J Musculoskelet Neuronal Interact 2023; 23(2):228-235

Journal of Musculoskeletal and Neuronal Interactions JMNI

Original Article

The relationship between cartilage thickness and muscle thickness or leg length discrepancy in poliomyelitis sequelae

Alper Uysal[1], Murat Güntel[2†], Hava Özlem Dede[3]

[1]Physical Medicine and Rehabilitation Clinic, Hatay Education and Research Hospital, Hatay, Turkey;
[2]Neurology Department, Medicine Faculty, Hatay Mustafa Kemal University, Hatay, Turkey;
[3]Clinical Neurophysiology, Neurology Clinic, Hatay Education and Research Hospital, Hatay, Turkey
[†]Deceased February 6, 2023

Abstract

Objectives: To evaluate the relationship between cartilage loss and differences in muscle thickness and/or leg length in poliomyelitis sequelae (PMS). Our study is the first to evaluate the relationship between cartilage loss and both muscle atrophy and leg length discrepancy in the same population. **Methods**: 37 patients with PMS and 38 healthy controls were included. Talar and distal femoral cartilage thicknesses and gastrocnemius medialis and quadriceps femoris muscle thicknesses were measured via ultrasound. Leg length differences and manual muscle strength were also evaluated. **Results**: The mean muscle thicknesses and cartilage thicknesses were thinner in the more affected legs than in the less affected legs in the patient group. All of the ultrasonographic measurements were thinner in the less affected legs of the patient group than in the right legs of the control group, except for the knee cartilage thicknesses. While there was a correlation between the cartilage thickness difference and the muscle thickness difference between the less and more affected legs in the patient group, there was no correlation between the cartilage thickness difference and leg length differences. **Conclusions**: Patients with PMS are predisposed to osteoarthritis. Talar and knee cartilage thicknesses may be more associated with the muscle thickness than the leg length discrepancy in PMS.

Keywords: Cartilage Thickness, Leg Length Discrepancy, Muscle Thickness, Poliomyelitis, Ultrasound

Introduction

Poliomyelitis (PM) is a fecal orally transmitted viral disease that often causes infection in young children, can involve the central nervous system, and may even cause various sequelae that persist in adulthood in some individuals[1]. Although great strides were made to prevent PM with the development of the vaccine in the 1950s, the disease is still endemic in a few countries such as Nigeria and Pakistan[2]. It is estimated that there are 12 to 20 million individuals currently still living with PMS globally[3].

Polio virus infection often has a subclinical course. However, it can also be seen in a typical clinical picture characterized by flaccid paralysis and muscle weakness as a result of diffuse anterior horn involvement in the central nervous system. Paralytic PM, which can cause severe limitations in activities of daily living develops in 0.5% of all infections[4]. The disease often affects one or both lower extremities to varying degrees. In individuals with PMS, joint diseases develop earlier as a result of muscle weakness, abnormal alignment patterns such as genu valgum, hypotonia, and ligament laxity and related pathologies (genu recurvatum). Soft tissue release and corrective osteotomy operations can be applied to correct alignment and stability of the joint before the pathologies progress further. Total knee arthroplasty should be considered in the presence of painful osteoarthritis, particularly the genu recurvatum associated with ligament laxity[1]. Osteoporosis, scoliosis, kyphosis,

The authors have no conflict of interest.

Corresponding author: Alper Uysal, Physical Medicine and Rehabilitation Clinic, Hatay Training and Research Hospital, Hatay, Turkey. Hatay Training and Research Hospital, Güzelburç, 31001 Antakya/Hatay, Turkey
E-mail: alperuysal82@gmail.com
ORCID ID: 0000-0002-4114-1649

Edited by: G. Lyritis
Accepted 21 March 2023

and degenerative disc diseases are other musculoskeletal problems that develop as a result of muscle weakness[5,6]. Prevention of obesity, exercise, treatment of osteoporosis, orthoses (such as antirecurvatum orthoses to protect the anatomical structure of the knee and prevent and delay surgery) and walking aids (to reduce the risk of falling and related fractures) are important steps in the management of the patients with PMS[6,7].

The only study in the literature evaluating the talar and distal femoral cartilage thickness in PMS patients did not address the relationship between leg length difference and cartilage thicknesses. In addition, lower extremity muscles were not evaluated by an imaging method in the previous study[8]. In our study, we investigated whether there is a relationship between talar and distal femoral cartilage thicknesses, lower extremity muscle thicknesses and strengths, and leg length differences in PMS patients. Our study is the first to evaluate the relationship between cartilage loss and both muscle atrophy and leg length discrepancy in the same population.

