Electromyography analysis of Rectus femoris and Biceps femoris muscles activation in adults with achondroplasia

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Abstract
Background. Achondroplasia is a genetic rare condition characterized by shorter stature and disproportionate upper and lower limb length. This study aimed to investigate the activation of lower limb agonist-antagonist knee muscles, Rectus femoris and Biceps femoris, in adults with achondroplasia during the squat, through surface electromyography (sEMG) signals.
Methods. Eight participants, four women (45.8±15.9 years old) and four men (39.8±14.9 years old) executed three isometric maximum voluntary contractions (iMVC) applying Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) standard recommended tests for these muscles. The sEMG signals were recorded for 30 seconds while executing the squat movement, including the contraction and relaxation phases.
Results. Rectus femoris presented higher activation in men compared to women with achondroplasia, while Biceps femoris was more activated in women. In both men and women, coactivation of these muscles occurred during the squat.
Conclusion. In adults with achondroplasia, Rectus femoris and Biceps femoris muscles act synergistically while performing the squat, with coactivation.

Keywords: Maximum voluntary contraction, Squat, Skeletal dysplasia, Coactivation

1 Introduction

Skeletal dysplasias (SD) are a heterogeneous group of 771 rare bone conditions with origin in genetic mutations, being short stature a common feature. One of the most prevalent SD is achondroplasia (ACH), occurring in 1 in 25 000 births [1], presenting a disproportionate short with proximal shortening of the upper and lower limbs [2].

Adults present a final height of a -6.0 standard deviation score (SDS) which translates in average to less than 45 cm (males) and 40 cm (females) compared to the average height population [3]. The anatomic features such as macrocephaly and disproportionate short stature lead to biomechanical and postural changes [4] affecting other anatomic structures. Is frequently observed in joints hyperlaxity; lumbar spine hyperlordosis and stenosis are described in 70% of adults with ACH, knees with genu varus and a tendency for obesity [5].

The musculoskeletal system plays a vital role in human activities such as body movements, walking, running, jumping, breathing, and blood pumping. Muscles need to be active, which can be achieved by performing regular exercises and complex body movements [6]. The World Health Organization's global action plan on physical activity 2018–2030 indicates that there are disparities in physical activity participation by age, gender, disability, socioeconomic status, and geography reflecting limitations and inequities in the socioeconomic determinants and opportunities for physical activity for different groups and different abilities [7]. People with achondroplasia are recognized to have a physical disability and have traditionally received little indication or stimulus for regular physical activity [8]. Many physical education teachers have taught students with achondroplasia in their classes, but little information is available concerning sport potential. Of the many adapted physical education textbooks, disability sports books and sports medicine articles for people with disabilities, only a few include sections on achondroplasia [9].

Towards stimulating this population to be more physically active, it was prepared a research project to identify the facilitators and constraints of physical activity for adults with achondroplasia. For this study, the squat was selected for analysis as it is simple to execute, is a compound movement and does not require the use of any material or device. Also, the squat is largely used as a workout to stimulate the lower limb muscles, especially the quadriceps, hamstrings, gastrocnemius, and soleus and it is also important for activities of daily living (ADLs). But while sitting and walking activate lower limb muscles, these movements never activate multiple types of muscle groups, as the squat can [10].

sEMG is a technique used to detect and monitor myoelectric signals during muscle contraction and has been applied in multiple evaluations as detection of muscle activity and diagnosis of nerve compression or injury [13].

The squat recruits distinct muscle groups that involve the hip, knee, and ankle joints, consisting of one of the most common exercises in strength training [14]. It has been previously demonstrated that an increased range of the squat causes a higher force divergence between the Rectus femoris (RF) and Biceps femoris (BF) muscles, as the activation of the RF is higher with increasing range [15]. Also, a study by Mckean 2012, described that average-height men and women have different strategies to perform the squat in addition to the range of motion, with women presenting greater knee flexion and men presenting greater trunk flexion while performing the squat with a greater range of motion [16]. Muscle activity patterns of RF and BF have not been described in adults with achondroplasia, existing no comparison of force production capacity nor strength normalized for differences in muscle morphology or size.

The disproportionate limb length reduced whole body and segmental muscle mass in individuals with achondroplasia originates altered muscle architecture [11,12] which may also lead to changes in force production capacity. The aim of this study was therefore to analyze muscle activity of RF and BF, two agonist-antagonist knee muscles, through surface electromyography (sEMG) in women and men with achondroplasia during the squat movement.

