Original article

Effect of muscle contractions on cartilage: morphological and functional magnetic resonance imaging evaluation of the knee after spinal cord injury☆

CrossMark

Marco Kawamura Demange, Camilo Partezani Helito*, Paulo Victor Partezani Helito, Felipe Ferreira de Souza, Riccardo Gomes Gobbi, Alexandre Fogaça Cristante

Universidade de São Paulo, Faculdade de Medicina, Departamento de Ortopedia e Traumatologia, São Paulo, SP, Brazil

ARTICLE INFO

ABSTRACT

Objective: To evaluate the effect of complete absence of muscle contractions on normal human cartilage in the presence of joint motion.

Methods: Patients with complete acute spinal cord injuries were enrolled. All patients underwent magnetic resonance imaging (MRI) on both knees as soon as their medical condition was stable and at six months after the primary lesion. All patients received rehabilitation treatment that included lower-limb passive motion exercises twice a day. The MRIs were analyzed by two radiologists with expertise in musculoskeletal disorders. A region of interest was established at the patellar facets and trochlea, and T2 relaxation times were calculated. The area under the cartilage T2 relaxation time curve was calculated and standardized.

Results: Fourteen patients with complete spinal cord injuries were enrolled, but only eight patients agreed to participate in the study and signed the informed consent statement. Two patients could not undergo knee MRI due to their clinical conditions. Initial knee MRIs were performed on six patients. After six months, only two patients underwent the second bilateral knee MRI. Both patients were neurologically classified as Frankel A. An increase in T2 values on the six-month MRI was observed for both knees, especially in the patellofemoral joint.

Conclusion: The absence of muscle contractions seems to be deleterious to normal human knee cartilage even in the presence of a normal range of motion. Further studies with a larger number of patients, despite their high logistical complexity, must be performed to confirm this hypothesis.

Efeito da contração muscular na cartilagem: avaliação morfológica e funcional por imagens de ressonância magnética do joelho após trauma medular

R E S U M O

Palavras chave:
Trauma medular
Joelho
Cartilagem, articulação
Imagem de ressonância
magnética
Contração muscular

Objetivo: Avaliar o efeito da completa ausência de contração muscular na cartilagem humana normal na presença de movimento articular.

Métodos: Pacientes com lesão completa da medula espinal foram incluídos. Todos os pacientes foram submetidos à ressonância magnética (RM) em ambos os joelhos assim que as condições clínicas foram estabilizadas e depois de seis meses da lesão inicial. Todos os pacientes receberam tratamento de reabilitação que incluía movimentos passivos para exercitar os membros inferiores duas vezes por dia. RM foram analisadas por dois radiologistas com experiência em doenças musculoesqueléticas. As regiões de interesse consideradas foram as da patela e na tróclea, e os tempos de relaxamento T2 foram calculados. A área da cartilagem abaixo dos valores de relaxamento em T2 foi calculada e padronizada.

Resultados: Catorze pacientes com lesão medular completa foram incluídos, porém apenas oito pacientes concordaram em participar do estudo e assinaram o termo de consentimento informado. Dois pacientes não puderam fazer RM dos joelhos devido às condições clínicas. RM inicial foi feita em seis pacientes. Após seis meses, apenas dois pacientes fizeram a segunda RM de ambos os joelhos. Ambos estavam em condição neurológica classificada como Frankel A. Um aumento dos valores em T2 no sexto mês foi observado em ambos os joelhos, especialmente na articulação patelofemoral.

Conclusão: A ausência de contração muscular parece ser deletéria à cartilagem do joelho humano normal, mesmo na presença de movimentos articulares normais. Mais estudos com um número maior de pacientes devem ser feitos para confirmar esta hipótese.

