

ORIGINAL ARTICLE

The effect of knee joint loading and immobilization on the femoral cartilage thickness in paraplegics

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Background: Femoral cartilage thickness has been used as an indicator for immobilization and unloading in patients with spinal cord injury (SCI). However, conflicting results have been reported on this subject.

Objectives: (i) To determine femoral cartilage thickness alterations after prolonged immobilization, (ii) to demonstrate the effect of the daily standing or ambulation time on the cartilage and (iii) to analyze the predictors of the femoral cartilage in patients with SCI.

Methods: A total of 50 patients with SCI and 50 healthy age and sex-matched volunteers were enrolled in the study. A physician scanned both knees of all participants and measurements were taken at three locations: trochlear notch, midpoints of the medial and lateral condyle.

Results: The trochlear notch, medial and lateral condyle femoral cartilage thickness of both sides were significantly thicker in the control group ($P < 0.05$). Patients with < 1 h daily standing/walking time had higher thickness measurements in all sub parameters than patients with > 1 h daily standing/walking time ($P < 0.05$). Daily standing/walking time and the Walking index for SCI score were statistically significant predictors for cartilage thickness.

Conclusion: SCI patients had thinner knee cartilage compared with healthy individuals in ultrasonographic assessment. More than 1 h daily standing/walking time may have a negative effect on the femoral cartilage thickness. Thus, ultrasonographic evaluation of the femoral cartilage should be considered in clinical practice to detect early cartilage thinning in patients with SCI.

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INTRODUCTION

Mechanical loading and movement are essential for the maintenance of the integrity of skeletal tissues including articular structures and cartilage. Prolonged immobilization after spinal cord injury (SCI) has been suggested to be a cause of contractures, periarticular osteoporosis, heterotopic ossification, osteoarthritis and periarticular connective tissue alterations. Lower extremity articular cartilage needs some regimen of joint loading and motion to maintain its native physical and biochemical properties.^{1,2} Thus, femoral cartilage thickness has been used as an indicator for immobilization and unloading in patients with SCI. Studies in patients with SCI have revealed conflicting results in respect of cartilage thickness. Enneking and Horowitz reported that the articular cartilage of the knee was histologically normal in a patient with SCI; whereas, Vanwanseele *et al.* identified progressive thinning of the articular cartilage after SCI.^{3–5}

Together with widespread use in clinical practice, musculoskeletal ultrasonography has become a common diagnostic tool to determine cartilage thickness, resulting with a growing databank in the literature. However, the aforementioned discrepancies have emerged with the ultrasonography results of articular thicknesses in the same way. Kara *et al.*⁶ recently reported that the articular cartilage of knee joints in patients with SCI were significantly thicker compared with the ones in healthy controls and the articular thickness was negatively correlated with disease duration and severity. The finding of increased articular cartilage seems to be a paradox when it is considered with the

findings of other studies of patients with different types of immobility in which cartilage thicknesses were reported to be decreased ultrasonographically.^{7,8}

Another important study which may shed light on this paradox was conducted by Kilic *et al.*⁹ Decreases in femoral cartilage thickness assessed by ultrasonography were determined from a.m. to p.m. on the same day. To the best of our knowledge, this diurnal alteration in the femoral cartilage has not been taken into account by any previous researchers and this methodological difference may have led to inaccurate interpretations.

As there has been disagreement in previous studies due to some possible confounding factors and methodological diversity, the present study was conducted. The aims were (i) to determine femoral cartilage thickness alterations after prolonged immobilization by measuring the cartilage thickness at the same time of day, (ii) to demonstrate the effect of daily standing or ambulation time on cartilage thickness and (iii) to analyze the predictors of femoral cartilage in patients with SCI.

MATERIALS AND METHODS

Study design and participants

The study was conducted with a cross-sectional case-controlled design. Approval for the study was granted by the Local Ethics Committee of Numune Training and Research Hospital, Ankara (256/2014). Patients with SCI, who were admitted to the SCI Unit of Turkish Armed Forces rehabilitation center between June 2014 and December 2014, were enrolled consecutively for the

study. The inclusion criteria for the patients were (a) age between 18 and 50 years, (b) grade A, B, C or D on the American Spinal Injury Association Impairment Scale (AIS), (c) level of injury below T2, (d) traumatic etiology and (e) medical clearance to participate. The age limit of 18–50 years was set to avoid confounding factors such as various physical activity levels and joint degeneration related to aging. Participants were excluded if they (a) had a history of knee pain, (b) trauma, (c) surgery or (d) knee joint deformities causing decreased range of motion and contractures. It was predicted that a clinically relevant difference of 0.55 cm would be detected between the two groups according to a study by Kara *et al.*⁶ Based on a power of 80% and a type-I error of 0.05, the sample size required per group was calculated to be a minimum of 42 subjects. A total of 50 patients who met the study criteria and 50 age and sex-matched healthy volunteers participated in the study. After receiving oral and written information, all participants signed a statement of informed consent.

