Change of Knee Cartilage Components in Stroke Patients with Genu Recurvatum Analyzed by Zero TE MR Imaging

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Research Article

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Abstract

-BACKGROUND: Genu recurvatum in stroke patient hemiplegia causes readily cumulative damage and degenerative changes of knee cartilage. It is important to detect early lesions of cartilage for appropriate treatment and rehabilitation.

-PURPOSE: The purpose is to provide theoretical basis for early rehabilitation of hemiplegia patients.

-STUDY TYPE: Cross-sectional study.

-POPULATION: 39 Stroke patients with genu recurvatum and 9 healthy volunteers.

-SEQUENCE: We used zero TE double echo imaging sequence.

-ASSESSMENT: Analyze the water content in knee joint cartilage at 12 different sites of stroke patients with genu recurvatum using a method similar to porosity index.
-STATISTICAL TESTS: Statistical analysis was performed using SPSS 17.0 statistical software. The mean ± standard deviation was used to represent the mean. The independent sample t test was used for all mean comparisons. When the data did not conform to the normal distribution or variance heterogeneity, the non-parametric test was used. $P < 0.05$ was considered statistically significant.
-RESULTS: When compared hemiplegia limb vs. non-hemiplegia limb in patients, the ratio of deep/shallow free water content of the cartilages at the junction of the femur and anterior horn (1.16 vs. 1.06) and posterior horn (1.13 vs. 1.25) of lateral meniscus were significant differences ($P<0.05$).
-DATA CONCLUSION: Conclusion is that Genu recurvatum in stroke patients with hemiplegia can cause changes in moisture content of knee cartilage, and the changes of knee cartilage are more obvious with the increase of genu recurvatum. The so-called "healthy limb" is no longer the real meaning of healthy limb, and should be considered simultaneously with the affected limb in the development of rehabilitation treatment plan.
Key words: Stroke, Genu recurvatum, Cartilage, Zero TE sequence, MRI

1. Introduction

About 70% of stroke patients have hemiplegia, of which 40-60% have knee hyperextension [1]. Long term hyperextension of the knee changes the mechanical trend of the lower limbs, and the knee joint load-bearing reaction is poor, so that the stability of the standing phase decreased and body leaned forward. These changes would induce internal stress uneven distribution in knee joint, cause knee pain and cartilage injury walking in this way for long time, and lead to cumulative damage and degenerative changes of knee cartilage [2]. Other tissues around knee joint such as the meniscus also have pathological changes [3]. Therefore, it is no doubt that hemiplegic patients with knee reflexes are a group of patients with early knee injury. At present, there is no effective drug to treat cartilage injury and repair cartilage defect [4]. If the lesion is detected by imaging before irreversible damage occurs to the articular cartilage, and appropriate treatment is adopted, normal knee function can be maintained and disability can be avoided. Therefore, it is important to detect early lesions of cartilage.

Cartilage is mainly composed of chondrocytes and extracellular matrix. The extracellular matrix is mainly composed of water, collagen fibers and proteoglycan, and water accounts for 80% of the wet weight of cartilage [5]. In osteoarthropathy, the initial histological and biochemical changes in cartilage are collagen fiber breakdown, decreased proteoglycan content, and increased the water dispersion [6]. So, early lesions of cartilage is manifested as increased moisture percentage, which is associated with loss or damage of matrix components [7]. The detection of moisture changes in cartilage is helpful for early detection of cartilage lesions.

Although the gold standard for imaging diagnosis of osteoarthropathy is X-ray examination with the Kellgren-Lawrence grading system [8], X-ray examination does not directly assess cartilage. In the past 20 years, MRI has become the main means for the examination of osteoarthropathy [9]. It is generally considered to be a powerful tool for the examination of early osteoarthropathy, especially for tissue component imaging [8]. Traditional MRI uses T2WI and T2Mapping to image cartilage [10-11], but these MRI sequences can only image the long TE tissues, and can image the superficial and intermediate layers of articular cartilage, while the deep and calcified layers cannot be imaged [12], so they cannot reveal the pathological changes of the deep and calcified layers, especially the early changes [13]. Ultra-short TE sequences overcome this problem by imaging both long TE tissues and short TE tissues [14]. Recently, many scholars have used this sequence to study articular cartilage, especially UTE T2*mapping and T1Rho mapping, which could quantitatively analyze early changes in endochondral injury [15-18]. However, these techniques are difficult to be applied in clinical practice because of their complexity, long scanning time and the influence of magic angle effect. And some scholars used the porosity index of the double-echo UTE sequence to evaluate the porosity of the bone cortex, calculated as the ratio of the image intensities of the second echo (indicating signals from pore water) and the first echo (indicating signals from all water), which was highly consistent with the results measured by Micro-CT [19,20]. This method is relatively simple and has potential for clinical use.