Introduction

Several in vitro and animal studies have shown that a certain amount of mechanical loading and joint movement is required to maintain normal cartilage morphology, biochemical composition, and biomechanical properties.[1,2]

Spinal cord injury (SCI) causes decreases in muscle mass, cardiovascular fitness, bone density, and unloading due to the absence of muscle contractions.[3,4] Previous studies have shown differences in patellar and tibial cartilage thickness, mainly progressive thinning (atrophy), in SCI patients compared with age-matched healthy volunteers due to the absence of normal joint loading and movement.[5]

These differences may be due to inadequate cartilage nutrition and the absence of good effects of loading and movement of the joint, which are of major importance for the maintenance of the morphological and functional integrity of articular cartilage.[6,7]

One important reason for this cartilage thinning is immobilization. Some authors have concluded that exercises such as continuous passive motion can prevent this type of alteration.[8] However, we believe that the published evidence is insufficient to conclude that this type of movement in the absence of muscle contractions can prevent articular cartilage damage.

Therefore, the objective of this study was to evaluate the effect of the complete absence of muscle contractions on normal human cartilage in the presence of joint motion.

Method

This study received institutional review board (IRB) approval from our institution. We enrolled patients with a complete spinal cord lesion with tetraplegia or complete paraplegia. We did not enroll patients with spinal cord lesions at the lumbar level to assure the complete absence of lower limb muscle contractions.

All patients underwent knee magnetic resonance imaging (MRI) after the diagnosis of their acute lesion as soon as their medical condition was stable to avoid harm due to this exam.

All MRI scans were performed with a 1.5-T MR imager (Signa Excite HD; GE Healthcare, Waukesha, WI, USA) using a dedicated knee coil (HD T/R 8-channel High- Resolution Knee Array). The scans were performed using an MRI knee imaging protocol with sagittal and coronal T1-weighted sequences, as well as sagittal, coronal, and axial T2-weighted sequences with fat saturation fast spin-echo sequences.

Spin-echo images used to calculate T2 maps were obtained with the following parameters: TR/TE, 1200/8 ms; section thickness, 3.5 mm; slice spacing, 0.7 mm; field of view, 10.00 cm; image matrix, 192 × 192; bandwidth, 31.25 kHz; and
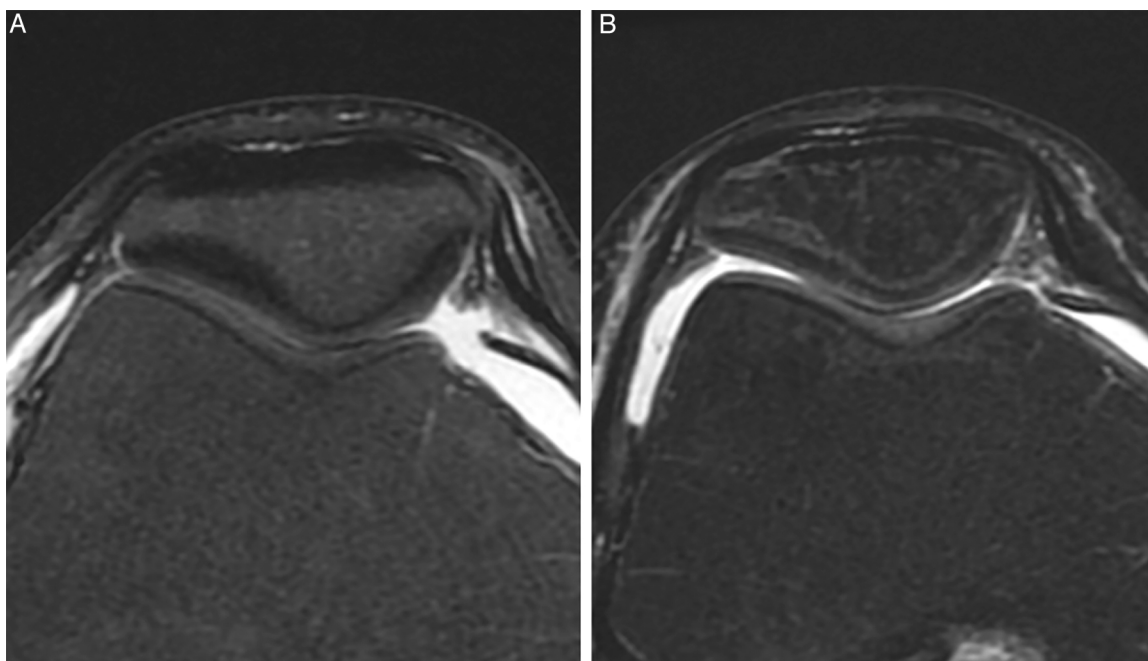
Fig. 1 – Axial T2WI at the patellofemoral joint. Initial imaging (A) and imaging at the one-year follow-up (B) demonstrating a similar cartilage signals.

total acquisition time, 3 min 50 s. Using a sagittal locator, a single axial data set was obtained for the patellofemoral joint.