Assessment

Patients with SCI were assessed according to the AIS.¹⁰ Demographic and clinical data including age, gender, time since injury, etiology, degree and level of neurological impairment and a rounded-up duration of daily standing/walking were recorded. The spasticity of the knee flexor and extensor muscles were assessed with the Modified Ashworth Scale.¹¹ Walking capability was assessed with the Walking Index for Spinal Cord Injury (WISCI-II) which categorizes a person's walking capability related to the need for physical assistance and assistive devices and/or braces. It is a 20-item scale with a score ranging from 0 to 20. A higher score indicates a better and more independent walking status.¹² The same physician, who was an experienced musculoskeletal sonographer, scanned both knees of all the participants using the same ultrasound device with a 7.5–12-MHz linear transducer (LOGIQ 7 Pro; GE Yokogawa Medical System, Tokyo, Japan). All cartilage thickness measurements were evaluated in the morning at 08:00–09:00 a.m. to standardize the assessments. Although the subjects were lying supine on the examination table with their knees in maximum flexion, the probe was positioned transversely to the leg just above the superior margin of the patella and perpendicular to the femoral articular surface. Distal femoral cartilage thickness was measured from the thin hyperechoic line at the soft tissue cartilage interface to the hyperechoic line at the cartilage-bone interface. These measurements were obtained from three locations: trochlear notch, midpoints of the medial and lateral condyle (Figure 1).

To evaluate the intra-observer and inter-observer reliability, the ultrasonographic cartilage assessments of five healthy individuals and five patients with SCI (a total of 20 knees) were obtained separately by two raters according to the study methodology. Both raters repeated all the measurements after 1 day, blinded to the initial records. The intra-observer and inter-observer reliability were found to be moderate to good (1.84–9.2% coefficient of variation and

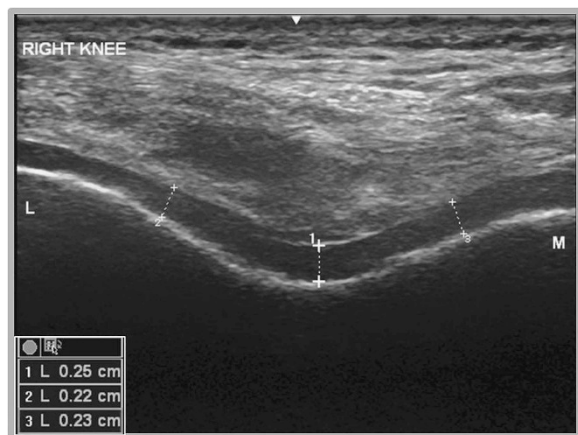


Figure 1 Femoral cartilage thickness measurements via ultrasound in a suprapatellar axial view. L, lateral; M, medial. A full color version of this figure is available at the *Spinal Cord* journal online.

1.75–8.7% coefficient of variation, respectively) for the ultrasonographic femoral cartilage thickness measurements.

Data analysis

Statistical analysis was performed using SPSS version 15.0 (SPSS Inc., Chicago, IL, USA). Continuous variables were presented as mean \pm s.d. and categorical variables were summarized as frequencies and percentages. Categorical variables were analyzed with a χ^2 test. The distributions of the numeric variables were examined using the Kolmogorow–Smirnov test for normality. The differences between the groups were determined with the Mann–Whitney *U*-test. A multiple linear regression model was used to identify independent predictors of cartilage thickness. Statistical significance was defined as $P < 0.05$.

RESULTS

The mean age values were 31.46 ± 7.33 years and 32.02 ± 8.23 years in the SCI and control groups, respectively, ($P > 0.05$). The gender ratios were similar at: 76% male in the patient group and 74% male in the control group. Of all the patients, 34 (68%) were motor complete (AIS A and B), and 16 were motor incomplete (AIS C and D). The demographic and clinical features of the SCI patients are summarized in Table 1.