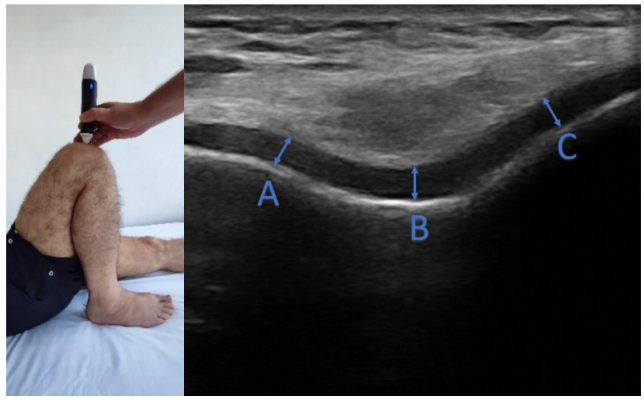

Figure 1. Distal femoral cartilage thickness measurement A: Medial femoral condyle B: intercondylar area C: Lateral femoral condyle.

Materials and Methods

Participants and Demographic Characteristics

Our study included 37 patients aged 18-65 years whose PM diagnosis was supported by electro-neurophysiological examinations. All electro-neurophysiological studies were performed by the same specialist (clinical neurophysiologist). 38 healthy people with similar demographic characteristics were included as the control group. Patients with rheumatologic disease, malignancy, fracture in the lower extremity, other neurological diseases, and total knee arthroplasty were excluded from the study. Age, gender, body mass index, and FAC (Functional Ambulation Category) levels of all participants were noted. The study was conducted between December 2021 and August 2022.

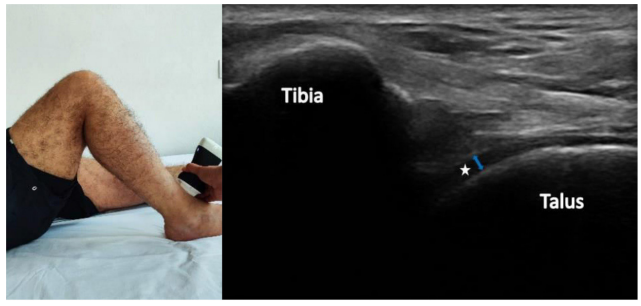

Figure 2. Talar cartilage thickness measurement (Asterisk).

Grading of Muscle Strength by Manual Method

Hip, knee, and ankle flexor and extensor muscle strengths were evaluated manually. With this method, muscle strength was rated as 5/5 (full muscle strength), 4/5 (muscle strength showing partial resistance to full counterforce), 3/5 (muscle strength that can only complete the movement against gravity), 2/5 (the muscle strength that completes the movement only when the effect of gravity is removed), 1/5 (unable to complete its movement even when the effect of gravity is removed, only contraction), and 0 (no movement or contraction).

Assessment of Leg Shortness

While the patient was lying in the supine position, the amount of leg shortness was calculated by measuring the lengths of the lower extremities on both sides. Lower extremity lengths were calculated by measuring the distance between spina iliaca anterior superior and medial malleolus using a tape measure[9]. The amount of shortness was determined as the difference between the lengths of the right and left extremities.

Ultrasonographic measurements

Both distal femoral cartilage thicknesses were measured from the suprapatellar region with the knees at maximum flexion, while the participants were lying on their backs. Measurements were made in the axial position using a wireless linear ultrasound (US) probe (Clarius L7 HD before May 2022 and Clarius L7 HD_3 after May 2022). Distal femoral cartilage thicknesses were measured from the midpoints of the lateral femoral condyle, intercondylar area and medial femoral condyle. Cartilage thickness was determined by measuring the distance between the thin hyperechoic line at the synovial space-cartilage interface and the sharp hyperechoic line at the cartilage-bone interface[10] (Figure 1). Cartilage thickness

values of the lateral femoral condyle, intercondylar area and medial femoral condyle were summed up and the result was divided by 3. The average knee cartilage thickness was also calculated for both sides.

Talar cartilage thickness measurements were made while the patient was lying on his back with his knees flexed at 90° and his feet were in a straight position, in contact with the examination bed. The US probe was placed in the longitudinal position medial to the tibialis anterior tendon. Talar cartilage thickness was determined by measuring the distance between the sharp hyperechoic line at the cartilage-bone interface and the thin hyperechoic line at the fat tissue interface in the resulting image[11] (Figure 2).