The contrast and signal-to-noise ratio of short TE tissues imaging with zero TE sequence are basically the same as that of ultra-short TE sequence [21]. The difference between them is those the readout gradient of ultra-short TE sequence is started at the beginning of data acquisition, while that of zero TE sequence is started before radiofrequency pulse.

No literature has reported the changes of early knee cartilage in stroke patients with hemiplegia knee retraction by MRI. In this study, zero TE double-echo imaging sequence was used to analyze the water content in knee joint cartilage of stroke patients genu recurvatum using a method similar to porosity index, and the study focused on three questions: 1) Is there any difference between the knee joint cartilage of the hemiplegia side and the non-hemiplegia side in stroke patients? 2) Are the changes of knee cartilage related to the degree of genu recurvatum? 3) Is there any difference between the knee cartilage of stroke patients and normal people? This study aims to provide theoretical basis for early rehabilitation of hemiplegia patients.

2. Subjects and Methods

2.1. *Patient population.* This study was approved by the Ethics Committee of the Beijing Rehabilitation Hospital (Protocol Number:2020bkkyLW008). All the methods were carried out in accordance with relevant guidelines and regulations. Patients were hospitalized in the Neurological Rehabilitation Center of the Beijing Rehabilitation Hospital from January 2019 to October 2020, and healthy volunteers were staff members and students. All the patients and healthy volunteers in the study had written informed consent.

Inclusion criteria: 1) Initial onset of stroke, course of disease more than 6 months, with hemiplegia on one side of the limb; 2) No previous history of knee injury; 3) Can walk independently and safely at least 100 m, have walked for at least 3 months before inclusion, FAC grade III or above; 4) Brunnstrom stage III and above of the hemiplegia lower extremity; 5) No obvious abnormal signals were observed in the upper cartilage and meniscus of conventional MRI on T2WI and PD.

Exclusion criteria: 1) Accompanied by obvious cognitive impairment (simple mental state checklist < 24 points), audio-visual comprehension disorder, unable to cooperate; 2) Complicated with neurological diseases that affect walking ability, such as involuntary movement, Parkinson's disease, tremor, etc.; 3) With severe heart, lung, liver and renal insufficiency; 4) Routine MRI findings of both knees indicated cartilage and meniscus injury; 5) Patients with claustrophobia and unable to complete MRI examination.

The loss of normal cartilage volume begins around the age of 40 [22], hence the reason why healthy patients aged around 40 were selected as the control group instead of age-matched healthy patients. Inclusion criteria for healthy volunteers: 1) Age between 35 and 50 years old; 2) No history of knee osteoarthropathy; 3) No history of knee injury; 4) Routine MRI showed no abnormal changes in cartilage and meniscus.

2.2. ***Imaging technique.*** All subjects were scanned with a GE Pioneer 3.0T MRI scanner, using a dedicated 16-channel knee surface coil and 3D dual echo UTE sequence for MRI examination of both subjects' knees. The scanning parameters are as follows: TR/TE1/TE2, 12/0/4.6 ms; Matrix, 400 x 400; FOV 180 mm; 2.0 mm thickness; Volume of voxel 0.4 5x 0.45 x 2.0mm^3; Flap Angle 8°; Half bandwidth 125 kHz; NEX=1. The positioning line was perpendicular to the posterior edge of the femoral internal and external condyle, and 20 layers of sagittal images were collected continuously. The scanning time of each knee joint was 8 m and 22 s.

2.3. ***Imaging processing and data measurement.*** After data acquisition, it is transmitted to GE AW4.6 workstation. The images were processed and measured by a radiologist with 16 years of experience in MRI image processing. Select a patient or healthy volunteer, open TE=0 images in the 3D synchroview firstly and select the appropriate sagittal level in which the measured cartilage is the best displayed. The signal intensity of the cartilage at the thickest bearing point of the medial and lateral femoral condyles, the thickest bearing point of the medial and lateral tibial condyles, the anterior or posterior junction of the femur and the horn of the medial and lateral meniscus, and the anterior or posterior junction of the tibia and the horn of the medial and lateral meniscus, were measured respectively. The high signal intensity line of calcified layer was used as the dividing line between cartilage and subchondral bone. The thickness of the whole cartilage was measured firstly, and then the cartilage was divided into shallow layer and deep layer according to Williams [23] method (Figure 1), with the center of cartilage thickness as the boundary. The shallow layer referred to the center of cartilage thickness to the articular surface, and the deep layer referred to the center of cartilage thickness to the high signal intensity line of calcified layer. To avoid errors, an elliptical region of interest (ROI) was used. The ROI size was defined as covering the entire cartilage area to be measured. During the measurement of each position, the center of cartilage length was selected as the measurement area, measured once before and after it, and the value of the center position was averaged as the final measurement value. The cartilage at the junction of the anterior and posterior horns of the medial and lateral meniscus and tibia was an exception. The cartilage here was very thin and difficult to measure. The length of half of the cartilage near the center was taken for measurement, and the center of the cartilage was used as the measurement point. Then open the TE = 4.6 ms images and repeated the above measurement process.

