Cine MRI of the Triangular Fibrocartilage Complex during Radial–Ulnar Deviation

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Abstract

Purpose Changes in the shape of the triangular fibrocartilage complex (TFCC) during radial–ulnar deviation were studied using "cine-mode" magnetic resonance imaging (MRI) in 10 right wrists of healthy volunteers, 5 wrists of TFCC tear, and 5 wrists of ulnar styloid nonunion.

Subjects and Methods The wrist was fixed in a custom acrylic device, which only allows radial and ulnar deviation. Coronal MR images of nine radial–ulnar deviated positions (every 5 degree from 15 degrees radial deviation to 25 degrees ulnar deviation) were obtained in volunteers and patients. Cine-mode MRI was assembled and was output to MPEG video to observe.

Results Cine MRI demonstrated the ulnar side of the TFCC was elongated by average 15 mm in 15 degrees of radial deviation and shortened by average 8 mm in 25 degrees of ulnar deviation in all normal TFCC subjects. Distal portion of the triangular fibrocartilage (TFC) was compressed during radial–ulnar deviation in 10 healthy volunteers and in 3 patients, but proximal portion of the TFC was stable throughout the motion. In contrast, the wavy deformities on the disc in ulnar deviation were observed in three patients with horizontal tear inside the TFCC. In nonunion of the ulnar styloid process, the fragment was snapped in maximum ulnar deviated position or elongation of the space between the styloid fragment and ulna was seen.

Conclusion This study indicated normal and abnormal changes in the shape of the TFCC during radial–ulnar deviation motion on cine MRI. The abnormal dynamic changes of the TFCC may be seen in ulnar deviated position in patients, which are related to positive ulnocarpal stress test with the wrist forced ulnar deviated.

Keywords
- cine-mode MRI
- triangular fibrocartilage complex
- radioulnar deviation
- changes in shape

The triangular fibrocartilage complex (TFCC) plays an important role in the stability and mobility of the ulnar side wrist.[1,2] Patient with TFCC tear usually claims ulnar-sided wrist pain, click, instability of the distal radioulnar joint (DRUJ), decrease of power grip, and loss of range of wrist and forearm motion. Clinically, the ulnocarpal stress test is widely used for evaluation of TFCC tear, in which the wrist is forced ulnar deviated simultaneously with the forearm forced pronated or supinated.[3] Patient often claims pain only with forced ulnar deviation. As the TFCC is a soft tissue insertion between the radius, ulna, and carpal bones, changes in its shape should occur during radioulnar deviation.[4] When the TFCC is torn, positional changes also may induce changes in strains around the TFCC, which may induce pain.

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Several biomechanical studies have described changes in the shape of the TFCC during rotation.[5–8] Shape of the triangular fibrocartilage (TFC) does not demonstrate obvious changes during forearm rotation in vitro.[8] One study attempted to demonstrate the dynamic changes of the TFCC during forearm rotation in vivo,[4] in which very small changes in the shape of the TFC were recognized with the exception of thinning of the TFC in coronal plane of pronation. However, dynamic changes of the TFCC during radial–ulnar deviation were uncertain, especially in vivo.

Magnetic resonance imaging (MRI) is a useful diagnostic tool for delineation of the TFCC.[9] High-resolution and fat suppression MRI can demonstrate the TFCC well.[9–11] Recent technology in MRI achieved faster imaging with precise delineation that made cine-mode MRI possible. Cine MRI may provide further information on joint motion and changes in shape or length of the soft tissues.[12,13]

In this study, using custom positioning device and cine-mode MRI, changes in the shape of the TFCC during radio-ulnar deviation plane were studied in healthy volunteers and in patients with TFCC tear and ulnar styloid nonunion to reveal how and what kind of changes in shape occurred in the normal and injured TFCC.

