석 사 학 위 논 문

Pathomechanism of Triangular Fibrocartilage Complex Injuries in Patients with Distal Radius Fractures: A Magnetic Resonance Imaging Study

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이 논문을 석사학위 논문으로 제출함

2022년 8월

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1. Introduction

Distal radius fracture (DRF), one of the most common fractures occurring in elderly people, accounts for approximately 18% of fractures in patients older than 65 years (1,2). Triangular fibrocartilage complex (TFCC) tear, the injury most associated with unstable distal radius fractures, has been reported in 39% to 84% of cases (2,3). This concomitant injury may contribute to development of chronic wrist pain, decreased grip strength, and restricted motion (4).

Better visualization and diagnosis of TFCC injury can be achieved by use of arthroscopic examination, however, it is not a standardized test for use in all patients with distal radius fractures (5,6). Although MRI scanning is used for diagnosis of TFCC injuries, MRI testing is not performed routinely in all patients with distal radius fractures at the time of the injury (7). Instead, the test is recommended for patients who have symptoms related to TFCC injury after the fracture treatment has ended, which can cause a delay in treatment of the injury.

Some studies using MRI in patients with DRF have demonstrated the prevalence of TFCC injuries, however, studies on the pathomechanism of TFCC injuries concomitant to DRF have rarely been reported (7). According to findings from previous studies, radiologic features such as fracture pattern, magnitude of displacement, and presence of an ulnar styloid fracture may be independent predictors of TFCC injuries related to DRF (2,8,9). This study hypothesized that performing an analysis of radiologic parameters in MRI studies of patients with DRF may foster understanding of the pathomechanism of TFCC injuries.

The purpose of this study is to conduct radiographic examination and MRI studies in order to determine the fracture mechanism of distal

radius fracture and the prevalence and the pathomechanism of TFCC injuries concomitant to fracture.

2. Materials and Methods

Sixty-three patients underwent surgical management for treatment of distal radius fracture in a single fellowship-training hospital between March 2020 and July 2021. Inclusion criteria were patients who underwent open reduction and internal fixation of the fracture. Patients younger than 18 years old and those who had previously occurring arthritis of the wrist or degenerative TFCC injuries on the affected wrist were excluded. Those patients underwent MRI scanning, and five patients who refused the test were excluded, so that 58 patients were finally included in this study (Figure 1).

An analysis of simple radiographic parameters (radial inclination, radial length, distal radioulnar joint (DRUJ) gap, sagittal/radial transition ratio, DRUJ gap on the unaffected wrist, and presence of a distal ulnar fracture) and patterns of TFCC injury in the MRI scan was performed by two orthopedic surgeons using the Palmar classification. Regarding classification of fractures, the Fernandez classification and the AO/OTA classification were used in defining the mechanism of injury and the fracture pattern, respectively. Other assessments included general demographics and underlying osteoporotic disease.

A standard 4 view x-ray of the injured wrist and PA and lateral views of the uninjured side were obtained for all patients. Measurement of the DRUJ gap distance was performed on both sides in order to better evaluate widening of the DRUJ. DRUJ distance was defined as the maximum distance between either the volar or dorsal cortical rim of the sigmoid notch of the radius and the ulnar head. The radial translation ratio was calculated as the fraction of the DRUJ gap distance relative to the radioulnar width of the proximal fracture fragment. On

the lateral x-ray, sagittal translation was defined as the distance between the volar cortex of the radius shaft and the volar cortical margin of the distal fracture fragment. The sagittal translation ratio was calculated as the fraction of the sagittal translation to the AP width of the proximal fracture fragment (2,8).

Articular involvement of the fracture and the presence of an ulnar styloid fracture, which is then classified as a tip, middle, or base fracture each separating 1/3 of the ulnar styloid, was evaluated in this study. In addition, ulnar styloid fracture was classified as type 1,2,3 each corresponding to distal to base where superficial horizontal fibers of the TFCC are inserted, base fracture and proximal to the base fracture, respectively (9,10).

Radial length was defined as the distance between two lines drawn perpendicular to the long axis of the radius on the AP projection from the apex of the radial styloid and the level of the ulnar aspect of the articular surface. Radial length was measured on the uninjured wrist and the radial length gap between both sides of the wrist was obtained for evaluation of the pure radial shortening distance (Figure 2).