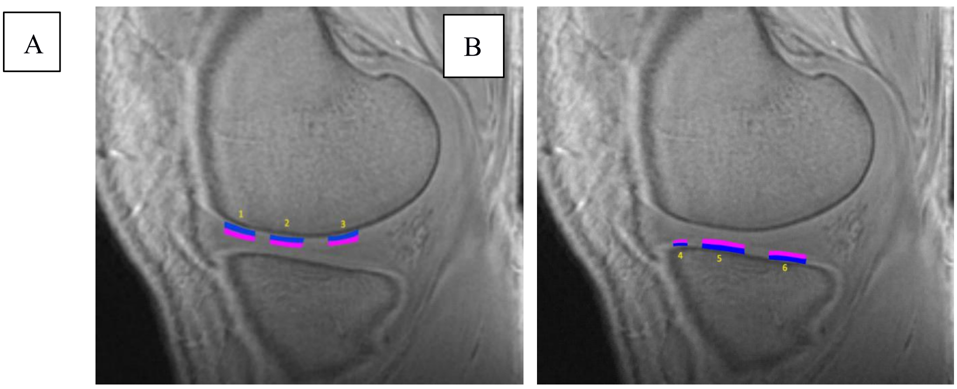


FIGURE 1: Cartilage position measured in this study. Zero TE MR imaging demonstrated the cartilage at femur (A) and tibia (B) in knee joint. The marked targets are measured. 1, the cartilage at the junction of the femur and anterior horn of the medial (lateral) meniscus. 2, the cartilage at

the bearing region of medial (lateral) condyle of femur. 3, the cartilage at the junction of the femur and posterior horn of the medial (lateral) meniscus. 4, the cartilage at the junction of the tibia and anterior horn of the medial (lateral) meniscus. 5, the cartilage at the bearing region of medial (lateral) condyle of tibia. 6, the cartilage at the junction of the tibia and posterior horn of the medial (lateral) meniscus. Blue square indicates deep layer of cartilage and the pink square shallow layer of cartilage.

In the images of TE = 0, the signal intensity of cartilage was mainly formed by hydrogen protons of free water and bound water. In the TE = 4.6 ms images, the signal intensity of cartilage was mainly formed by hydrogen protons in free water. Therefore, the relative content of free water in shallow and deep layers of cartilage could be calculated according to the signal intensity, that is, the percentage of free water content = I (TE = 4.6 ms) /I (TE = 0 ms) ×100%, and then the ratio of free water in deep and shallow layers and the ratio of bound water could be calculated.

2.4. ***Statistical analysis.*** Statistical analysis was performed using SPSS 17.0 statistical software. The cartilages of 12 position including the thickest bearing cartilages of the medial and lateral femoral condyles, the thickest bearing cartilages of the medial and lateral tibial condyles, the anterior or posterior junction cartilages of the femur and the horn of the medial and lateral meniscus, and the anterior or posterior junction cartilages of the tibia and the horn of the medial and lateral meniscus were comparatively studied between the stroke patients with hemiplegia and healthy volunteer group, between the healthy limb and paralyzed limb in stroke patients, and among the stroke patients with no genu recurvatum, with mild and with severe genu recurvatum, respectively. The mean ± standard deviation was used to represent the mean. The independent sample t test was used for all mean comparisons. When the data did not conform to the normal distribution or variance heterogeneity, the Mann Whitney test was used. $P < 0.05$ was considered statistically significant.

3. Results

3.1. *Patients.* A total of 151 stroke patients with hemiplegia received rehabilitation treatment in the Neurological Rehabilitation Center of the Beijing Rehabilitation Hospital from January 2019 to October 2020. A total of 39 patients with complete data met the study criteria, including 30 males and 9 females, ranging in age from 32 to 60 years old, with an average age of 49 years old, and body mass index (BMI) ranging from 21 to 31 kg/m^2. In 3 cases, no gait data was available, 9 cases without genu recurvatum (< 5^0), 15 cases with mild genu recurvatum (5-10^0) and 12 cases with severe genu recurvatum (>10^0). There were 9 healthy volunteers, 5 males and 4 females, ranging in age from 35 to 50 years old, with an average age of 42.5 years old. BMI was between 20 and 26 kg/m^2. The morphology and signal of knee cartilage and meniscus were normal in conventional MRI examination. The paralyzed limbs, time of illness and walking time length of the patients were recorded (Table 1).