The comparison of the SCI and control groups revealed that all femoral cartilage thickness measurements were significantly better in the control group ($P < 0.05$). (Figure 2). In the SCI group, the within group analysis showed that SCI patients with < 1 h daily standing/walking time had higher thickness measurements in all sub parameters

Table 1 Demographic and clinical features of the patients

| | Patients (n:50) |
|---------------------------------------|------------------|
| Age (years) mean \pm s.d. | 31.46 \pm 7.33 |
| Gender, n (%) | |
| Male | 38 (76) |
| Female | 12 (24) |
| Time since injury (months) \pm s.d. | 31.1 \pm 38.19 |
| Etiology, n (%) | |
| Motor vehicle accident | 20 (40) |
| Fall | 15 (30) |
| Gunshot wound | 6 (12) |
| Violence | 1 (2) |
| Other | 8 (16) |
| Level of injury, n (%) | |
| Thoracic | 38 (76) |
| Lumbosacral | 12 (24) |
| AIS, n (%) | |
| A and B (Motor Complete) | 34 (68) |
| C and D (Motor Incomplete) | 12 (24) |
| WISCI-II (median range) | 5 (0–20) |
| Daily standing/walking time | |
| > 1 h | 34 (68) |
| > 1 h | 16 (32) |
| MAS (median range) | |
| Knee flexor | 0 (0–2) |
| Knee extensor | 0 (0–4) |

Abbreviations: AIS, American Spinal Injury Association Impairment Scale; MAS, Modified Ashworth Scale; WISCI-II, Walking Index for Spinal Cord Injury.

than patients with >1 h daily standing/walking time ($P < 0.05$). (Figure 3). There was not significant difference between femoral cartilage thickness of the patients who were in AIS A, B, C and D ($P > 0.05$).

Daily standing/walking time was found to be statistically significant in the prediction of right and left femoral medial condyle cartilage thickness in multiple linear regression analysis. The WISCI-II score was statistically significant predictor for left trochlear notch and medial condyle cartilage thickness (Table 2).

DISCUSSION

The results of this study revealed that SCI patients had thinner knee cartilage and the decrease in femoral cartilage was more profound in patients who had >1 h daily standing/walking time. There were significant relationships between daily standing/walking time and WISCI-II score and knee cartilage thickness.

The effect of unloading on the femoral cartilage has been investigated in animal models and human subjects in various studies.^{4-8,13-15} Animal studies have revealed that the mechanical, biochemical and morphological properties of the cartilage were altered after immobilization and did not always recover upon remobilization.^{4,5} In humans, changes in cartilage have been demonstrated in different types of immobilization.⁶⁻⁸ Vanwanseele *et al.* reported that there was significantly lower mean cartilage thickness in the patella, medial, and lateral tibia of patients with SCI compared

with healthy individuals according to magnetic resonance imaging findings.^{4,5} At 12 and 24 months post injury, the reduction in the cartilage was more prominent.^{4,5} The results of the present sonographic study were parallel to those magnetic resonance imaging studies. In contrast to these results, Kara *et al* reported an increase in cartilage thickness in paralyzed individuals compared with healthy participants.⁶ Authors commented that their findings of thicker cartilage values in patients with SCI might be caused by immobilization and denervation in addition to knee biomechanics and edema. It has been shown that femoral cartilage thickness may change from a.m. to p.m. on the same day.⁸ There was no data about the time of cartilage thickness assessment in the previous sonographic study. Therefore, in the current study the measurements were taken at the same time of the day.

In the assessments of the current study, the cartilage thickness was found to be thinner in the medial section compared with the lateral and trochlear areas. In addition, daily standing/walking time was found to be a significant predictor for medial cartilage thickness. This could be explained by biomechanical properties as the medial compartment bears a greater load during normal standing and walking because the center of gravity passes medially to the knee.¹⁶

Patients with SCI may believe that exercises including excessive standing and walking training will accelerate their recovery and may therefore exceed the rehabilitation schedule, even though it is

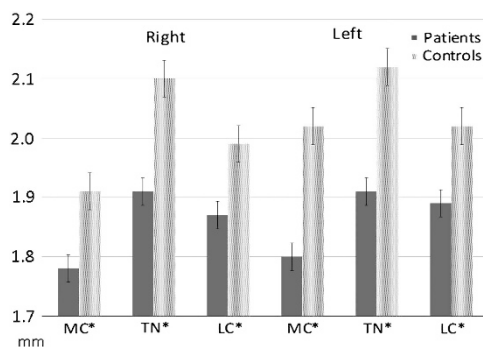


Figure 2 Comparison of the sonographic distal femoral cartilage measurements of the two groups. LC, lateral femoral condyle; MC, medial femoral condyle; TN, trochlear notch. *indicates that there is a statistically significant difference between the two groups.