An MRI examination of the injured wrist was performed on all patients using a 3.0T MRI scanner (Magnetom 3.0T, Siemens, Germany / Ingenia 3.0T, Philip, Netherlands). Statistical analysis was performed using the SPSS statistical package (Version 22.0; IBM). The Chi-square test was used for evaluation of categorical variables and the T-Test was used for evaluation of continuous variables. The level of significance was set as p value < 0.05.

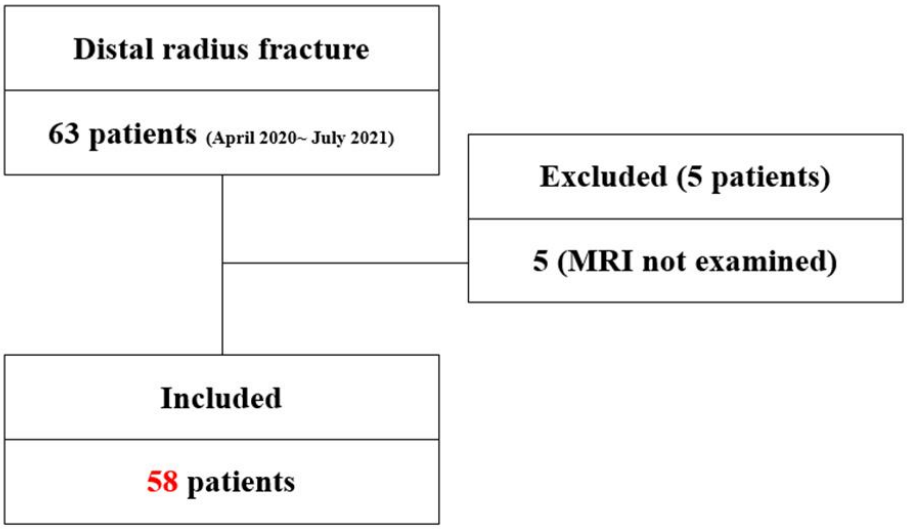

Figure 1. Patient's flow chart. Patient profiles and the groups included in the study. MRI: magnetic resonance imaging.

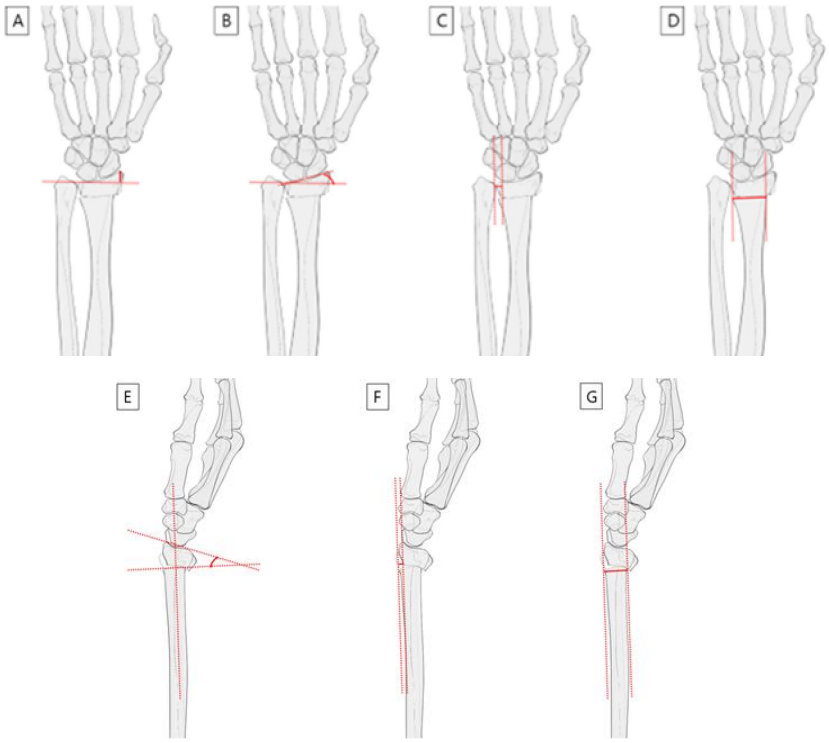

Figure 2. Radiologic parameter measurement technique. (A) Radial length (B) Radial inclination. (C) DRUJ distance. (D) Fracture site width. (E) Dorsal angulation. (F) Sagittal translation. (G) Anteroposterior width. Radial translation ratio = C/D, Sagittal translation ratio = F/G. DRUJ: distal radioulnar joint.