Table 1: Indexes related to stroke patient.

Paralyzed limb	Number of patients	Sex		Time of illness (months)	Walking time (months)	handedness	
		Male	Female			Left	Right
Left limb	18	12	6	6-30	3-15	0	18
Right limb	21	18	3	6-28	3-18	9	15

Note: one patient with right paralyzed limb is left and right handedness.

3.2. *Volunteer versus patient.* In the patients with right limb hemiplegia, the affected limbs were compared with the corresponding limb of healthy volunteers. The deep free water content of the cartilage at the junction of tibia and anterior horn, and posterior horn of the lateral meniscus and the junction of femur and anterior horn of the medial meniscus of the affected limb was decreased. The content of free water in the deep layer of cartilage at the junction of tibia and posterior horn of medial meniscus decreased, and the content of conjunct water in the shallow layer also decreased. However, the free water content in the shallow layer and the binding water in the deep layer of cartilage at the junction of the femur and the posterior horn of the lateral meniscus of the affected limb decreased. The content of free water in the bearing cartilage of the medial femoral condyle of the affected limb is relatively increased. When the relative healthy limb of the patients with right limb hemiplegia were compared the corresponding limb of healthy volunteers, the deep binding water of the cartilage at the junction of the tibia and the posterior horn of the medial meniscus of the relative healthy limb was reduced. At the junction cartilage of femur and posterior horn of the medial meniscus, the free water content in the shallow layer of cartilage decreased, while the free water content in the deep layer increased and the combined water decreased. The free water content in the shallow layer of cartilage at the junction of femur and posterior horn of lateral meniscus decreased. Deep free water content in the bearing cartilage of the medial femoral condyle of healthy limbs is relatively high.

When comparing the affected limb of the patients with left limb hemiplegia with the corresponding limb of healthy volunteers, we found that the deep binding water of the cartilage at the junction of the tibia and anterior horn and posterior horn of the medial meniscus and junction of the femur and posterior horn of the medial meniscus of the affected limb decreased. The free water content in the shallow layer of cartilage at the junction of femur and posterior horn of lateral meniscus, the junction of the tibia and posterior horn of the medial meniscus and the bearing area of lateral condyle of tibia decreased. When the relative healthy limb of the patients with left limb hemiplegia were compared the corresponding limb of healthy volunteers, the deep free water content of cartilage at the junction of femur and anterior horn of medial meniscus, the junction of tibia and anterior horn and posterior horn of lateral meniscus, and the junction of tibia and posterior horn of lateral meniscus of the relative healthy limb were lower, and the free water content of shallow layer of cartilage at the junction of tibia and anterior horn of lateral meniscus was also lower. The free water content in the shallow and deep layers of cartilage in the lateral condyle of tibia of the relative healthy limbs decreased.

The changes in the above indicators were statistically significant, with $P < 0.05$ (Figure 3).

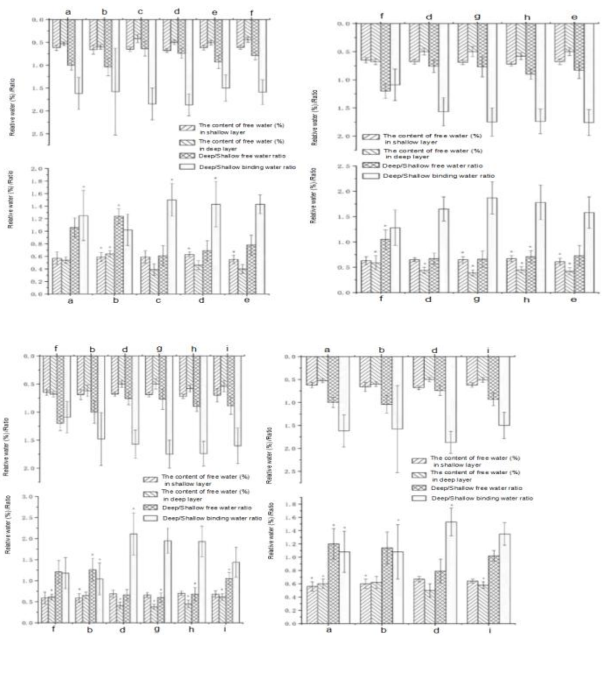


FIGURE 3: Histograms display statistically significant knee cartilages between hemiplegic