Subjects and Methods

Ten right wrists of normal healthy volunteer with a mean age of 23.5 years (range: 23–25), 5 wrists with isolated TFCC tears with a mean age of 32 years (range: 23–46; 3 right and 2 left), and 5 wrists with nonunion of the ulnar styloid process with a mean age of 22 years (range: 18–27; 4 right and 1 left) were studied. The institutional ethical board approved this study. Ulnar variance of the volunteers and patients ranged within $\pm$ 1 mm. Patients of isolated TFCC tear were diagnosed by positive physical examination, arthrogram, “static” fat suppression T1-weighted MRI, and T2*-weighted MRI. Two patients had radial to central slit tear in the fibrocartilaginous disc that was described as class 1A tear in the Palmer’s classification and the other three had the horizontal type (intraregional fibrocartilage) tear in the TFCC, which was not described in the Palmer classification.[14] Additional detachment of the TFCC at the ulnar fovea origin was seen in two of five ulnar styloid nonunion patients. Three patients with isolated horizontal TFCC tear and four patients with ulnar styloid nonunion demonstrated moderate to severe instability of the DRUJ, click, and slacking of the wrist. These diagnoses were confirmed subsequently by arthroscopy at the time of repair surgery.

A 1.0T superconductive MRI (Magnex 1.0α, Shimadzu Corporation, Kyoto, Japan) with surface coil (round type, 5 cm of diameter) was used for MR acquisition. The wrist was fixed in a custom acrylic device (►**Fig. 1**), which could be set every 5 degree of radial and ulnar deviation using ratchet gear, and did not allow any changes in the flexion–extension angle of the wrist against the motion plane. The examination was started from 15 degrees of radial deviation to 25 degrees of ulnar deviation with 5 degrees interval. Three or four coronal images at nine radial–ulnar deviation positions (every 5 degree) were obtained. Three pulse sequences of fast spin echo (SE) T1-weighted (repetition time [TR] = 150 ms, echo time [TE] = 18 ms), fast SE T2-weighted (TR = 3,000 ms, TE = 125 ms), and fat-suppression T1-weighted images (TR = 200 ms, TE = 18 ms) were used. Matrix size of 256 $\times$ 256, 16 cm field of view, 2 number of excitation, 1 mm slice thickness, and 1 mm slice gap were used. Acquisition time was 8 to 10 seconds for 1 position, thus 90 seconds for total acquisition. The images were recorded in close-loop video format from cine-mode display, which was programmed in the MR system.

Fig. 1 All acrylic positioning device which allows 15 degrees radial deviation and 25 degrees ulnar deviation without any positional changes on flexion–extension.

Three pulse sequences, spin echo T1-weighted image, fast spin echo T2-weighted image, and fat suppression T1 weighted image, were compared to confirm which pulse

