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Utility of Tomosynthesis for Diagnosis of Wrist Joint Disorders
—Focus on Triangular Fibrocartilage Complex Injury—

Department of Orthopaedics, Graduate School of Medical Science, Kyoto Prefectural University of Medicine [1]

Development of Multidisciplinary Promote for Physical Activity, Kyoto Prefectural University of Medicine [2]

Department of Radiology, Graduate School of Medical Science, Kyoto Prefectural University of Medicine [3]

Department of Orthopaedic Surgery, Japanese Red Cross Kyoto Daini Hospital [4]

Shinji Tsuchida,
M.D., Ph.D.

Shinji Tsuchida [1], Ryo Oda [1], Shogo Toyama [1,2], Kei Yamada [3], Hiroyoshi Fujiwara [4]

1. Introduction

The triangular fibrocartilage complex (TFCC) is a complex of ligaments and fibrous cartilage on the ulnar side of the wrist and is a soft tissue that cannot be separated histologically.[1] More specifically, it consists of the radioulnar ligament, ulnolunate ligament, ulnotriquetral ligament, ulnar collateral ligament, triangular fibrocartilage, and meniscus homologues. The fibrocartilage functions as articular disc to buffer loads from ulnar carpal bones and to transmit stresses to ulna. The ligaments serve to stabilize the distal radioulnar joint and the ulnar carpal row during pronation and supination of the forearm. TFCC tears are a major cause of ulnar-sided wrist pain, but due to the complicated morphology and functionality, it is often difficult to assess the location and severity of tears in images. Therefore, the localized assessments which are ulnar fovea sign, ulnar compression, or other tests and various imaging examinations are performed to assess the condition prior to surgery, and a final diagnosis depends on invasive arthroscopy of the wrist. Arthrography have utility as a supplemental examination, but because it provides projected images of the overall wrist that is in principle difficult to use for identifying the detailed location of tears. In contrast, tomosynthesis is a technology that offers high quality digital multi-slice tomographic images at low dose levels that can be used for tomography even after arthrography. Therefore, it may be possible to use tomosynthesis for detailed assessment of TFCC tears before surgery.

2. Purpose

The purpose is to verify the utility of tomosynthesis by comparing the sensitivity, specificity, and diagnostic accuracy calculated from tomosynthesis image (Tomosynthesis) and 3.0 Tesla MR image (3T-MRI) after arthrography of TFCC tears.

3. Subjects and Methods

Subjects were 42 patients that underwent surgery for TFCC tears in our department from January 2012 to September 2017. The average patient age at the time of surgery was 35.6 years and the average waiting period to the surgery from when the patient first became aware of ulnar wrist pain was 5.9 months. A 1:1 mixture of meglumine sodium amidotrizoate injection and lidocaine was used as the arthrographic contrast medium. Using fluoroscopy, the contrast medium was first injected into the radiocarpal joint (RCJ). If it did not leak out to the distal radioulnar joint (DRUJ), then contrast medium was injected into the DRUJ, according to the double-injection method. For tomosynthesis, we used T-smart (Tomosynthesis-Shimadzu Metal Artifact Reduction Technology) from Shimadzu Corporation with imaging parameters of 40 degrees tube angle, 9-inch field-of-view, and 0.5 mm slice pitch. Frontal images of the wrist were obtained with the forearm slightly pronated on the table. 3T-MRI coronal section images of the wrist were obtained with the same arm position as Tomosynthesis.