2 Methodology

2.1 Participants

Eight adults with achondroplasia, 4 women (45.8±15.9 years old) and 4 men (39.8±14.9 years old) volunteered to participate in this study after recruitment through ANDO Portugal, the National Association for skeletal dysplasia. This research was approved by Évora University Ethical Committee, following the declaration of Helsinki and all participants provided their written informed consent before participation in this study. Each participant attended one testing session at Robocorp lab, Coimbra Polytechnic Institute, Portugal, during which were conducted anthropometric measurements, bioimpedance analysis and sEMG evaluation of the knee extensors and flexors. Data collection was conducted between November 2022 to March 2023.

Participants presented a fat mass (%) of 33.7±4.6 in women and 24.8±17.4 in men, measured by bioimpedance, using a multifrequency segmental analyzer scale Tanita MC780-PMA scale. Regarding physical activity habits, participants replied to the IPAQ questionnaire's short version, a self-administered questionnaire on physical activity habits [17].

Table 1. Participants' characteristics (N = 8), mean and standard deviation (SD)

	Age (years)	Height (cm)	Weight (kg)	Fat mass (%)
Women (n=4)	45.8±15.9	114±5.9	51.1±7.2	33.7±4.6
Men (n=4)	39.8±14.9	125±13.5	55.8±20.4	24.8±17.4

2.2 Experimental protocol

The protocol developed for this study included the following steps: identification of RF and BF muscles in each participant; Skin cleaning over the muscles belly with isopropyl alcohol; Placement of sEMG electrodes in the dominant limb (right limb for all participants, after each participant self-selecting the right foot when asked to stand in one foot); Execution and recording of three repetitions of iMVC for RF and BF; Squat demonstration by a researcher and training of the movement by participants with corrective indications when needed; and sEMG signal recording during a squat, performed for 30 seconds to the highest number of complete repetitions.

The sEMG activity of RF and BF was collected with PLUX® EMG device (PLUX – Wireless Biosignals, S.A., Lisbon, Portugal) at 1000 Hz sampling frequency, with the placement of active surface electrodes (Al/AgCl), disk shape 10 mm diameter, in the muscles belly, as per SENIAM recommendations [18] for the most efficient signal acquisition. Participants were requested to stand with feet shoulder-width, bend their knees to sit until their thighs were parallel to the floor and perform squats. After placing the electrodes on the selected muscles, EMG data normalization was performed through three iMVC tests against manual resistance applied by the same researcher following SENIAM recommendations [18].

The iMVCs were performed for 5 to 10 seconds in each muscle, with an interval of 60 seconds between data acquisition to avoid tiredness. A sitting positioning was applied to execute both iMVC. To activate the BF, participants were requested to execute a knee flexion performed using a knee flexion at 90° and hip flexed at 90° and to activate RF, participants were requested to execute a knee extension, with the knee flexed at 60° and hip flexed 90° [19].

2.3 Data processing

The sEMG signals were visually inspected before processing to ensure sEMG signal quality [20,21]. sEMG data were normalized to the maximum values by applying a 60-millisecond (ms) window frame to analyze the amplitude peak of iMVC of the selected muscles. From the 30 seconds of performing the squat, eight consecutive squat cycles were selected from each participant and analyzed through a MatLab® code (version R2020b, Mathworks, Inc., Natick, MA, USA). The sEMG data were digitally filtered (10–490 Hz), full-wave rectified and smoothed through a low-pass filter (13 Hz, seventh-order Butterworth digital filter).

Fig. 1. Man (left) and woman (right) performing a squat movement.

2.4 Statistical Analysis

Data were collected on a personal computer (LG gram, Lg electronics) and the statistical analysis was performed using Jamovi (Jamovi statistics platform, version 2.3, Australia). Descriptive data was assumed parametric following the Shapiro-Wilk test and all results are reported as means and standard deviations.

Table 2. Normality test data

	Age (years)	Height (cm)	Weight (kg)	Fat mass (%)
Shapiro-Wilk	0.849	0.800	0.874	0.973

3 Results

Considering the short and disproportionate stature of adults with achondroplasia, it is relevant to assess physical activity habits, physical performance level and analyze muscle activation capacity. To capture physical activity level, participants performed the 6 minutes walking test (6MWT) and were asked to execute a maximum number of squat repetitions for 30 seconds (Squats). Regarding physical activity habits, participants replied to the IPAQ questionnaire, short version, within a time frame of one week before or after the sEMG collection date.