patients and healthy volunteers, in which one or more of the four indexes with $p<0.05$ (*).In the patients with left limb hemiplegia, the hemiplagic limbs (A) and the healthy limbs (B) were compared with the corresponding limb of healthy volunteers relatively. C and D) were the hemiplagic limbs (C) and the healthy limbs (D) were compared with the corresponding limb of healthy volunteers relatively in patients with right limb hemiplegia. a, cartilage at the junction of the femur and the posterior horn of the medial meniscus; b, cartilage at the junction of the femur and the posterior horn of the lateral meniscus; c, cartilage at the junction of the tibia and the anterior horn of the medial meniscus; d, cartilage at the junction of the tibia and the posterior horn of the medial meniscus; e, the thickest bearing cartilage of the medial femoral condyle; f, the thickest bearing cartilage of the lateral tibial condyle; g, cartilage at the junction of the femur and the anterior horn of the medial meniscus; h, cartilage at the junction of the tibia and the anterior horn of the lateral meniscus; i, cartilage at the junction of the tibia and the posterior horn of the lateral meniscus.

3.3. *Hemiplegia limb vs. non-hemiplegia limb.* There were significant differences in the ratio of deep/shallow free water content of the cartilage at the junction of the femur and anterior horn and posterior horn of lateral meniscus and the junction of the tibia and anterior horn and posterior horn of and medial meniscus ($P < 0.05$) (Table 2). The deep free water content of cartilage at the junction of tibia and anterior horn of medial meniscus was higher in non-hemiplagia limbs, while the deep free water content of cartilage at the junction of posterior horn was higher in non-hemiplagia limbs, and the combined water content of cartilage was higher in hemiplegia limbs.

Table 2: Comparison of affected limb and healthy limb in hemiplegic patients.

Cartilage	Index	Healthy limb (39)	Affected limb (39)	t	P
The cartilage at the junction of the femur and anterior horn of the lateral meniscus	The content of shallow free water (%)	0.64±0.07	0.65±0.08	-0.106	0.915
	The content of deep free water (%)	0.59±0.06	0.61±0.08	-0.985	0.328
	Deep/shallow free water ratio	1.06±0.16	1.16±0.19	-2.548	0.013
	Deep/shallow binding water ratio	1.36±0.38	1.69±2.39	-0.856	0.394
The cartilage at the junction of the femur and posterior horn of the lateral meniscus	The content of shallow free water (%)	0.59±0.09	0.61±0.08	-1.198	0.235
	The content of deep free water (%)	0.64±0.07	0.61±0.07	1.816	0.073
	Deep/shallow free water ratio	1.25±0.21	1.13±0.22	2.494	0.015
	Deep/shallow binding water ratio	1.03±0.32	1.20±0.51	-1.749	0.085
The cartilage at the junction of the tibia and anterior horn of the medial meniscus	The content of shallow free water (%)	0.62±0.10	0.69±0.08	-3.052	0.003
	The content of deep free water (%)	0.41±0.10	0.45±0.08	-1.921	0.058
	Deep/shallow free water ratio	0.63±0.15	0.67±0.14	-1.243	0.218
	Deep/shallow binding water ratio	1.61±0.30	1.96±1.03	-2.030	0.048
The cartilage at the junction of the tibia	The content of shallow free water (%)	0.66±0.07	0.66±0.04	0.034	0.973

and posterior horn of the medial meniscus	The content of deep free water (%)	0.43±0.08	0.47±0.08	-2.139	0.036
	Deep/shallow free water ratio	0.67±0.14	0.73±0.16	-1.759	0.083
	Deep/shallow binding water ratio	1.80±0.56	1.58±0.23	2.4227	0.030

3.4. *Comparison between the patients with no genu recurvatum and those with genu recurvatum.* Compared with the affected limbs, the content of free water in the shallow layer of cartilage at the junction of tibia and anterior horn of lateral meniscus and the femur and anterior horn and posterior horn of lateral meniscus were higher in the patients with genu recurvatum than in those with no genu recurvatum. The deep binding water of the cartilage at the junction of the femur and the anterior and posterior horns of the lateral meniscus was higher than that in the patients with no genu recurvatum, while the deep binding water of the cartilage at the junction of the tibia and the posterior horn of the medial meniscus was lower than that the patients with no genu recurvatum. In addition, the deep free water of the cartilage at the junction of the femur and the posterior horn of the medial meniscus was lower than that the patients with no genu recurvatum, while the load-bearing cartilage at the lateral condyle of the tibia was higher than that in the patients with no genu recurvatum.

Compared with healthy limbs, the deep free water content of the cartilage at the junction of the tibia and the anterior horn of lateral meniscus, the cartilage at the junction of the femur and the anterior horn of medial meniscus and the bearing region of lateral condyle of tibia in the patients with genu recurvatum was higher than that in those with no genu recurvatum. The free water in the shallow layer of cartilage at the junction of femur and posterior horn of medial meniscus and the junction of femur and posterior horn of lateral meniscus were higher than in those with no genu recurvatum. The deep binding water of cartilage at the junction of femur and posterior horn of lateral meniscus was higher than that in those with no genu recurvatum (Figure 4).