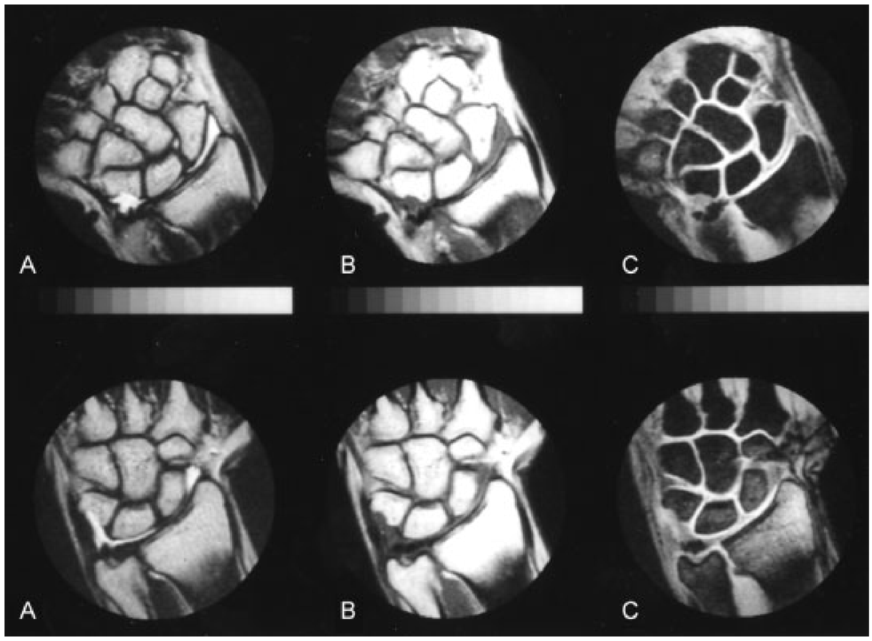

Fig. 2 Magnetic resonance delineation of the wrist. (**A**) Fast spin echo T2-weighted image. (**B**) Spin echo T1-weighted image. (**C**) Fat suppression T1-weighted image.

sequences delineated the TFCC best in health volunteers. Then the cine-mode MR was assembled in MPEG format files, and transferred to personal computer for observation. Details of changes in the shape of the TFCC were analyzed in plain films of each healthy volunteer and patient as well.

Results

Cine MRI of the Intact TFCC in Healthy Volunteers

The TFCC was delineated as a low-intensity structure in all pulse sequences. Because of its contrast with high-signal intensity of fat in the bone marrow, fat-suppression T1 MRI is the best for TFCC delineation (►**Fig. 2**).

In normal wrists, cine-mode coronal MRI demonstrated the scaphoid extended with ulnar deviation, and flexed with radial deviation. The lunate rotated approximately 22 degrees around the capitate during the radial–ulnar deviation. The ulnar side of the TFCC was elongated by an average of 15 mm in length in 15 degrees of radial deviation and shortened by an average of 8 mm in 25 degrees of ulnar deviation (►**Fig. 3**). Normal changes in the shape of the proximal half of the TFC were stable with radial–ulnar deviation (►**Fig. 3**), in contrast the distal half of the TFC demonstrated compression from the ulnar edge of the lunate, radial edge of the triquetrum, and ulnotriquetral interosseous ligament. Intensities of the TFC, lunate, triquetrum, and

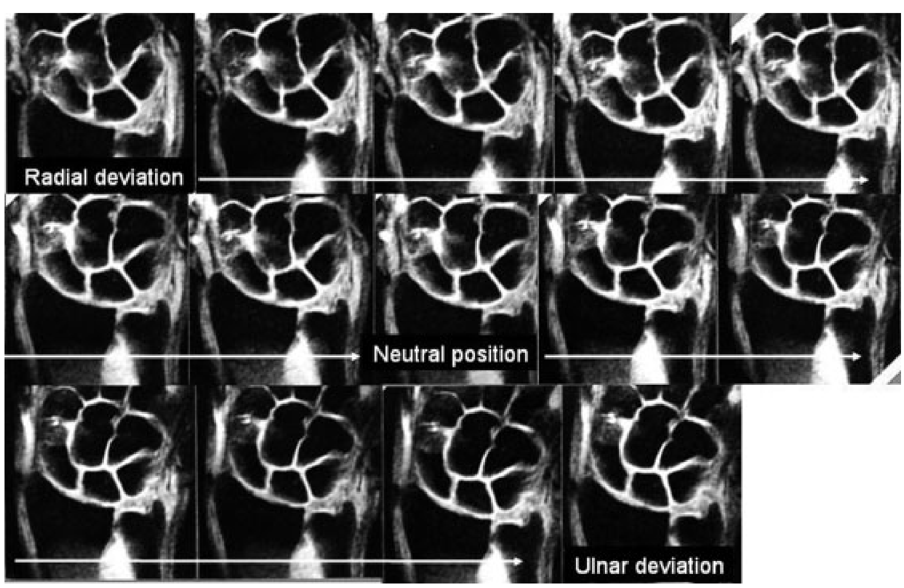

Fig. 3 Sequential cine-mode magnetic resonance imaging of the healthy volunteer.