From the IPAQ questionnaire responses, a total score was obtained by the sum of the duration (minutes) and frequency (days) of walking, moderate-intensity, and vigorous-intensity activity. The volume of activity was computed by weighting each type of activity by its energy requirements of multiples of the resting metabolic rate (METs) to yield a score in MET minutes per week (MET-min/W) [22]. Considering three level scores of activities: inactive, minimally active and HEPA active (health-enhancing physical activity), 6 out of 8 participants were inactive for scoring significantly below 600 MET-min/W, one man was minimally active (>600MET-min/W), and just adult (man) reached the HEPA active score.

Table 3. Participants' physical activity habits, mean and standard deviation (M±SD)

	Squats (n/30s)	6MWT (m)	MET min/W
Women (n=4)	15.8±1.6	87±28.0	231±55.3
Men (n=4)	19.8±9.6	402±111.0	1524±1270.0

Considering fat mass percentage (FM%), with women presenting 33.7±4.6 and men 24.8±17.4, it was observed a significant correlation of -0.894 ($p<0.001$, 95%CI) between FM% and MET min/W and -0.778 ($p<0.05$, 95%CI) between FM% and squat repetitions. Regarding muscle activation during the squat, men and women presented a higher RF activation compared to BF, yet women presented a higher activation of BF (22%) compared to men (9%). Interestingly, men also presented a higher amplitude between both muscles. In the contraction phase, the RF activation was similar in men and women, with a higher peak in men, reaching 59% of activation. And while the RF activation pattern in men and women had a concordance of 90%, the difference for both genders regarding BF was 68% after applying Variance accounted for (VAF) for means (see fig.2).

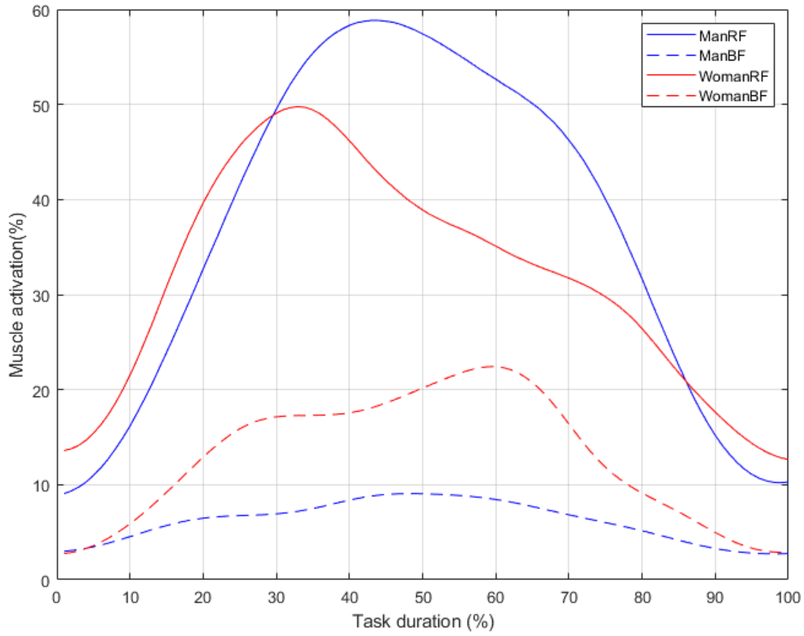

Fig. 2. Normalized muscle activation for Rectus femoris (RF) and Biceps femoris (BF) EMG during eight squat cycles.

4 Discussion

Muscle size is a pre-determining factor for activation and strength and muscle architecture can also influence strength [15]. The type of exerted force, whether muscles act as agonists or antagonists, affects the relationship between the time and frequency of the selected activity. Although squats are one of the most common exercises to increase lower limb muscle strength, which improves knee stability and promotes functional muscle mobilization patterns [23], the weaker activation of BF in men is possibly because this exercise does not provide a sufficient stimulus for knee flexor muscles. The higher RF activation in men is aligned with previous findings in athletic men with achondroplasia that has identified a higher RF coactivation in knee extension compared to average-height people [11].

In women, it was observed a higher BF activation compared to men, most likely due to reduced strength in the RF. As in both men and women was observed coactivation, this may be related to muscle synergy to compensate for lower muscle strength in this population. Factors such as the trunk angle and the squat depth during the squat may have a role in the muscle activation and strength needed to execute the movement, yet this will require further investigation. Also, the incremental demand for muscle coactivation may be related to the reduced physical activity levels observed in most participants as well as the high body fat percentage.

Understanding how muscle is activated and the activation patterns in both genders, can be relevant supportive information towards an oriented, adjusted, and beneficial physical activity and exercise prescription and program settings for this population.

Limitations

Results must be read carefully as the study included only 8 participants. Recruitment was highly impaired as achondroplasia is a rare condition and a limited number of participants were available.