For quadriceps femoris muscle thickness measurement, US images were taken from the midpoint of the distance between the anterior superior spina iliaca and the upper end of the patella while the patient was in the supine position. At this point, the quadriceps femoris muscle thickness was considered as the sum of the vastus intermedius and rectus femoris muscle thicknesses when the probe was in the sagittal position. The distance between the femoral bone cortex and the superficial fascia of the rectus femoris was measured[12] (Figure 3).

The gastrocnemius medialis muscle thicknesses were measured while the patients were lying in the prone position with their legs extended and relaxed and their feet hanging off the examination bed. After scanning the muscle throughout the entire length of it in the sagittal plane, the measurement was made from the thickest part of the muscle[13] (Figure 4).

All measurements were made 3 times by a physiatrist experienced in musculoskeletal ultrasonography and the mean values were included in the study. Optimum probe contact was applied to the tissue to obtain an image, especially in the muscle thickness measurements, and the reduction of tissue thickness due to excessive compression was avoided. All sonographic measurements were made by a physiatrist with 6 years of US experience. Since the ultrasonographic measurements of both sides of the healthy control group were similar, the right leg data of the control group were used in the study.

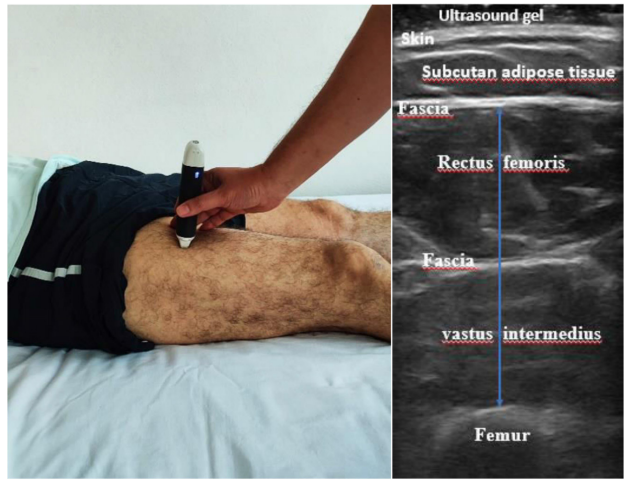

Figure 3. Quadriceps femoris muscle thickness measurement.

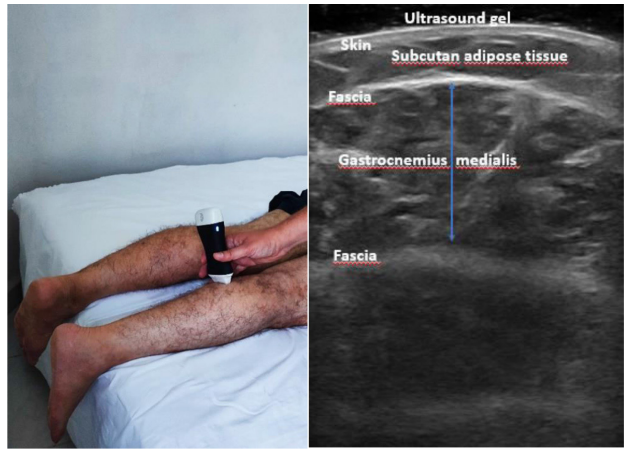

Figure 4. Gastrocnemius medialis muscle thickness measurement.

Evaluation of Measurements for Correlation Analysis

Leg length discrepancy is an indicator of the difference between the lengths of both lower extremities. Therefore, we used the difference values between both legs to evaluate the relationship between leg length difference and other parameters. We calculated the difference between less affected and more affected leg measurements in the patient group separately for each parameter (muscle thickness and strength, cartilage thickness, and leg length). We then evaluated the correlation between these parameters.

In this study, femoral and talar cartilage thicknesses, and quadriceps femoris and medial gastrocnemius muscle thicknesses were measured by ultrasonographic evaluation of both lower extremities in the patient and control groups. These values were compared between the patient and control groups and between the less and more affected extremities in the patient group.

Statistical Analysis

Descriptive statistics were given as arithmetic mean ± standard deviation, median and interquartile range for continuous data, and as frequency and percentage for categorical data. Conformity of continuous data with the assumption of normality was evaluated according to the Shapiro Wilk Test and coefficient of variation. The statistical

Table 1. Demographic data of groups.