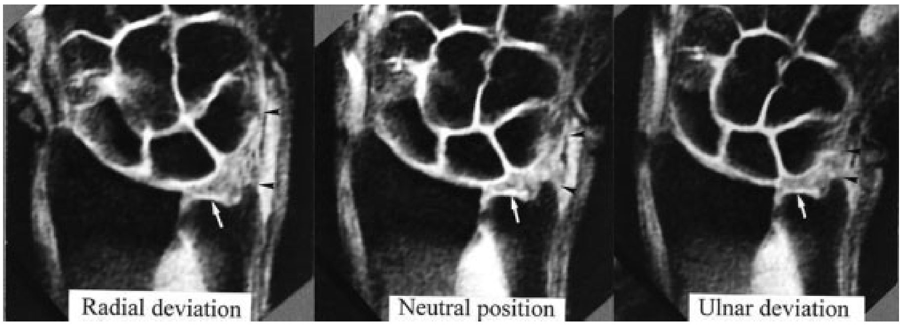

Fig. 4 Normal changes in the shape of the triangular fibrocartilage complex during radial–ulnar deviation in a healthy volunteer. Ulnar side of the TFCC is stretched in radial deviated position and is shortened in ulnar deviated position (arrowheads). High signal intensity in the disc, due to increasing pressure is shown. Note small changes in the shape of the disc during radial–ulnar deviation (white arrow).

ulnar head were slightly higher on ulnar deviation and lower on radial deviation (►**Figs. 3** and **4** and ►**Video 1**).

Video 1

Cine MRI of intact TFCC. Online content including video sequences viewable at: www.thieme-connect.de/products/ejournals/html/10.1055/s-0038-1668542.

Cine MRI of the TFCC tears

Wavy deformities in the TFC with radioulnar deviation were observed in three horizontal TFCC tear patients (►**Figs. 5** and **6**). At maximum ulnar deviation, the TFC was compressed in radioulnar direction (►**Fig. 5** and ►**Video 2**). Intensity of the disc was slightly higher on ulnar deviation and lower on radial deviation and this tendency was obvious than the normal volunteers. The changes in the shape of the TFCC in two patients with traumatic radial slit tear of the TFC were identical to normal changes in shape of healthy volunteers.

Video 2

Cine MRI of horizontal type TFCC injury. Online content including video sequences viewable at: www.thieme-connect.de/products/ejournals/html/10.1055/s-0038-1668542.

Cine MRI of Ulnar Styloid Nonunion

In the two patients with ulnar styloid nonunion, snapping of the ulnar styloid fragment was detected at maximum ulnar deviated position (►**Figs. 7** and **8**, and ►**Video 3**). These two