5 Conclusions

Adults with achondroplasia have significantly short stature compared with average-height people, mostly due to reduced lower limb length, as architectural changes may interfere with muscle activation. The preliminary findings of this study show a tendency of different knee muscle activation patterns between men and women with achondroplasia, while both presented muscle coactivation, possibly to increase lower limb muscle capacity and facilitate ADLs. Further studies are needed to understand how muscle activation in men and women with achondroplasia is related to their physical fitness and how it can be improved.

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References

1. Savarirayan, R., Rimon, D.: The Skeletal dysplasias. Best pract. Res Clin Endocrinol Metab 16:547-60 (2002).
2. Pauli R.: Achondroplasia: a comprehensive clinical review. OJRD 14(1) (2019).

3. Merker A. et al.: Growth in achondroplasia: Development of height, weight, head circumference, and body mass index. AJHG 1723–34 (2018).
4. de Vries, O., Fredwall S.: Physical fitness, and activity level in Norwegian adults with achondroplasia. American journal of medical genetics 1023–32 (2020).
5. Fredwall S. et al.: High prevalence of symptomatic spinal stenosis in Norwegian adults with achondroplasia: a population-based study. OJRD 123 (2020).
6. Callens, N., Carvil, P., Van Walleghem, M., González-Cinca, R.: ESA/ELGRA Gravity-Related Research Summer School: An Introduction to Microgravity and Hypergravity Research for University Students. Microgravity Sci Technol 33, 1–7 (2021).
7. Global action plan on physical activity 2018–2030: more active people for a healthier world. https://apps.who.int/iris/bitstream/handle/10665/272722/9789241514187-eng.pdf, Geneva: World Health Organization, last accessed 2023/05/20.
8. Pritchard, E. Incongruous encounters: the problem of accessing accessible spaces for people with dwarfism. Disability & Society. 541–60 (2021).
9. Low, L., Knudsen, M., Sherrill, C.: Dwarfism: New interest area for adapted physical activity. Adapted Phys Act 1–15 (1996).
10. Shankhwar, V., Singh, D., Deepak, K.: Characterization of Electromyographic Signals from Biceps and Rectus Femoris Muscles to Evaluate the Performance of Squats Coupled with Countermeasure Gravitational Load Modulating body gear. Microgravity Science and Technology 33:49 (2021)
11. Sims DT, Onambélé-Pearson GL, Burden A, Payton C, Morse CI.: Specific force of the vastus lateralis in adults with achondroplasia. J Appl Physiol Bethesda Md Mar 1;124(3): 696–703 (2018).
12. Perry, J., Burnfield, J.: Gait analysis: normal and pathological function. SLACK, Thorofare, NJ (2010).
13. Reaz, M., Hussain, M., Mohd-Yasin F.: Techniques of EMG signal analysis: detection, processing, classification, and applications. Biological procedures online 11–35 (2006).
14. Gullett, J., Tillman, M., Gutierrez, G., Chow, J.: A biomechanical comparison of back and front squats in healthy trained individuals. J Strength Cond Res (2009).
15. Sousa, C. et al.: Atividade eletromiográfica no agachamento nas posições de 40º, 60º e 90º de flexão do joelho. Rev Bras Med Esporte 310–6 (2007).
16. Mckean, M., Burkett, B.: Does segment length influence the hip, knee, and ankle coordination during the squat movement? Journal Fit Res. 23–30 (2012).
17. Booth, M. Assessment of Physical Activity: An International Perspective. Research Quarterly for Exercise and Sport. 114–20 (2000).
18. SENIAM project, deliverable 8, European Recommendations for Surface ElectroMyoGraphy. Roessingh Research and Development. (1999).
19. Roldán-Jiménez, C., Bennett, P., Cuesta-Vargas, A.: Muscular activity and fatigue in lower-limb and trunk muscles during different sit-to-stand tests. PLoS ONE. 1–12 (2015).
20. Allison, G. Trunk muscle onset detection technique for EMG signals with ECG artifact. J Electromyogr Kinesiol. 209–16 (2003).
21. Silva, L. et al. Trunk muscle activation during golf swing: Baseline and threshold. J Electromyogr Kinesiol. 1174–82 (2013).
22. Guidelines for Data Processing and Analysis of the International Physical Activity Questionnaire (IPAQ) – Short and Long Forms, revision (2005).
23. Lee L. et al.: Differences in the muscle activities of the quadriceps femoris and hamstrings while performing various squat exercises. BMC SpSciMed Reh (2022).