		Patient (n=37)	Control (n=38)	P
Gender	Female (n/%)	12 (32.4)	14 (36.8)	0.688*
	Male (n/%)	25 (67.6)	24 (63.2)	
Age		49.91 ± 5.41	51.50 ± 7.34	0.293**
Weight (kg)		80.43 ± 15.65	79.13 ± 10.41	0.672**
Height (cm)		1.69 ± 0.06	1.69 ± 0.06	0.919**
BMI (kg/m^3)		28.10 ± 5.13	27.64 ± 3.45	0.647**

*BMI, body mass index, * Pearson Chi-Square Test, ** Independent Sample T-Test.*

Table 2. Comparison of the mean muscle strengths of the less affected legs and the more affected legs within the patient group.

	More Affected legs (n=37) Median (IQR 25/75)	Less affected legs (n=37) Median (IQR 25/75)	P*
Hip flexor	2.0 (1.0/4.0)	5.0 (2.0/5.0)	< 0.001
Hip extensor	2.0 (1.0/4.0)	5.0 (2.0/5.0)	< 0.001
Knee flexor	2.0 (1.0/4.0)	5.0 (2.0/5.0)	< 0.001
Knee extensor	2.0 (1.0/4.0)	5.0 (2.0/5.0)	< 0.001
Ankle dorsiflexor	2.0 (0.0/4.0)	5.0 (2.0/5.0)	< 0.001
Ankle plantar flexor	2.0 (0.0/4.0)	5.0 (2.0/5.0)	< 0.001

*IQR 25/75; quarterly interval, * Mann-Whitney U Test.*

Table 3. Ultrasound values of the less affected legs and more affected legs of the patient group and the right legs of the control group.

	Patient Group		Control Group	P*
	More Affected legs (n=37)	Less affected legs (n=37)	Right legs (n=38)	
LFCT (mm)	1.29 ± 0.43^a	2.04 ± 0.48^b	2.16 ± 0.25^b	**<0.001**
ICNT (mm)	1.01 ± 0.40^a	1.98 ± 0.48^b	2.08 ± 0.30^b	**<0.001**
MFCT (mm)	1.23 ± 0.43^a	1.97 ± 0.47^b	2.11 ± 0.24^b	**<0.001**
ADFCT (mm)	1.18 ± 0.38^a	2.00 ± 0.45^b	2.12 ± 0.25^b	**<0.001**
TCT (mm)	0.55 ± 0.13^a	0.90 ± 0.21^b	1.04 ± 0.22^c	**<0.001**
QFMT (mm)	18.23 ± 6.53^a	28.09 ± 8.01^b	37.09 ± 4.18^c	**<0.001**
GMMT (mm)	10.69 ± 2.00^a	16.95 ± 1.96^b	18.79 ± 1.69^c	**<0.001**

LFCT, lateral femoral condyle thickness; ICNT, intercondylar notch thickness; MFCT, medial femoral condyle thickness; ADFCT, average distal femoral condyle thickness; TCT, talar cartilage thickness; QFMT, quadriceps femoris muscle thickness; GMMT, gastrocnemius medialis muscle thickness
** One-Way Analysis of Variance, The difference between means with different lowercase letters in the same row was found to be statistically significant (p<0.05).*

difference between the patient and control groups in terms of categorical variables was determined by Pearson Chi-Square Test. The statistical difference between the groups in terms of continuous variables was evaluated with the Independent Sample t test if the assumption of normality was provided; If not, it was determined by the Mann Whitney-U Test. Statistical difference between groups in terms of continuous variables was determined by One-Way Analysis of Variance. If a significant difference was detected between the groups as a result of the One-Way Analysis of Variance, the pairwise comparisons that caused the difference were made with the Tukey Post-hoc Test. Spearman correlation analysis was performed for the analysis of the relationship between the variables.

Table 4. Correlations in the patient group.

		ADFCTD	TCTD	QFMTD	GMMTD	KESD	PFSD	LLD
ADFCTD	Correlation coefficient Sig. (2-tailed) N	1.000 . 37	0.493** 0.002 37	0.432** 0.008 37	0.082 0.629 37	0.413* 0.011 37	0.106 0.531 37	0.228 0.175 37
TCTD	Correlation coefficient Sig. (2-tailed) N	0.493** 0.002 37	1.000 . 37	0.154 0.364 37	0.347* 0.036 37	0.458** 0.004 37	0.303 0.068 37	0.039 0.820 37
QFMTD	Correlation coefficient Sig. (2-tailed) N	0.432** 0.008 37	0.154 0.364 37	1.000 . 37	0.219 0.193 37	0.524** 0.001 37	-0.085 0.615 37	0.244 0.146 37
GMMTD	Correlation coefficient Sig. (2-tailed) N	0.082 0.629 37	0.347* 0.036 37	0.219 0.193 37	1.000 . 37	0.234 0.164 37	0.610** 0.000 37	0.008 0.962 37
KESD	Correlation coefficient Sig. (2-tailed) N	0.413* 0.011 37	0.458** 0.004 37	0.524** 0.001 37	0.234 0.164 37	1.000 . 37	0.222 0.186 37	0.295 0.076 37
PFSD	Correlation coefficient Sig. (2-tailed) N	0.106 0.531 37	0.303 0.068 37	-0.085 0.615 37	0.610** 0.000 37	0.222 0.186 37	1.000 . 37	0.256 0.127 37
LLD	Correlation coefficient Sig. (2-tailed) N	0.228 0.175 37	0.039 0.820 37	0.244 0.146 37	0.008 0.962 37	0.295 0.076 37	0.256 0.127 37	1.000 . 37

