high body mass index in US children and

- adolescents, 2007-2008. *The Journal of the American Medical Association* **303**(3), 242-249.
- Ozmun, J.C., Mikesky, A.E. and Surburg, P.R. (1994) Neuromuscular adaptations following prepubescent strength training. *Medicine and Science in Sports and Exercise* **26**(4), 510-514.
- Sailors, M. and Berg, K. (1987) Comparison of responses to weight training in pubescent boys and men. *The Journal of Sports Medicine and Physical Fitness* **27**(1), 30-37.
- Sampei, M.A., Novo, N.F., Juliano, Y. and Sigulem, D.M. (2008) Anthropometry and body composition in ethnic Japanese and Caucasian adolescent boys. *Pediatrics International* **50**(5), 679-686.
- Tanner, J.M. (1962) *Growth at adolescence*. 2nd edition. Oxford: Blackwell Scientific Publications.
- Velez, A., Golem, D.L. and Arent, S.M. (2010) The impact of a 12-week resistance training program on strength, body composition, and self-concept of Hispanic adolescents. *Journal of Strength and Conditioning Research* **24**(4), 1065-1073.
- Vincent, W.J. (1995) *Statistics in Kinesiology*. Champaign IL: Human Kinetics.
- Vrijens, J. (1978) Muscle strength development in the pre-and post-pubescent age. *Medicine Sport* **11**, 152-158.
- Weeks, B.K. and Beck, B.R. (2012) Twice-weekly, in-school jumping improves lean mass, particularly in adolescent boys. *Pediatric Obesity* **7**(3), 196-204.
- Weltman, A., Janney, C., Rians, C.B., Strand, K., Berg, B., Tippitt, S., Wise, J., Cahill, B.R. and Katch, F.I. (1986) The effects of hydraulic resistance strength training in pre-pubertal males. *Medicine and Science in Sports and Exercise* **18**(6), 629-638.
- Yanagiya, T., Kanehisa, H., Kouzaki, M., Kawakami, Y. and Fukunaga, T. (2003) Effect of gender on mechanical power output during repeated bouts of maximal running in trained teenagers. *International Journal of Sports Medicine* **24**(4), 304-310.
- Yoshitake, Y., Takai, Y., Kitamura, T., Kawanishi, M. and Kanehisa, H. (2011) Body mass-based exercise in middle-aged and older women. *International Journal of Sports Medicine* **32**(12), 924-928.

Key points

- An 8-wk body mass-based squat exercise training decreased percent body fat in adolescent boys.
- The body mass-based squat exercise training increased muscle size and strength capability of the knee extensors in adolescent boys.
- The squat exercise training improves vertical jump height in adolescent boys.

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