For Tomosynthesis, TFCC tears was defined as a disc proper tear if contrast medium leaked from the RCJ via the disc and into the DRUJ, a foveal tear if contrast medium leaked to the ulnar fovea, a lunotriquetral ligament (LT) tear if contrast medium appeared continuously from the ulnocarpal joint (UCJ) to the midcarpal joint, and an peripheral ulnar side TFCC tear if it was found contrast medium infiltrated into the peripheral area of the TFCC on the ulnar side and it leaked into the ulnar side beyond meniscus homologue from the prestyloid recess **(Fig. 1)**.
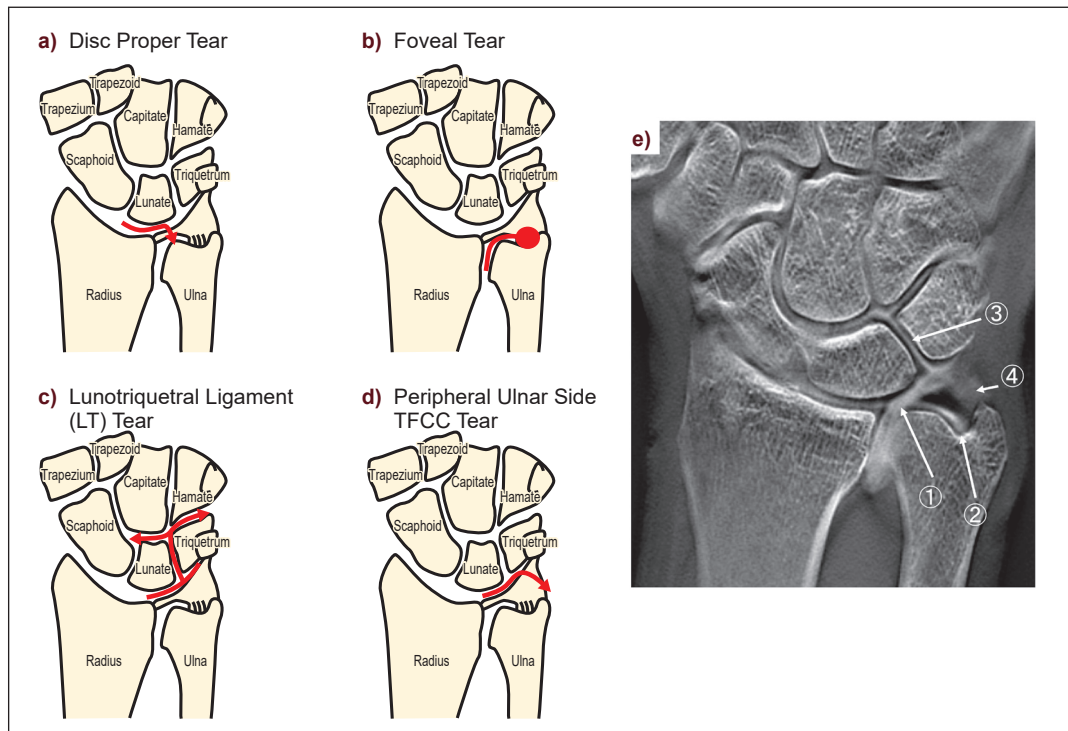
Fig.1

For 3T-MRI, TFCC tears was defined as a disc proper tear if a continuous brightness variation from the ulnocarpal to DRUJ was observed in the disc proper, a foveal tear if a brightness change was observed in the foveal attachment area no the triangular ligament, an LT tear if there was a discontinuity in ligament between the lunate and triquetrum, and an peripheral ulnar side TFCC tear if there was a discontinuity between the meniscus homologue and ulnar collateral ligament area.

The sensitivity of Tomosynthesis and MRI to the TFCC tears recognized by arthroscopy and the sensitivity, specificity, positive predictive value, and negative predictive value of Tomosynthesis and 3T-MRI to each tear were calculated. And then statistically analyzed assuming a significant difference of $p < 0.05$ based on the McNemar test.

4. Results

The sensitivity of Tomosynthesis and 3T-MRI with respect to overall TFCC tears was 97.6 % and 90.4 %, respectively (p = 0.25). The results for each tear are: For foveal tears, although no significant difference in specificity and sensitivity, the sensitivity and negative predictive value of Tomosynthesis were both 100 %, which was higher than the 84.4 % and 85 % respectively for 3T-MRI. For LT tears, Tomosynthesis provided 97.4 % specificity, which was significantly higher than the 56.7 % for 3T-MRI (p = 0.00008) **(Table 1)**.

Table 1

Comparison of Tomosynthesis vs 3T-MRI for Overall TFCC Tears

	Tomo	3T-MRI	McNemar test
Sensitivity	97.6 %	90.4 %	p = 0.25
Specificity	—	—	
Positive Predictive Value	— (100 %)	— (100 %)	
Negative Predictive Value	—	—	

Comparison of Tomosynthesis vs 3T-MRI for Disc Proper Tears

	Tomo	3T-MRI	McNemar test
Sensitivity	82.4 %	78.7 %	p = 0.48
Specificity	100 %	77.7 %	p > 0.5
Positive Predictive Value	100 %	92.9 %	
Negative Predictive Value	60 %	50 %	

Comparison of Tomosynthesis vs 3T-MRI for Foveal Tears

	Tomo	3T-MRI	McNemar test
Sensitivity	100 %	84.4 %	p = 0.25
Specificity	87.5 %	73.9 %	p = 0.13
Positive Predictive Value	86.4 %	72.7 %	
Negative Predictive Value	100 %	85 %	

Comparison of Tomosynthesis vs 3T-MRI for LT Tears

	Tomo	3T-MRI	McNemar test
Sensitivity	100 %	50 %	p = 0.25
Specificity	97.4 %	56.7 %	p = 0.0008
Positive Predictive Value	85.7 %	16.7%	
Negative Predictive Value	100 %	87.5 %	