ADFCTD, average distal femoral condyle thickness difference; TCTD, talar cartilage thickness difference; QFMTD, quadriceps femoris muscle thickness difference; GMMTD, gastrocnemius medialis muscle thickness difference; KESD, knee extensor strength difference; PFSD, plantar flexor strength difference; LLD, leg length discrepancy

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

In all statistical analyses, the limit of significance was determined as $p<0.05$ and SPSS 22 statistical package program was used.

Results

Demographic data of both groups were similar ($p>0.05$) (Table 1). The median strength values of all the muscles examined in the patient group were lower in the more affected leg than in the less affected leg ($p<0.001$) (Table 2). The median FAC level of the patients was 2 (0-5). The leg length discrepancy of the patients with PMS was 3.1 cm (mean value) or 3 cm (median value).

In terms of lateral femoral condyle thickness (LFCT), intercondylar notch thickness (ICNT), medial femoral condyle thickness (MFCT), and average distal femoral condyle thickness (ADFCT) values, a statistical difference was found between the more affected leg and the less affected leg or the most affected leg of the patient group and the right leg of the control group (p values <0.001) (Table 3). The talar cartilage thickness values were statistically different from each other in all 3 groups (all p values <0.005). QFMT and GMMT values were statistically different in all three groups (all p values <0.001) (Table 3).

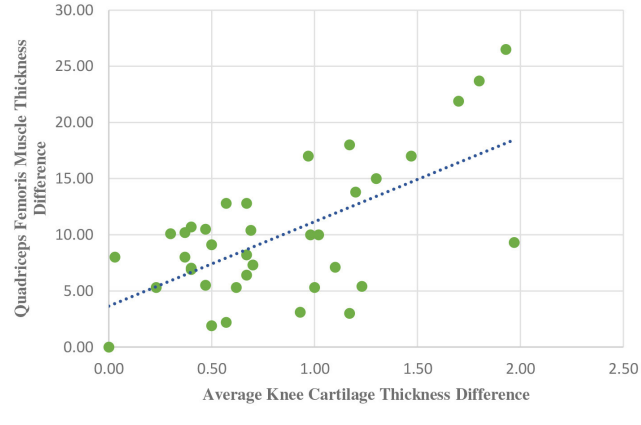

Figure 5. Correlation graphic between avarage knee cartilage thickness difference and quadriceps femoris muscle thickness difference (r=0.432, p=0.008).

We observed a positive and moderate correlation between the differences in the thickness of the knee cartilage and the differences in knee extensor muscle strength (r=0.413, p=0.011), quadriceps femoris muscle thickness (r=0.432,

p=0.008) (Figure 5), and talar cartilage thickness (r=0.493, p=0.002) between both lower extremities in the patient group. We observed a moderate correlation between the difference in talar cartilage thickness and the difference in gastrocnemius medialis muscle thickness (r=0.347, p=0.036), and knee extensor strength (r=0.458, p=0.004). We found a moderate correlation between QFMTD and KESD (r=0.524, p=0.001) and between GMMTD and PFSD (r=0.610, p=0.000) (Table 4). A correlation between leg length differences and ankle dorsiflexor muscle strength differences (r=0.419, p=0.01) or knee flexor strength differences (r=0.600, p=0.000) was found in the present study.

Discussion

We found that the mean talar and knee cartilage thicknesses and quadriceps femoris and gastrocnemius medialis muscle thicknesses of the PM patients were thinner in their more affected legs than in their less affected legs. In the less affected side of the patient group, the mean values of all US measurements were thinner than the mean values of the healthy group, excluding the knee cartilage thickness. We found a positive and moderate correlation between the differences in the thickness of the knee cartilage and the differences in knee extensor muscle strength, quadriceps femoris muscle thickness, and talar cartilage thickness between both lower extremities in the patient group. We observed a moderate correlation between the difference in talar cartilage thickness and the difference in knee cartilage thickness, gastrocnemius medialis muscle thickness, and knee extensor strength. A correlation between leg length differences and ankle dorsiflexor muscle strength differences or knee flexor strength differences was found in the present study.