A second MRI was performed six months after the spinal cord injury. None of the patients exhibited improvement in the neurological condition of the lower limb at the time of the second evaluation.

All patients received rehabilitation treatment, including lower limb passive motion exercises twice a day. The rehabilitation team included physiotherapists and a physiatrist.

The MRIs were analyzed by two radiologists with expertise in musculoskeletal disorders.

A region of interest (ROI) was placed at the patellar facets and trochlea, and the T2 relaxation time was calculated. The area under the curve of the cartilage T2 relaxation time was calculated and standardized

Results

We enrolled 14 patients with complete spinal cord injuries who met our inclusion criteria, but only eight patients agreed to participate in the study and signed the informed consent form.

Two patients could not undergo knee MRI due to clinical conditions, and six patients underwent the initial knee MRI.

After six months, only two patients had undergone the second bilateral knee MRI. Both patients were neurologically classified as Frankel A, defined as a lack of motor activity or sensibility below the level of the injury.

Table 1 presents the T2 mapping values for the two patients in both knees. Note that there is an increase in the T2 value at the six-month MRI for both knees, especially in the patellofemoral joint (Figs. 1 and 2).

Discussion

To our knowledge, this is the first study providing evidence of early cartilage degradation by prospectively performing MRI with T2 mapping in non-ambulatory complete spinal cord injury patients. Previous MRI studies had suggested this hypothesis but could not prospectively perform serial MRI exams.[5]

The addition of a T2 mapping sequence to a routine MRI protocol at 3.0 T improved the sensitivity of the detection of cartilage lesions within the knee joint from 74.6% to 88.9%, with only a small reduction in specificity. The greatest improvement in sensitivity with the use of the T2 maps was in the identification of early cartilage degeneration.[9]

Kara et al.[10] performed ultrasonographic measurements of femoral cartilage thickness in forty-six patients with spinal cord injury. Mid-point ultrasonography femoral cartilage thickness measurements were obtained from the right lateral condyle, right intercondylar area, right medial condyle, left medial condyle, left intercondylar area, and left lateral condyle. They observed that the femoral cartilage thickness differed between SCI patients and paired healthy controls and that it displayed a negative correlation with disease duration and severity. Findikoglu et al.[11] investigated cartilage degradation based on the turnover of C-telopeptide fragments of collagen type-II (CTX-II), a molecule specific to articular cartilage in SCI patients, with respect to clinical functional status. uCTX-II levels were significantly higher in patients with American Spinal Injury Association Impairment Scale grade A, non-functional ambulators, and patients who did not ambulate at all ($p < 0.05$).

Table 1 – T2 scores showing T2 values at different sites of the patellofemoral joint.