Comparison of Tomosynthesis vs 3T-MRI for Ulnar Peripheral Tears

	Tomo	3T-MRI	McNemar test
Sensitivity	88.9 %	88.9 %	p = Not a Number
Specificity	54.5 %	45.4 %	p = 0.13
Positive Predictive Value	34.8 %	30.7 %	
Negative Predictive Value	94.7 %	93.8 %	

5. Examples of Typical Cases

A 25-year-old male noticed pain from the ulnar side of his right wrist during carpentry work, which was diagnosed by a local physician one week later and treated conservatively with orally administered

NSAIDs and topical ointment. Because the pain did not improve, he was referred to our department, where we examined him one month later. The MRI and arthrography examination revealed a disc proper tear and peripheral ulnar side TFCC tear, but none of the images showed an LT tear or foveal tear. With Tomosynthesis, we were able to diagnose not only the disc proper tear and peripheral ulnar side TFCC tear, but also an LT tear and foveal tear. All findings by Tomosynthesis were consistent with that of arthroscopy(Fig. 2).

6. Consideration

MR and arthrographic images have been considered effective y for the diagnostic imaging of TFCC tears. After having the 3.0 Tesla MRI in clinical practices, the diagnoses accuracy has been improved, with sensitivity and specificity increasing to 86 % and 100 %, respectively.[2] Even in this research, 3T-MRI sensitivity for detecting TFCC tears was

over 90 %, which is comparable to the high values previously reported. Meanwhile, arthrography has been performed since about 1960 before MRI was available, and has been reported to achieve TFCC tears sensitivity of 85 %.[3] In this research as well, arthrographic images without tomosynthesis resulted in sensitivity of 87.7 %, which is comparable to values reported in the past. As an alternative to MRI and arthrography, Moritomo, et al. reported that the radial imaging of mainly ulnar fovea using an arthrographic CT achieved excellent sensitivity and specificity [4], but radiation dose levels remained a problem. To achieve diagnostic imaging that is less invasive and more convenient, a new imaging technology needs to be introduced. Tomosynthesis is a low dose diagnosis method, requiring one-tenth or less radiation dose than CT, and can be performed in the same room and in the same body position as arthrography. The average exposure time is five seconds, which is quite short and helps reduce the stress on patients. The spatial resolution of tomosynthesis is considered comparable to that of radiography, about
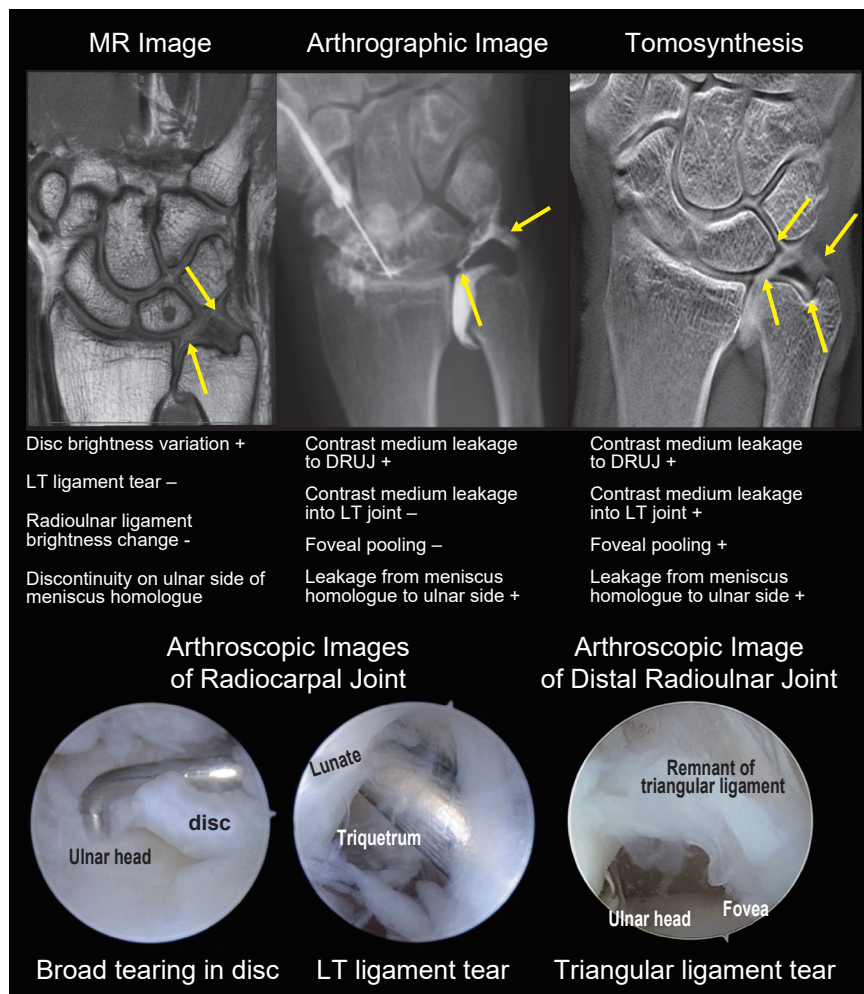