Leg length discrepancy is the height difference between both legs. Therefore, we used a method similar to that of Eckstein et al.[14] to evaluate the correlation between leg length difference and other parameters. Eckstein et al. measured the thickness of the knee cartilage at different times in the OA patient group and the control group. They then calculated the cartilage thickness change between different times in both groups and compared the cartilage thickness changes of both groups[14].

The relationship between increased mechanical load on the joint and osteoarthritis has been shown previously[15]. As a result of muscle weakness in PMS patients, more load is placed on the joint and surrounding ligaments and joint instability develops. Therefore, musculoskeletal problems are more common in individuals with PMS[16]. In the etiopathology of joint diseases in patients with PMS, besides muscle weakness and some related mechanic disorders such as abnormal alignment and ligamentous laxity, leg length discrepancy is also blamed[1,9]. Leg length discrepancy worsens gait and function in patients with PMS[17]. Leg length discrepancy can also be seen in cerebral palsy, especially in the unilateral form[18]. Moreover, upper extremity shortness may develop in individuals with neonatal brachial plexus palsy over years, and this can be partially cured by neurosurgical reconstruction[19].

It is known that leg length discrepancy in people without neurological impairment can trigger joint degeneration in the early period[20], by impairing gait balance and weight transfer and can lead to knee osteoarthritis[21].

However, PM is a neurological disease that can result in both muscle and bone pathologies such as muscle paralysis and atrophy, bone thinning, and short limb length[22]. Although both muscle weakness and leg length asymmetry have been suggested as parameters that may cause arthrosis in PMS patients[1,9], the data of our study showed that there was a relationship between only muscle weakness difference and cartilage thickness difference in PMS patients, not the leg length disperency. As supported by our data, the relationship between muscle weakness and cartilage destruction may be stronger than the relationship between leg length discrepancy and cartilage destruction. We think that the results were like this because PM is a disease characterized by combined pathologies such as muscle weakness and leg length difference. Although it was thought that there was a relationship between leg length discrepancy and osteoarthritis in patients with PMS[9], we did not find a study on this subject in the literature review.

The literature on the relationship between the severity of muscle paralysis and the level of leg shortness in patients with PMS is contradictory[23]. We did not observe any correlation between leg length differences and muscle strength differences, except for ankle dorsiflexor muscle strength differences or knee flexor strength differences.

Nam et al. found an association between leg length difference and falling in PMS patients whereas they did not detect any association between muscle strength and falling[24].

We observed a relationship between cartilage thickness measurements and muscle thickness measurements. In the patient group, a positive and moderate correlation was found between the knee cartilage thickness difference and quadriceps femoris muscle thickness difference, and between the talar cartilage thickness difference and gastrocnemius medialis muscle thickness difference. US is a reliable method used in the determination of muscle thickness. Muscle cross-sectional area is a good indicator of muscle strength and is related to muscle thickness. Gellhorn et al. showed that muscle thickness measurement is superior to strength measurements for assessing quadriceps function in individuals with knee osteoarthritis[25].

Gilles et al. measured the quadriceps muscle thickness by US and the quadriceps cross-sectional area by MRI in patients with patellofemoral pain syndrome and found a good correlation between both measurements[26].

Consistent with the literature, there was a correlation between the quadriceps femoris muscle thickness difference and knee extensor strength difference, and between gastrocnemius medialis muscle thickness difference and plantarflexor muscle strength difference in our study. However, a study published in 2020 showed that muscle quality (the amount of fat in the muscle) was more effective

on walking speed than muscle thickness in individuals with knee osteoarthritis[27].

In our study, we found a correlation between the knee cartilage thickness difference and knee extensor muscle strength difference. Contrary to the literature[28,29], we did not find a correlation between the difference in plantar flexor muscle strength and the difference in the talar cartilage thickness. We think that this may be related to manual muscle testing as stated in the limitation of the study.

A meta-analysis determined that there was a significant decrease in isometric plantar flexion, dorsiflexion, eversion, and inversion torque measurements in patients with ankle OA. However, it is not clear whether ankle OA is more related to the plantar flexor or the dorsiflexor muscle weakness or both[29].