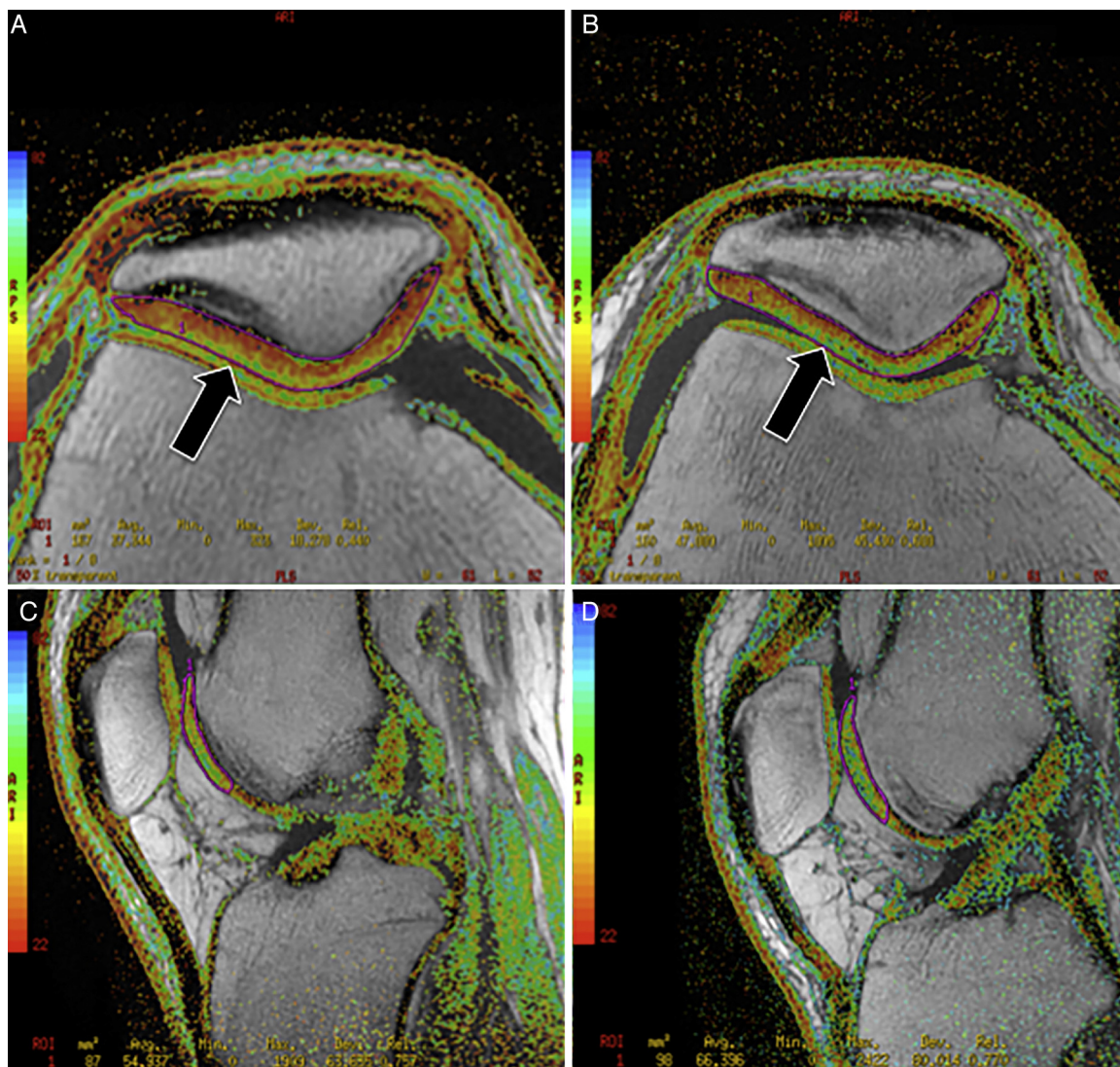|	Patient 1				Patient 2			
	Right knee		Left knee		Right knee		Left knee	
	Trochlea	Patella	Trochlea	Patella	Trochlea	Patella	Trochlea	Patella
First MRI	54	37	56	46	53	41	53	41
Second MRI	66	45	66	55	64	56	55	54

Fig. 2 – Axial (A and B) and sagittal (C and D) T2 mapping images at the patellofemoral joint. Initial imaging (A and C) and imaging at the one-year follow-up (B and D) demonstrating qualitative changes and increased T2 values at the superficial layer of the patellar cartilage (black arrows). According to the scale used, green points represent worse cartilage quality.

Ruckstuhl et al.[12] demonstrated the effect of increased or reduced loading on shoulder articular cartilage. The following three groups were compared: individuals with paraplegia with high shoulder demand ($n = 11$), individuals with quadriplegia with reduced loading of the shoulder joint ($n = 8$), and a control group ($n = 9$). There was no difference in cartilage thickness or minimum joint space according to MRI with 3D reconstruction. In an animal study, Moryama et al.[13] observed that the cartilage thickness in spinal cord-injured knees decreased in the tibial and posterior femoral regions but increased in the anterior femoral region. Spinal cord injuries were associated with a decreased number of chondrocytes in the anterior regions and decreased cartilage matrix staining only in the tibial region. The authors consider that cartilage alterations after SCI would not be explained by only the suppression of mechanical forces due to unloading and immobilization; rather, there may be influences on the cartilage in addition to the change in mechanical forces.