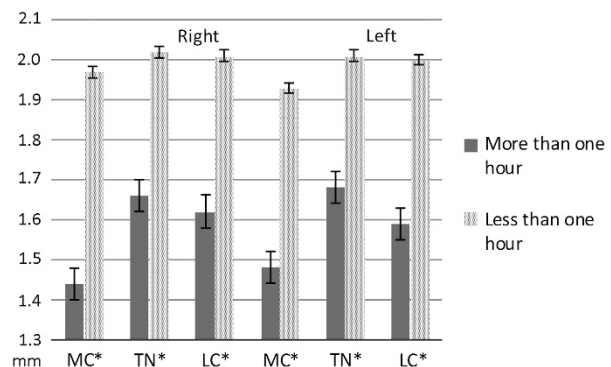


Figure 3 The effect of standing/walking on the femoral cartilage thickness. Abbreviations: LC, lateral femoral condyle; MC, medial femoral condyle; TN, trochlear notch. *indicates that there is a statistically significant difference between the two groups.

Table 2 Multiple linear regression analysis of cartilage thickness, B-values.

| | Right | | | Left | | |
|--|---------------------|--------|--------|---------------------|---------------------|--------|
| | MC | TN | LC | MC | TN | LC |
| Current age | 0.079 | 0.153 | 0.051 | 0.164 | 0.112 | 0.151 |
| Age at the time of injury | -0.088 | -0.176 | -0.060 | -0.174 | -0.135 | -0.165 |
| Post-injury time | -0.005 | -0.009 | -0.002 | -0.013 | -0.008 | -0.010 |
| Male/female | 0.113 | 0.085 | 0.159 | 0.034 | 0.070 | 0.089 |
| Complete/incomplete | 0.085 | 0.133 | -0.060 | -0.022 | 0.006 | -0.050 |
| LEMS | 0.008 | 0.009 | 0.002 | 0.007 | 0.011 | 0.002 |
| More than hour daily standing/walking time | -0.339 ^a | -0.243 | -0.249 | -0.448 ^a | -0.121 | -0.206 |
| WISCI-II score | -0.020 | -0.027 | -0.032 | -0.031 ^a | -0.059 ^a | -0.024 |
| MAS-knee flexor | 0.229 | 0.114 | 0.219 | 0.160 | 0.117 | 0.335 |
| MAS-knee extensor | -0.018 | 0.016 | -0.042 | -0.084 | 0.014 | -0.014 |

Abbreviations: CI, confidence interval; LC, lateral femoral condyle; LEMS, lower extremity motor score; MAS, Modified Ashworth Scale; MC, medial femoral condyle; TN, trochlear notch; WISCI-II, Walking Index for Spinal Cord Injury.
^aindicates that prediction of the indicator is statistically significant.

regulated by a physical medicine and rehabilitation specialist. The results of the study showed that SCI patients with >1 h daily standing/walking time had thinner cartilage. Factors that may contribute to decreased cartilage thickness in patients with SCI in addition to immobilization are (i) deterioration of articular vascular supply due to extensive exercises, (ii) unbalanced pressure on cartilage during standing or walking exercises and (iii) increased intra-articular pressure impairing cartilage diffusion due to spasticity.¹⁷ Patients are prescribed home exercises as they practice with physiotherapist including standing or walking exercises. Current results should not be perceived as less practice thicker cartilage. Routine sonographic evaluation may be helpful in detecting cartilage thinning thus cartilage alteration may shape exercises. Because both standing and walking are showed to be important in order to keep the health condition, prevent muscle atrophy, contractures, periarticular osteoporosis, heterotopic ossification and promote well-being and increase quality of life.^{4,5}

The WISCI-II score was found to be a significant predictor related with decreased femoral cartilage. These findings could be surprising when healthy individuals, who were showed to have thicker knee cartilage, is considered as they have standing or walking activities obviously more than those with SCI. However, healthy individuals have intact neuromuscular functions such as proprioception, periarticular muscle strength and tonus. The current literature suggests that if the patients need to enhance walking, rehabilitation programs should be aimed to walking exercises. In the lights of current findings task specific exercises might be initiated after gaining appropriate muscle strength and maintained under the sonographic control.

A possible limitation of the current study is that cartilage thickness measurements were obtained in a cross-sectional study design. There might be time-dependent changes in cartilage thickness in a patient with SCI. It is suggested that future studies evaluating cartilage thickness alterations are conducted as longitudinal studies with repeated measurements. In addition, daily standing/walking time was derived from interviewing. Selecting actual observation as an outcome of daily standing/walking time might be more reasonable in future studies.

In conclusion, SCI patients had thinner knee cartilage compared with healthy individuals in the ultrasonographic assessment. More than 1 h daily standing/walking time may have a negative effect on the femoral cartilage thickness. Thus, periodic ultrasonographic evaluation of the femoral cartilage should be considered in clinical practice to detect early cartilage thinning in patients with SCI.

DATA ARCHIVING

There was no data to deposit.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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