Angerova et al. found that the knee cartilage thickness values of PMS patients were thinner in the more affected legs than in the less affected legs. They found that talar cartilage thicknesses were similar between both lower extremities in the patient group. They also compared the data of the patient group with those of the healthy control group. They observed that the patient group had thinner knee cartilages in the more affected legs and thinner talar cartilages in both legs compared to the healthy control group[8]. In constrast to previous study we found that talar cartilage thicknesses were thinner in the more affected legs than in the less affected legs. We found that the mean talar cartilage thickness on the less affected side of the patient group was thinner than the mean value of the healthy subjects. Change (decrease) in cartilage thickness is an indicator of progression in osteoarthritis[14]. Angerova et al. observed a moderate and statistically significant correlation between knee cartilage thickness and knee extensor muscle strength[8]. Similarly, we found a positive and moderate correlation between the differences in the thickness of the knee cartilage and the differences in knee extensor muscle strength between both lower extremities in the patient group.

Thoren-Jönsson et al. showed that approximately half of the patients who were offered mobility aids did not want to use them[30]. Patients should be informed about the importance of using orthoses and/or mobilization aids to improve weight transfer, correct knee genu recurvatum, facilitate mobilization, and reduce the risk of falling. Future studies involving larger patient groups are needed to clarify possible interactions in this regard.

The relatively small size of our patient group is the first limitation of our study. Second, the muscle cross-sectional area was not evaluated. Third, the pennation angle and echo intensity parameters of the muscles were not included in the study. Grading of muscle strength by manual method is another limitation of our study. The last limitation of our study was that we did not use an X-Ray for leg length measurement, but we preferred measuring with a tape measure in our study due to the radiation risk.

Conclusion

In our study, we found that the ankle and knee joints of patients with PMS were prone to osteoarthritis. Moreover, we observed a relationship between the progression of osteoarthritis and the difference in muscle thickness. Orthoses and/or walking aids should be prescribed to patients who need them to reduce the overload on the joint associated with muscle weakness and to support joint stabilization. In the light of the data of our study, we have no doubt that future studies will be conducted on the effect of regular use of orthoses and/or walking aids on the prevention of osteoarthritis in patients with PMS or other neurological deficits such as hemiplegia and cerebral palsy. We think that new studies are needed to develop other evidence-based treatment approaches.

Ethics approval

Approval was obtained from the ethics committee of Hatay Mustafa Kemal University (Research protocol code: 2021/114).

Consent to participate

All individuals gave written consent to participate in the study.

Acknowledgement

Murat GÜNTEL lost his life in the great Hatay earthquake on February 6, 2023. With respect to the memory of our dear friend Murat GÜNTEL...

References

1. Prasad A, Donovan R, Ramachandran M, et al. Outcome of total knee arthroplasty in patients with poliomyelitis: a systematic review. EFORT Open Reviews 2018; 3(6):358-362.
2. Organization WH. Poliomyelitis, Fact sheet no. 114. WHO INT October 2014.
3. Gonzalez H, Olsson T, Borg K. Management of postpolio syndrome. The Lancet Neurology 2010;9(6):634-642.
4. Groce NE, Banks LM, Stein MA. Surviving polio in a post-polio world. Social Science & Medicine 2014; 107:171-178.
5. Lo JK, Robinson LR. Postpolio syndrome and the late effects of poliomyelitis. Part 1. pathogenesis, biomechanical considerations, diagnosis, and investigations. Muscle & nerve 2018;58(6):751-759.
6. Laffont I, Julia M, Tiffreau V, Yelnik A, Herisson C, Pelissier J. Aging and sequelae of poliomyelitis. Annals of physical and rehabilitation medicine 2010; 53(1):24-33.
7. Lo JK, Robinson LR. Post-polio syndrome and the late effects of poliomyelitis: Part 2. treatment, management, and prognosis. Muscle & nerve 2018;58(6):760-769.
8. Angerova Y, Mezian K, Kara M, et al. Ultrasonographic evaluation of the distal femoral and talar cartilage thicknesses in patients with poliomyelitis: a cross-