3. Results

The mean age of the patients was 65.21 years (range: 19 - 89 years; 15 male and 43 female); 15 men and 43 women were included in the study (Table 1). According to the data from AO/OTA classification, 16 patients had A2 fractures, eight patients had A3 fractures, four patients had B3 fractures, and 4, 8, and 12 patients had C1, 2, 3 fractures, respectively (Table 2). According to the Fernandez classification, 29 patients had type I fractures, and 4, 12, and 13 patients had Type II, III, V fractures. Twenty-six patients showed widening of the DRUJ gap compared to the unaffected wrist. Associated distal ulnar fractures were detected in 38 patients (65%). All patients in this study had a definite traumatic TFCC injury; 1A (n=5), 1B(n=19), 1C (n=33), and 1D (n=1).

No significant relationship was observed between fracture classification (AO/OTA, Fernandez) and types of TFCC injury (Palmar classification): AO/OTA, Fernandez (Table 3). Intra-articular fracture involvement, presence of an ulnar styloid fracture had no significant effect on type of TFCC injury: articular involvement ($p>0.05$), ulnar styloid fracture ($p>0.05$). Type lC TFCC injuries were significant in patients with osteoporosis compared with other groups ($p<0.01$). Regarding age related statistics, more Type 1C injuries were observed in significantly older patients compared with younger patients ($p<0.01$).

For radiologic parameters, except for radial length gap, there was no significant difference in the type of injury (Table 4). Radial length gap between intact and injured wrist showed significant relevance with the pattern of TFCC injury. Increased radial length gap showed relevance with type lC injuries ($p<0.05$).

Table 1. Demographic Data

Index		TFCC pattern relevance (p value)
Index age (average)	65.21	>0.05
Gender (male : female)	8:2	>0.05
BMI (average)	24.05	>0.05
Osteoporosis (%)	37.9	>0.05

BMI: body mass index; TFCC: triangular fibrocartilage complex.

Table 2. TFCC Injury Pattern

TFCC injury pattern (palmar classification)	N
1A	5
1B	19
1C	33
1D	1

N: number; TFCC: triangular fibrocartilage complex.

Table 3. Fracture Classification with TFCC Injury Pattern

	Palmar classification				
	1A	1B	1C	1D	Total
AO/OTA classification					
A2	2	5	9	1	17
A3	0	5	6	0	11
B3	1	2	1	0	4
C1	1	1	2	0	4
C2	0	4	6	0	10
C3	1	2	9	0	12
Total	5	19	33	1	58
Fernandez classification					
1	2	11	15	1	29
2	1	2	1	0	4
3	1	3	8	0	12
5	1	3	9	0	13
Total	5	19	33	1	58

Fracture classification (AO/OTA, Fernandez) had no statistical significance with TFCC injury. ($p>0.05$ / $p>0.05$ respectively). AO: arbeitsgemeinschaft fur osteosynthesfragen; OTA: orthopedic trauma association; TFCC: triangular fibrocartilage complex.

Table 4. Radiologic Parameter with TFCC Injury Pattern

	Palmar classification				
Radiologic parameter	1A	1B	1C	1D	p-value
DRUJ gap	-0.014	0.28	0.25	0.07	>0.05
Radial length	6.69	5.25	3.14	11.9	>0.05
Radial length gap	3.53	5.04	6.27	-5.16	<0.05*
Radial inclination	18.06	14.026	13.982	23.9	>0.05
Dorsal angulation	-2.02	5.13	7.84	-15.9	>0.05

Radiologic parameter, except radial length gap had no significant relevance with TFCC injury pattern. DRUJ: distal radioulnar joint; TFCC: triangular fibrocartilage complex; *: Statistically significant.

4. Discussion

According to a previous study, TFCC Injury with an exceeding dorsal angulation of 32' can be expected (10). However, in this study, all TFCC injuries were detected and dorsal angulation of more than 32' was detected in only seven of them; there was no statistical significance with the dorsal angularity of the fracture ($p>0.05$). In a cadaveric study, displacement of the intact TFCC complex together with the ulnar styloid base fracture fragment was observed, while TFCC avulsion injuries were detected in patients with ulnar styloid tip fractures. In this study, however, no correlation was observed between ulnar styloid fracture and patterns of TFCC injury type.