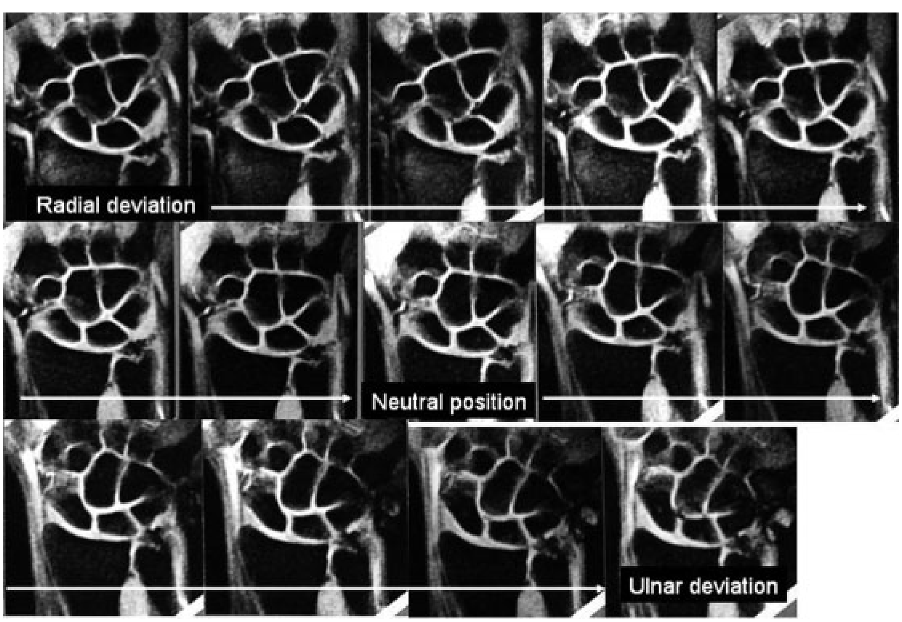

Fig. 5 Sequential cine-mode magnetic resonance imaging of horizontal-type triangular fibrocartilage complex tear patient.

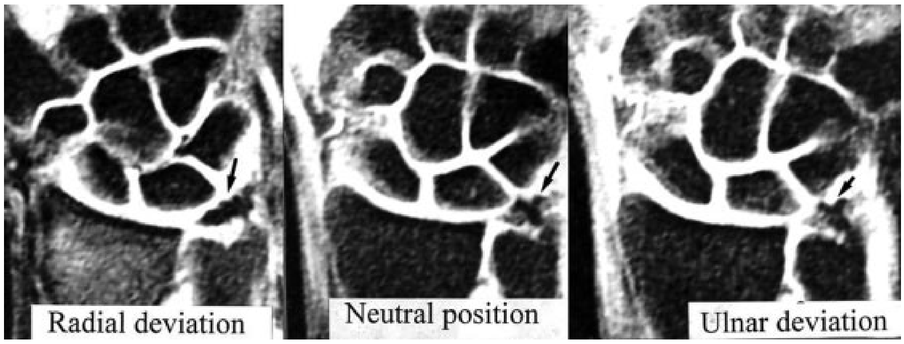

Fig. 6 Changes in the shape of the triangular fibrocartilage complex with its intrahorizontal slit tear during radial–ulnar deviation. Wavy deformity is demonstrated especially in ulnar deviation (arrows).

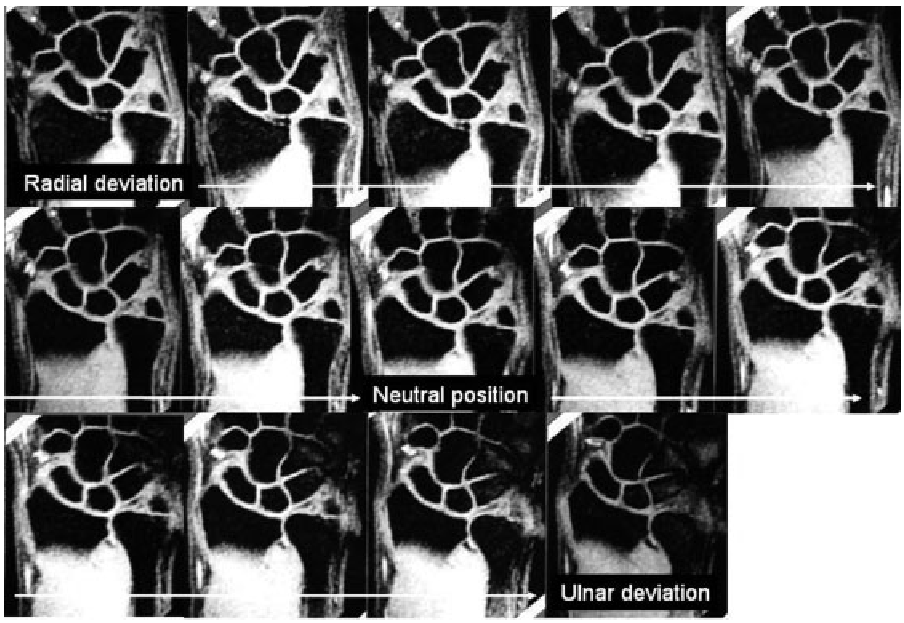

Fig. 7 Sequential cine-mode magnetic resonance imaging of nonunion of the ulnar styloid.