sectional observational study. European journal of physical and rehabilitation medicine 2020.
9. Yoon B-H, Lee Y-K, Yoo JJ, Kim HJ, Koo K-H. Total hip arthroplasty performed in patients with residual poliomyelitis: does it work? Clinical Orthopaedics and Related Research® 2014;472(3):933-940.
10. Malas FÜ, Kara M, Kaymak B, Akıncı A, Özçakar L. Ultrasonographic evaluation in symptomatic knee osteoarthritis: clinical and radiological correlation. International Journal of Rheumatic Diseases 2014; 17(5):536-540.
11. Yalçın S, Kara M, Öztürk GT, Özçakar L. Ultrasonographic measurements of the metacarpal and talar cartilage thicknesses in hemiplegic patients after stroke. Topics in Stroke Rehabilitation 2017;24(1):1-4.
12. Pardo E, El Behi H, Boizeau P, Verdonk F, Alberti C, Lescot T. Reliability of ultrasound measurements of quadriceps muscle thickness in critically ill patients. BMC anesthesiology 2018;18(1):1-8.
13. Wang J, Hu Y, Tian G. Ultrasound measurements of gastrocnemius muscle thickness in older people with sarcopenia. Clinical interventions in aging 2018; 13:2193.
14. Eckstein F, Collins J, Nevitt M, et al. Brief report: cartilage thickness change as an imaging biomarker of knee osteoarthritis progression: data from the Foundation for the National Institutes of Health Osteoarthritis Biomarkers Consortium. Arthritis & Rheumatology 2015;67(12):3184-3189.
15. Teng H-L, MacLeod TD, Kumar D, Link TM, Majumdar S, Souza RB. Individuals with isolated patellofemoral joint osteoarthritis exhibit higher mechanical loading at the knee during the second half of the stance phase. Clinical Biomechanics 2015;30(4):383-390.
16. Grimby G, Jönsson A-LT. Disability in poliomyelitis sequelae. Physical therapy 1994;74(5):415-424.
17. Gylfadottir S, Dallimore M, Dean E. The relation between walking capacity and clinical correlates in survivors of chronic spinal poliomyelitis. Archives of physical medicine and rehabilitation 2006;87(7):944-952.
18. Eek MN, Zügner R, Stefansdottir I, Tranberg R. Kinematic gait pattern in children with cerebral palsy and leg length discrepancy: effects of an extra sole. Gait & posture 2017;55:150-156.
19. Hamada Y, Kawabata H, Yasui N, Kitano M, Masatomi T. Growth disturbance of the paralytic limb in newborn brachial plexus palsy. Hand Surgery 1997;2(02):87-92.
20. Kuzma AL, Nichols LRB. Management of Mild Lower Extremity Deformity and Leg Length Discrepancy. Operative Techniques in Orthopaedics 2021; 31(2):100874.
21. Golightly YM, Allen KD, Renner J, Helmick C, Salazar A, Jordan JM. Relationship of limb length inequality with radiographic knee and hip osteoarthritis. Osteoarthritis and cartilage 2007;15(7):824-829.
22. Berner M, Pany-Kucera D, Doneus N, Sladek V, Gamble M, Eggers S. Challenging definitions and diagnostic approaches for ancient rare diseases: The case of poliomyelitis. International Journal of Paleopathology 2021;33:113-127.
23. Ratliff A. The short leg in poliomyelitis. The Journal of Bone and Joint Surgery. British volume 1959;41(1):56-69.
24. Nam KY, Lee S, Yang EJ, et al. Falls in Korean polio survivors: incidence, consequences, and risk factors. Journal of Korean medical science 2016;31(2):301-309.
25. Gellhorn AC, Stumph JM, Zikry HE, Creelman CA, Welbel R. Ultrasound measures of muscle thickness may be superior to strength testing in adults with knee osteoarthritis: a cross-sectional study. BMC musculoskeletal disorders 2018;19(1):1-8.
26. Giles LS, Webster KE, McClelland JA, Cook J. Can ultrasound measurements of muscle thickness be used to measure the size of individual quadriceps muscles in people with patellofemoral pain? Physical Therapy in Sport 2015;16(1):45-52.
27. Chopp-Hurley JN, Wiebenga EG, Bulbrook BD, Keir PJ, Maly MR. Evaluating the relationship between quadriceps muscle quality captured using ultrasound with clinical severity in women with knee osteoarthritis. Clinical Biomechanics 2020;80:105165.
28. Shih L-Y, Wu J-J, Lo W-H. Changes in gait and maximum ankle torque in patients with ankle arthritis. Foot & Ankle 1993;14(2):97-103.
29. Al-Mahrouqi MM, Macdonald DA, Vicenzino B, Smith MD. Physical impairments in adults with ankle osteoarthritis: a systematic review and meta-analysis. journal of orthopaedic & sports physical therapy 2018;48(6):449-459.
30. Thorén-Jönsson A-L, Grimby G. Ability and perceived difficulty in daily activities in people with poliomyelitis sequelae. Journal of Rehabilitation Medicine 2001; 33(1):4-11.