The ulnocarpal ligaments (ulnolunate and ulnotriquetral ligament) do not insert onto the ulna but are derived from the anterior part of the TFCC, and they connect the carpus to the ulnar by the palmar portion of the radioulnar ligament at its origin- the fovea. Type lC injury is defined as distal avulsion of the carpal attachment in TFCC. Findings from this study demonstrated an association of distal avulsion with direct radial shortening, which contradicts the previously held common belief that increased dorsal angularity makes the distal avulsion force stronger. When considering normal variance of ulnar head positioning, radial length alone in an injured wrist might not represent the degree of radial shortening. Measurement of radial length discrepancy compared with the intact wrist should be performed, and a gap of more than 6.3 mm (SD 4.7) might strongly suggest type lC TFCC injury.

As demonstrated in previous cadevaric studies, ECU subsheath (sECU), an integral part of TFCC, provides ulnocarpal stability and appears to precede dorsal and palmar injuries. In Bowstring phenomenon,

which explains rupture of sECU, avulsion injuries of dorsal soft tissues of the TFCC complex are manifested (10,11). Findings from other studies have demonstrated that dorsal angulation of distal radius fractures causes increased traction of palmar ligaments inserting within the foveal region, making them taut in extension and finally resulting in palmar injuries of the TFCC complex (12). This explains the mechanism by which dorsal and palmar injuries can co-exist.

Previous studies have demonstrated an association of TFCC injuries with the degree of dorsal or volar angulation of the fracture (13,14). In a cadaver study, sectioned TFCC resulted in increased dorsal angulation (13). In this study, TFCC injuries were detected in all patients, however, there was no significant relationship between the degree of dorsal angularity and TFCC injury.

The conclusion of this study is that radial compression and shortening of the distal radius causes peripheral tear of the ulnar side preceding tear of the palmar ligament. "Dart-throwing Motion" in the injury mechanism of distal radius fracture has been introduced in order to further explain this concept. Dart-throwing motion (DTM) plane can be defined as the plane on which functional oblique motion of the wrist occurs (15-18). Geometric anatomical factors, ligament factors, and musculature factors have been used to explain DTM, the functional ROM that extends wrist function with radial deviation (so called radial-extension) and flexes with ulnar deviation (so called ulnar-flexion). When considering a dorsal angulated fracture with DTM, axial compression force might accompany wrist extension and radial deviation not with wrist extension alone, and vice versa. Axial loading and radial deviating force during the injury mechanism of distal radius fracture causes shortening of the radial length. Regarding this concept of injury mechanism, findings from this study demonstrated that radial

shortening with a dorsally angulated fracture, regardless of the degree of angulation, increases tension in soft tissue of the ulnar side, leading to dorsal or palmar TFCC injury of the ulnar side.

Radial avulsion injury (D1) was detected in only one case, which showed a volar angulated fracture and the greatest increase in radial length distance (Figure 3). In this case, both distal radioulnar fractures occurred, however, there was greater displacement of the distal ulnar fracture fragment, which was shortened in length, and the distal radius was volar angulated. The patient was driving at the time of injury, with her wrist in a flexed position; as the car came to a sudden stop, she suffered a direct injury from the car handle with her wrist in a flexed position. In this case, considering DTM, direct axial force while her wrist was in a state of ulnar flexion caused greater displacement of the distal ulnar fracture. Unlike Colle's fracture mentioned above, ulnar deviated and volar angulating axial force decreases tension on palmar soft tissue of TFCC and makes detachment of sECU from the ulnar side more difficult, thereby transmitting the axial force to the radial avulsion of TFCC.

This study has several limitations. First, data on clinical outcome was not utilized. TFCC is the most associated secondary injury after distal radius fracture, however, because these injuries are mostly self-limiting or easily overcome with conservative management including physical therapy or medication, treatment after healing of the fracture is controversial (19,20). As demonstrated in this study, most of the patients had concomitant TFCC injuries, however, the overall outcomes after the surgery were not proven. In order to prove the clinical importance of this study, an analysis of patient outcome, such as clinical score (VAS, Mayo, DASH), follow-up data, period of symptom resolution, and number of patients receiving additional TFCC management including

surgery should be performed in the next study. The relatively small number of patients is another limitation of this study. Type D injury was detected in only case, and the results cannot be supported.