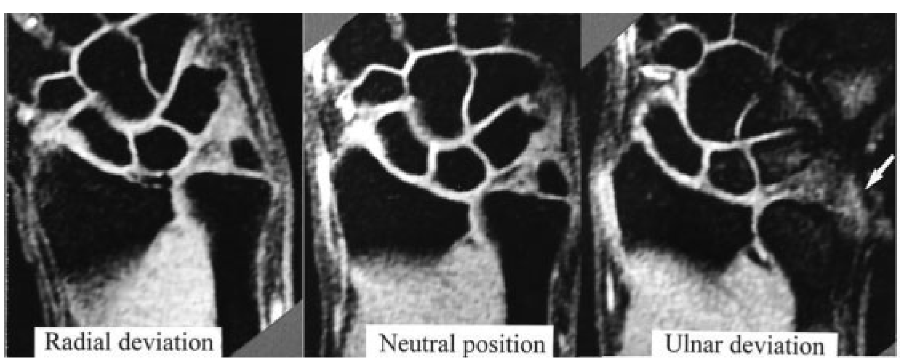

Fig. 8 Changes in the shape of the triangular fibrocartilage with nonunion of the ulnar styloid during radial–ulnar deviation is same as normal volunteers. Sudden dorsal snapping of the un-united ulnar styloid is seen in maximum ulnar deviation (white arrow).

patients demonstrated relatively larger fragment of the ulnar styloid. The triquetrum, hamate, and 5th metacarpal indicated high signal intensity at ulnar deviation. The other three wrists with relatively smaller ulnar styloid nonunion demonstrated elongation of the space between the fragment and ulna; however, no special changes in the shape of the TFCC were found during radioulnar deviation compared with those in intact TFCC (►**Video 4**).

Video 3

Cine MRI of large ulnar styloid non-union. In maximum ulnar deviation, dorsal snapping of the ulnar styloid fragment occurs. Online content including video sequences viewable at: www.thieme-connect.de/products/ejournals/html/10.1055/s-0038-1668542.

Video 4

Cine MRI of relatively smaller ulnar styloid non-union. Space between ulnar styloid fragment and ulnar head is widened in radial deviation in this movie. Online content including video sequences viewable at: www.thieme-connect.de/products/ejournals/html/10.1055/s-0038-1668542.

Discussion

As the TFCC is a soft tissue, it may demonstrate changes in its shape during wrist motion and/or forearm rotation.[4,5,7,8] When the TFCC is torn, it may further demonstrate abnormal dynamic changes in various wrist motions, which may induce pain, click, or slack. Clinically, patients usually claim pain with forced pronation–supination, such as twisting doorknob, and with ulnar deviation, such as gripping or knocking hummer. In the physical examination, the wrist is forced ulnar deviation with pronation–supination, and if the tear exists, there may be severe pain and/or click in TFCC tear patients.[3] With the ulnar deviation of the wrist, pressure around the TFCC may increase, and forced pronation–supination may produce traction and tension on the TFCC, thus inducing ulnar-sided wrist pain.

In previous biomechanical studies, changes in the shape of the TFCC during forearm rotation were described.[4,5,7,8] Nakamura et al[4] investigated in vivo changes in the shape of the TFC with high-resolution MRI, where minimal change in shape was noted. Makita et al[8] later confirmed this by biomechanical cadaver study. However, changes in the shape of the TFC during radial and ulnar deviation had not been investigated.