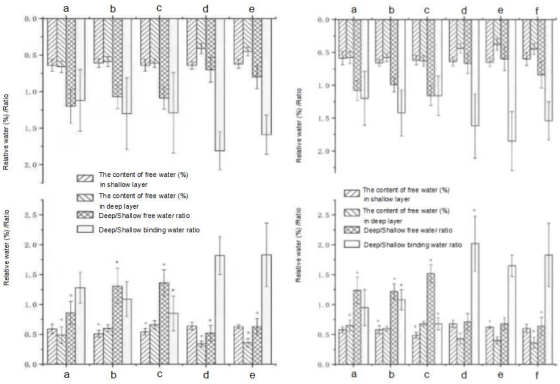


FIGURE 4: Histograms display statistically significant knee cartilages between patients with non genu recurvatum and those with genu recurvatum, in which one or more of the four indexes with $p<0.05$ (*). A) Comparison of the healthy limbs in patients with non genu recurvatum (top row) and those with genu recurvatum (bottom row). a, cartilage at the junction of the femur and the anterior horn of the medial meniscus; b, cartilage at the junction of the femur and the posterior horn of the medial meniscus; c, cartilage at the junction of the femur and the posterior horn of the lateral meniscus; d, cartilage at the junction of the tibia and the anterior horn of the lateral meniscus; e, the thickest bearing cartilage of the lateral tibial condyle. B) Comparison of the hemiplagic limbs in patients with non genu recurvatum (top row) and those with genu recurvatum (bottom row). a, cartilage at the junction of the femur and the posterior horn of the medial meniscus; b, cartilage at the junction of the femur and the anterior horn of the lateral meniscus; c, cartilage at the junction of the femur and the posterior horn of the lateral meniscus; d, cartilage at the junction of the tibia and the posterior horn of the medial meniscus; e, cartilage at the junction of the tibia and the anterior horn of the lateral meniscus; f, the thickest bearing cartilage of the

lateral tibial condyle.

3.5. *Comparison between the patients with mild genu recurvatum and those with severe genu recurvatum.* Compared with the affected limbs, the deep free water content of the cartilage at the junction of the femur and anterior and posterior horns of medial meniscus and the load-bearing area of the lateral condyle of femur in the patients with severe genu recurvatum was more than that in those with mild genu recurvatum. The deep binding water of cartilage at the junction of femur and anterior horn of medial meniscus and the bearing area of medial femoral condyle and the bearing area of medial tibial condyle was less than that of patients with mild genu recurvatum. The free water in the shallow layer of the cartilage at the junction of tibia and the anterior horn of the lateral meniscus was less than that in the patients with mild genu recurvatum.

Compared with healthy extremity, the free water content of the cartilage shallow layer at the junction of femur and posterior horn of medial meniscus in the patients with severe genu recurvatum was higher than that in patients with mild genu recurvatum, and the deep free water content of the cartilage at the junction of femur and anterior horn of lateral meniscus and the bearing area of medial condyle of femur was higher than that in patients with mild genu recurvatum.

The change of these indexes above was statistically significant, with $P < 0.05$ (Figure 5).

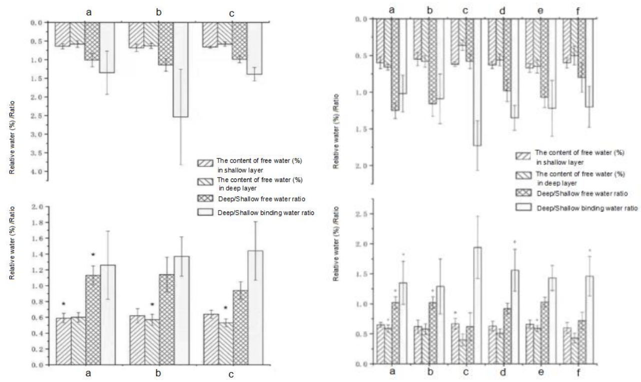
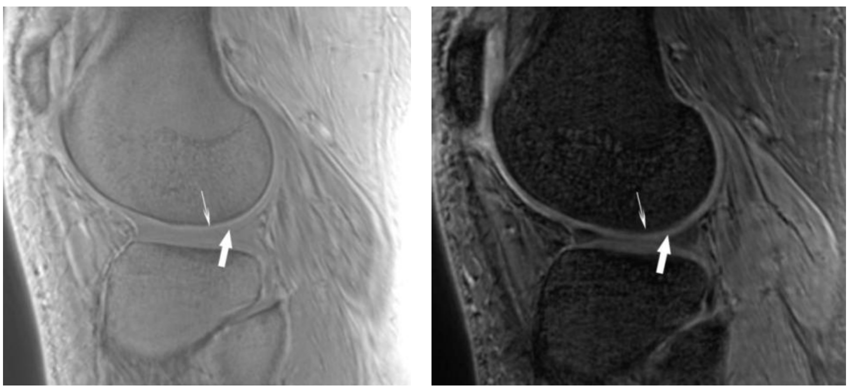