Vanwanseele et al.[5,14] performed a transversal study by analyzing knee cartilage in patients with complete traumatic spinal cord injuries with MRI at 6 ($n = 9$), 12 ($n = 11$), and 24 months ($n = 6$) after the injury. The results were compared with those in young, healthy volunteers ($n = 9$). The individual difference maps of 43% of the patients showed local areas of substantial thinning 6 and 12 months after injury. The data obtained by Vanwanseele et al.[5,14] corroborate our findings by showing a negative effect of spinal cord injury on knee articular cartilage. In our report, we prospectively compared each individual after a six-month period by performing two serial MRIs.

To evaluate the effect of overloading of articular cartilage, Muhlbauer et al.[15] compared cartilage thickness between nine triathletes and nine physically inactive volunteers. There was a high interindividual variability of the mean and maximum cartilage thickness values for all surfaces, both in the triathletes and in the inactive volunteers. In the patella, the femoral trochlea, and the lateral femoral condyle, the mean and maximum cartilage thickness values were slightly higher in the triathletes, but they were somewhat lower in the medial femoral condyle and in the medial and lateral tibial plateau. However, the differences did not attain statistical significance.

Torzilli et al.[2] observed that mechanical loading of sufficient magnitude can inhibit ECM degradation by chondrocytes when stimulated by interleukin (IL)-1. The molecular mechanisms involved in this process are not clear but probably involve altered mechanochemical signal transduction between the ECM and chondrocytes.

Continuous passive motion is commonly used postoperatively following cartilage surgery. Unfortunately, the clinical evidence[16–19] to support the use of continuous passive motion is lacking despite an overwhelming abundance of basic science support and the common clinical practice of continuous passive motion implementation postoperatively in knee cartilage restoration procedures.[20] The most commonly prescribed parameters within a Continuous passive motion regimen are initiated on the first postoperative day, with an initial range-of-motion of 0–30° and a frequency of 1 cycle per minute, applied for six to eight hours daily over six weeks.[21] Studies have demonstrated that continuous passive motion facilitates the repair of full-thickness defects in articular cartilage.[22,23]

The patients evaluated in this study had a normal passive range of motion during the six-month period after the SCI, but they presented articular cartilage damage. This result may have occurred because a normal range of motion without muscle contraction is not sufficient to maintain the nutrition and structural properties of the cartilage.

Our study has some limitations. First, there were only two patients included in the final six-month MRI study. As the MRI was performed for research purposes not related to their spinal cord injury, we had difficulty enrolling patients. Most patients indicated that the logistics of undergoing knee MRI are not easy considering their physical limitations. Second, we performed time-zero and six-month MRIs only, which does not provide information on the time at which the cartilage alterations began to occur. We consider that performing knee MRIs for research purposes in the initial three months after a traumatic spinal cord lesion would have very low acceptance among patients and their relatives.

Conclusion

The absence of muscle contractions seems to be deleterious to normal human knee cartilage even in the presence of a normal range of motion. Further studies with a larger number of patients, despite their high logistical complexity, must be performed to confirm this hypothesis.

Conflict of interest

The authors declare no conflicts of interest.