Figure 3. Type 1D injury case. 63 years old female patient injured with her wrist flexed had AO/OTA type A2 fracture with 15' volar angulation, showing 5mm increased radial length gap, had type 1D TFCC injury with relatively preserved peripheral & distal portion of TFCC. AO: arbeitsgemeinschaft fur osteosynthes-fragen; OTA: orthopedic traumat association; TFCC: triangular fibrocartilage complex.

5. Summary

This study was designed to analyze the prevalence of TFCC injury in patients with distal radius fractures and to suggest acceptable radiologic parameters for use in predicting the pattern of TFCC injury. A total of 58 patients with distal radius fracture, who underwent MRI examination before undergoing open reduction surgery between April 2020 and July 2021, were included in this study. An analysis of various radiologic parameters and the pattern of TFCC injury was performed by two orthopedic physicians. Statistically, radial length gap, which represents relative radial shortening, was the only parameter showing an association with the pattern of TFCC injury ($p<0.05$). The pathomechanism by which radial shortening might result in distal avulsion of TFCC was proposed in this study. No previous study has reported on the relevance between the pattern of TFCC injury and radial shortening. However, routine management of TFCC injuries has not been administered in patients with distal radius fracture. Conduct of further studies regarding clinical and functional outcome will be necessary in order to add clinical value to this result.

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Pathomechanism of Triangular Fibrocartilage Complex Injuries in Patients with Distal Radius Fractures: A Magnetic Resonance Imaging Study

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(Abstract)

Injury to the Triangular fibrocartilage complex (TFCC) is one of the most common complications following fracture of the distal radius. In this study an examination of TFCC injuries in patients with distal radius fractures was conducted using magnetic resonance imaging (MRI); the aim of the study was to analyze the prevalence of TFCC injury as well as to suggest acceptable radiologic parameters for use in prediction of the injury pattern. Fifty-eight patients with distal radius fractures who underwent MRI prior to undergoing open reduction surgery between April 2020 and July 2021 were included in this study. Analysis of various radiologic parameters, fracture type, and MRI classification of TFCC injuries was performed. Radiologic parameters were used in evaluation of distal radio-

ulnar joint (DRUJ), radial shortening, and dorsal angularity of the fracture. All patients in this study had definite traumatic TFCC injuries. A statistical relationship was observed between radial length gap between intact and injured wrist, which represents relative radial shortening, and the pattern of TFCC injury. In conclusion, shortening of the distal radius, causing peripheral soft tissue of the ulnar side to become more taut, has significant relevance with the pattern of TFCC injury. However, because no data on clinical outcome were utilized in this study, it is lacking in clinical perspective. Conduct of further studies on patients' clinical outcome will be necessary.

원위 요골 골절과 삼각섬유복합체 손상의 상관관계 및 병태생리: 자기공명영상 장치를 이용한 연구

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(초록)

삼각섬유복합체(TFCC) 손상은 원위 요골 골절 이후 흔히 발생하는 합병증 중 하나이다. 본 연구에서는 원위 요골 골절 환자에서 자기공명영상 장치(MRI) 검사를 시행하여 TFCC 손상의 유병률을 알아보고, TFCC 손상 패턴을 예상할 수 있는 적절한 방사선학적 지표를 제시하고자 한다. 원위 요골 골절의 관혈적 정복술을 시행 받기 전 MRI 검사를 시행한 58명의 환자가 연구에 포함되었다. 다양한 방사선학적 지표, 골절 분류, TFCC 손상의 MRI 분류를 조사하였다. 원위 요척골 관절, 요측 단축 및 골절의 후방 전위 등을 평가하기 위한 방사선학적 지표들이 사용되었다. 포함된 모든 환자에서 외상으로 인한 TFCC 손상이 MRI상에서 확인되었다. 요측 단축을 나타내는 radial length gap 값이 TFCC 손상과 통계학적으로 연관성을 보이는 유일한 지표였다. 결론적으로, 원위 요골 골절로 요측 단축이 척측 원위 인대 및 조직들의 긴장도를 높이게 되며 TFCC 원위 손상을 일으키는 것으로 예측된다. 하지만

본 연구는 임상적 지표들이 사용 되지 않아 추후 환자의 임상적 데이터를 포함한 연구가 이어져야 될 것으로 사료된다.