FIGURE 5: Histograms display statistically significant knee cartilages between patients with mild genu recurvatum and those with severe genu recurvatum, in which one or more of the four indexes with $p<0.05$ (*). A） Comparison of the healthy limbs in patients with mild genu recurvatum (top row) and those with severe genu recurvatum (bottom row). a, cartilage at the junction of the femur and the posterior horn of the medial meniscus; b, cartilage at the junction of the femur and the anterior horn of the lateral meniscus; c, the thickest bearing cartilage of the medial femoral condyle. B) Comparison of the hemiplagic limbs in patients with mild genu recurvatum (top row) and those with severe genu recurvatum (bottom row). a, cartilage at the junction of the femur and the anterior horn of the medial meniscus; b, cartilage at the junction of the femur and the posterior horn of the medial meniscus; c, cartilage at the junction of the tibia and the anterior horn of the lateral meniscus; d, the thickest bearing cartilage of the medial femoral condyle; e, the thickest bearing cartilage of the lateral femoral condyle; f, the thickest bearing cartilage of the medial tibia condyle.

4. Discussion

The preliminary results showed that the knee cartilage of the stroke patients had significant changes compared with the normal group, and the changes were more significant with the aggravation of the genu recurvatum degree, both the healthy limb and the affected limb changed.

Articular cartilage was divided into four layers, starting from the articular surface, the superficial layer, the intermediate layer, the deep layer and the calcified layer, below which was the subchondral bone. Conventional magnetic resonance imaging could not distinguish cartilage calcification layer from subchondral bone [24,25], and could not accurately measure cartilage changes. As subchondral bone was the same as bone cortex, T1 relaxation time is short and proton density was low [26], while cartilage calcification layer was different, although it had the same short T1 relaxation time as subchondral bone, proton density was high [27]. Although the proton density was very high, the T1 relaxation time of the upper deep cartilage was very long. Therefore, the calcification layer on UTE appears as a high signal line above the subchondral bone [28] (Figure 2). The high signal line was used to separate the cartilage layer from the subchondral layer, which avoided the influence of subchondral bone on the cartilage signal intensity and improved the accuracy of measurement.



A B

FIGURE 2: The appearance of cartilage on the zero TE double echo MR imaging. A) On TE=0ms

images, the calcified layer of the cartilage is a high signal line (thin arrow) above the subchondral bone and other layers involved in superficial layer, the intermediate layer and the deep layer are intermediate signal intensity (thick arrow). B) On TE=4.6ms images, the superficial layer, the intermediate layer and the deep layer of cartilage is showing high signal intensity (thick arrow), while the calcified layer of the cartilage and the subchondral bone are hypointensity (thin arrow).

Magnetic transfer imaging study [29] found that there were three different kinds of water molecules in articular cartilage: 80% is free water, with a long T2 value between 130-145 ms; 3% bound to proteoglycan, T2 value 8-12ms; 12% water binds to collagen, T2 value 3-18 ms. Multi-component T2 analysis of articular cartilage [30] yielded the same results, with 6% bound to collagen, 14% bound to proteoglycan, and 80% free water. Long T2* components obtained by UTE two-component analysis corresponded to free water, while short T2* components were proteoglycan bound water and collagen bound water [28]. Since PD images could only image long TE tissues, the obtained signal intensity approximately corresponds to free water. Therefore, the changes of free water and bound water, such as the changes of extracellular matrix water, proteoglycan and fibrinogen at different stages of osteoarthropathy, could be obtained by comparison between the two. The water content in the surface layer of normal cartilage was abundant and decreases to the deep layer of cartilage, while the degree of aggregation of proteoglycans was opposite [31]. The results showed that the content of binding water in deep layer was higher than that of the shallow layer seen all parts of the cartilage, the free water content of shallow layer in most parts of the cartilage was higher than that of deep layer, only the cartilages at the junction of the femoral and anterior horn and posterior horn of lateral meniscus or medial meniscus are an example, in which the free water content of deep layer was higher than the shallow layer. It might be related to stress, but the specific reasons need to be further studied.

Since the onset of osteoarthritis, proteoglycan and collagen fibrous network continued to degenerative changes. During the development of osteoarthritis, the three kinds of extracellular matrix changed correspondingly. The water content increased in the early stage of the disease, and decreased in the middle and late stage. Proteoglycan decreased increasingly from the beginning of osteoarthritis to the end. Highly ordered collagen fibers were disordered in the early stage and seriously broken in the late stage [32-35].