REFERENCES

1. Vanwanseele B, Lucchinetti E, Stüssi E. The effects of immobilization on the characteristics of articular cartilage: current concepts and future directions. Osteoarthr Cartil. 2002;10(5):408–19.
2. Torzilli PA, Bhargava M, Park S, Chen CT. Mechanical load inhibits IL-1 induced matrix degradation in articular cartilage. Osteoarthr Cartil. 2010;18(1):97–105.
3. Kocina P. Body composition of spinal cord injured adults. Sports Med. 1997;23(1):48–60.
4. Whiteneck GG, Charlifue SW, Frankel HL, Fraser MH, Gardner BP, Gerhart KA, et al. Mortality, morbidity, and psychosocial outcomes of persons spinal cord injured more than 20 years ago. Paraplegia. 1992;30(9):617–30.
5. Vanwanseele B, Eckstein F, Knecht H, Stüssi E, Spaepen A. Knee cartilage of spinal cord-injured patients displays progressive thinning in the absence of normal joint loading and movement. Arthritis Rheum. 2002;46(8):2073–8.
6. McKee P, Hannah S, Priganc VW. Orthotic considerations for dense connective tissue and articular cartilage – the need for optimal movement and stress. J Hand Ther. 2012;25(2):233–42.
7. O'Hara BP, Urban JP, Maroudas A. Influence of cyclic loading on the nutrition of articular cartilage. Ann Rheum Dis. 1990;49(7):536–9.
8. Knapik DM, Harris JD, Pangrazzi G, Griesser MJ, Siston RA, Agarwal S, et al. The basic science of continuous passive motion in promoting knee health: a systematic review of studies in a rabbit model. Arthroscopy. 2013;29(10):1722–31.
9. Kijowski R, Blankenbaker DG, Munoz Del Rio A, Baer GS, Graf BK. Evaluation of the articular cartilage of the knee joint: value of adding a T2 mapping sequence to a routine MR imaging protocol. Radiology. 2013;267(2):503–13.
10. Kara M, Tiftik T, Öken Ö, Akkaya N, Tunc H, Özçakar L. ltrasonographic measurement of femoral cartilage thickness in patients with spinal cord injury. J Rehabil Med. 2013;45(2):145–8.
11. Findikoglu G, Gunduz B, Uzun H, Erhan B, Rota S, Ardic F. Investigation of cartilage degradation in patients with spinal cord injury by CTX-II. Spinal Cord. 2012;50(2):136–40.
12. Ruckstuhl H, Krzycki J, Petrou N, Vanwanseele B, Stussi E. A quantitative study of humeral cartilage in individuals with spinal cord injury. Spinal Cord. 2008;46(2):129–34.
13. Moriyama H, Yoshimura O, Kawamata S, Takayanagi K, Kurose T, Kubota A, et al. Alteration in articular cartilage of rat knee joints after spinal cord injury. Osteoarthr Cartil. 2008;16(3):392–8.
14. Vanwanseele B, Pirnog C, Székely G, Stüssi E. Quantitative analysis of local changes in patellar cartilage in spinal cord injured subjects. Clin Orthop Relat Res. 2007;456:98–102.
15. Mühlbauer R, Lukasz TS, Faber TS, Stammberger T, Eckstein F. Comparison of knee joint cartilage thickness in triathletes

and physically inactive volunteers based on magnetic resonance imaging and three-dimensional analysis. Am J Sports Med. 2000;28(4):541–6.

16. Alfredson H, Lorentzon R. Superior results with continuous passive motion compared to active motion after periosteal transplantation. A retrospective study of human patella cartilage defect treatment. Knee Surg Sports Traumatol Arthrosc. 1999;7(4):232–8.

17. Marder RA, Hopkins G Jr, Timmerman LA. Arthroscopic microfracture of chondral defects of the knee: a comparison of two postoperative treatments. Arthroscopy. 2005;21(2):152–8.

18. Rodrigo JJ, Steadman JR, Silliman JF, Fulstone HA. Improvement of full-thickness chondral defect healing in the human knee after debridement and microfracture using continuous passive motion. Am J Knee Surg. 1994;7:109–16.

19. Schultz W, Göbel D. Articular cartilage regeneration of the knee joint after proximal tibial valgus osteotomy: a prospective study of different intra- and extra-articular operative techniques. Knee Surg Sports Traumatol Arthrosc. 1999;7(1):29–36.

20. Fazalare JA, Griesser MJ, Siston RA, Flanigan DC. The use of continuous passive motion following knee cartilage defect surgery: a systematic review. Orthopedics. 2010;33(12):878.

21. Karnes JM, Harris JD, Griesser MJ, Flanigan DC. Continuous passive motion following cartilage surgery: does a common protocol exist? Phys Sportsmed. 2013;41(4):53–63.

22. Williams JM, Moran M, Thonar EJ, Salter RB. Continuous passive motion stimulates repair of rabbit knee articular cartilage after matrix proteoglycan loss. Clin Orthop Relat Res. 1994;(304):252–62.

23. Salter RB. The physiologic basis of continuous passive motion for articular cartilage healing and regeneration. Hand Clin. 1994;10(2):211–9.