MRI is a noninvasive diagnostic tool, especially useful for musculoskeletal soft-tissue problems. Although clinical application of MRI for TFCC tear has been widely accepted recently, delineation of the TFCC itself and its tear has been controversial. Arthrogram is another diagnostic imaging tool for TFCC tear, whose diagnostic specificity is considered superior to that of MRI.[15] Kato et al[16] found that high-resolution MRI is not appropriate for delineation of details of the TFCC, whereas several researchers indicated advantage of high-resolution MRI for diagnosis of TFCC injuries.[10,11] Nakamura et al[9] indicated that fat suppression T1-weighted MRI delineated the TFCC best, followed by gradient echo T2*-weighted images and the quality of these images may be suitable to delineate the TFCC.

In this study, fat suppression fast SE T1-weighted MR image demonstrated the TFCC well. The reasons of well delineation of the TFCC in fat suppression MRI are: (1) contrast differences between the high signal of hyaline cartilage and low signal intensity of the fibrocartilage and ligaments; (2) contrast differences between high signal of joint fluid and low signal of fibrocartilage; (3) high signal gain; and (4) less influence of chemical shift artifact.[9]

We successfully obtained cine-mode MRI in radial–ulnar deviated motion in this study using the custom setting device. In cine MRI, intact TFCC demonstrated little changes in the shape of the TFC with stretching of the ulnar side of the TFCC (so-called meniscus homologue and ulnar joint capsule recognized as 6U-portal) from ulnar to radial deviated motion. Change in the shape of the TFC was minimal with radial and ulnar deviation. This is in line with the finding that the TFC simultaneously supports the ulnar carpus, induces smooth gliding of the carpus, and simultaneously transfers load between the ulnar carpus and ulna especially in the radial and ulnar deviation.

Increase of MR signal intensity inside the TFCC, lunate, triquetrum, and ulnar head with ulnar deviation in healthy volunteers was seen in this cine-mode MRI study, which may be due to increase of pressure in the ulnar space of the wrist.

Wavy deformity in the TFC was demonstrated during radioulnar deviation in three horizontal TFCC tear patients. Horizontal tear from ulno-distal side of the TFCC extends into the TFC. This tear was not described in the Palmer classification system.[14] Radiocarpal arthroscopy usually examines distal surface of the TFCC and cannot directly visualize inside injury of the TFCC. MRI only can delineate inside tear of the TFCC. When the wrist was ulnar deviated, the proximal carpal row moves radially. Forced or active ulnar deviation increases radial directional force of the disc both by the ulnar carpus directly and pulling effect through the ulnolunate and ulnotriquetral ligaments. Simultaneously, increase of compressive force between the ulnar carpus and ulna occurs. When there is a horizontal-type tear inside the TFCC, this force will induce wavy deformity on the distal half of the TFC, which was seen on cine MRI. This finding further suggests that wavy deformity is one of the causes of ulnar-sided wrist pain in TFCC injury patient, where abnormal mechanical stress on the TFC induces pain. In the other two patients with radial slit TFCC tear, the disc did not demonstrate severe changes in its shape. This may suggest other cause of pain in the radial slit tear of TFCC.

Snapping of the large nonunion ulnar styloid at maximum ulnar deviation was also delineated in cine MRI in two patients with relatively larger fragment. Increasing pressure between the ulnar carpus and ulna may snap out the large un-united styloid process in the ulnar deviated position. In contrast, the relatively smaller nonunion of the ulnar styloid process demonstrated only elongation of the space between the fragment and the ulna in radial deviated position. Different pathomechanics were suggested in ulnar styloid nonunion patients.

The intact TFCC may normally distribute increased load and pressure in ulnar deviated position. When the structure of the TFCC is damaged in the inside or outside, such as horizontal tear of the TFCC or ulnar styloid nonunion, abnormal changes in the shape of the TFCC may occur, such as the wavy deformity on the TFC, or snapping of the un-united ulnar styloid, and increased pressure or tension in the ulnar side of the wrist. These abnormal stresses in the TFCC in ulnar deviation position may correlate with positive ulnocarpal stress test.[3]

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Conflict of Interest
None.

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