The affected and healthy limbs of hemiplegia patients were compared with the corresponding limbs of the healthy volunteers, respectively. Both the affected and healthy limbs showed statistically significant differences in the parts of cartilage, which basically showed a decrease in shallow free water with or without a decrease in binding water, an increase or decrease in deep free water, and a decrease in binding water. These changes in the early and middle stages were consistent with the degeneration of articular cartilage. As for the different locations, it might be related to the changes in the mechanics of the affected and healthy limbs and the different mechanics of the cartilage, which needed to be further explained in conjunction with mechanical analysis. Many studies have found significant asymmetry between hemiplegic limbs and non-hemiplegic limbs in stroke patients. The hemiplegic limbs have slow gait rate, and their dysfunction leads to short standing time, prolonged swinging time, and reduced ground response [36-38], leading to insufficient power and poor progress. In order to adapt to this compensatory dysfunction, patients need to rely on the non-hemiplegic limb to maintain balance and push forward, resulting in biomechanical changes of the non-hemiplegic limb, presenting spastic gait

[39]. Patients liked to use the non-hemiplegic side of the limb to bear weight, resulting in asymmetry and interruption of the hemiplegic gait [40]. Therefore, the healthy limb degenerative changes occurred during the compensatory process, which was also confirmed by our experimental results. There were significant differences in some parts of cartilage in the healthy limbs between the patients with hemiplagia and the healthy volunteers, which indicated that the so-called "healthy limbs" of the patients had also changed to a certain extent and could not be called real healthy limbs. So, in the process of making rehabilitation treatment plans, they should be considered together with the affected limbs.

In stroke patients, the cartilages at the junction of femur and anterior and posterior horn of lateral meniscus, and the cartilages at the junction of tibia and anterior and posterior horn of medial meniscus in the healthy limb of knee were different from those in the affected limb, indicating that the mechanical mechanics and walking modes of the healthy limb in patients were different to compensate the function of the affected limb, leading to different degrees of damage.

Compared with the patients with no genu recurvatum, the cartilage in both affected and healthy limbs changed with statistical significance showed increased shallow and/or deep free water in the patients with genu recurvatum, but the deep free water in the junction of femur and posterior horn of medial meniscus of the affected limb was lower than that in patients with no genu recurvatum. Most of the cartilage changed by deep binding water decreased in the patients with no genu recurvatum, but only in the joint of tibia and posterior horn of medial meniscus of affected limb in the patients with genu recurvatum. Compared with the patients with mild genu recurvatum, the deep free water content of changed cartilages in the patients with severe genu recurvatum was increased, the binding water was decreased, and the free water in the shallow layer was decreased. The deep free water content of cartilage at the junction of femur and posterior horn of medial meniscus was lower than that of the patients with mild genu recurvatum. Therefore, we can see a trend: free water in the shallow and deep layers of cartilage first increased and then decreased in the patients with no genu recurvatum, the patients with mild genu recurvatum and the patients with severe genu recurvatum, while the deep cartilage binding water continued to decrease in the patients with mild genu recurvatum and the patients with severe genu recurvatum. This trend was very similar to the law of the degree of osteoarthropathy progression. At the early stage of cartilage injury, matrix metabolism was very active, matrix synthesis increased and proteoglycan content was increased. Afterwards, the collagen grid damaged and the proteoglycan is lost, and the free water content is increased [41]. Hence, the knee joint changes caused by the degree of genu recurvatum were closely related to the osteoarthropathy. If further study was combined with the onset time and walking time, it was possible to further reveal the course and degree of knee joint osteoarthropathy caused by the degree of genu recurvatum.

This study had the following shortcomings: 1) the sample size was small, and large sample tests were needed for further verification; 2) the signal strength conversion was adopted instead of the real data of free water and combined water, and the next step could be verified by UTE T2*mapping; 3) sometimes the cartilage is thin, and some errors would inevitably occur when measuring the deep and shallow layers; 4) there was no data of mechanical changes of knee joint with genu recurvatum, and these changes could not be perfectly explained.

5. Conclusion

Genu recurvatum in stroke patients with hemiplegia could cause changes in moisture content of knee cartilage. With the increase of genu recurvatum, the changes of knee cartilage were more obvious. Both the affected limb and the healthy limb in the stroke patients with hemiplegia appeared corresponding changes. The so-called "healthy limb" was no longer the real meaning of healthy limb, and should be considered simultaneously with the affected limb in the development of rehabilitation treatment plan, and it could not be used as the normal control group for the study of the affected limb.

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