MR Image	Arthrographic Image	Tomosynthesis
Disc brightness variation +	Contrast medium leakage to DRUJ +	Contrast medium leakage to DRUJ +
LT ligament tear –	Contrast medium leakage into LT joint –	Contrast medium leakage into LT joint +
Radioulnar ligament brightness change -	Foveal pooling –	Foveal pooling +
Discontinuity on ulnar side of meniscus homologue	Leakage from meniscus homologue to ulnar side +	Leakage from meniscus homologue to ulnar side +

Arthroscopic Images of Radiocarpal Joint

Arthroscopic Image of Distal Radioulnar Joint

Broad tearing in disc   LT ligament tear   Triangular ligament tear

Fig.2

4 megapixels, theoretically 16 times more than the 250,000 pixels of CT. Consequently, tomosynthesis has a possibility to visualize small features of a lesion in finer detail. Furthermore, tomosynthesis generates less artifacts, so the images can be analyzed even after contrast medium is used. Therefore, we verify this study with tomographic images obtained by the tomosynthesis after performing arthrography.

Although there was no significant difference between the sensitivity of Tomosynthesis and 3T-MRI to TFCC tears, the sensitivity of Tomosynthesis was a high 97.6 %. Tomosynthesis achieved 100 % specificity and positive predictive value for disc proper tears and 100 % sensitivity and negative predictive value for foveal tears and LT tears. Given that 3T-MRI fell short of 100 % for all of those measures, I thought the high diagnostic capability of Tomosynthesis could enable identification of tears that were difficult to diagnose by MRI.

Because the distal radioulnar ligament helps stabilize the DRUJ, particularly foveal tears can result in DRUJ instability problems. In such cases, diagnostic imaging is important for planning ligament suturing or reconstructive surgery. Though there was no statistically significant difference between Tomosynthesis and 3T-MRI in our study (p = 0.25 for sensitivity and p = 0.13 for specificity), the sensitivity and negative predictive value of Tomosynthesis were 100 %. It indicates that Tomosynthesis is presumably effective for preoperative diagnostic imaging. For LT tears, Tomosynthesis had 98 % diagnostic accuracy, which was significantly higher than the 57 % for 3T-MRI. The LT is an important part for diagnosing TFCC tears complicated with ulnocarpal abutment syndrome and LT tear can cause persistent pain after ulnar shortening osteotomy.[5] If LT tear is assessed before surgery, then the possibility of residual the pain due to LT tear can be considered in the treatment plan, which presumably means Tomosynthesis has utility for LT evaluation as well.

Though the difference is not significant, the lowest diagnostic accuracy in peripheral ulnar side TFCC tears was 62 % of Tomosynthesis, whereas theaccuracy of 3T-MRI was 83 %. The positive predictive value might have become lower as a result of diagnosing following cases as tear: small slit tears formed on the normal meniscus homologue, prestyloid recess, or ECU subsheath that form the ulnar periphery (which was minimal enough that it did not require

repairing) and contrast medium leakage into the ulnar side during other wrist movements after the contrast medium was injected. Therefore, for diagnostic imaging of TFCC tears, it is presumably important to judge comprehensively considering location of each tear and characteristics of each examination method. Arthrography can have 20 ~ 35 % false negatives due to lack of contrast medium leakage from the RCJ to the DRUJ for disc wear alone or lack of contrast medium leakage for flap blockage in small flap tears.[6] Given that there are 17.6 % false negatives for disc proper tears in this study as well, we thought it can be worth changing the contrast medium injection pressure or modifying other wrist movements after contrast medium injection until images are acquired.

Summary

1. The accuracy of Tomosynthesis and 3T-MRI for diagnosing TFCC tears before surgery was compared.
2. The diagnostic accuracy for foveal tears was 95 % for Tomosynthesis and 79 % for 3T-MRI. For LT tear the diagnostic accuracy for Tomosynthesis was significantly higher than 3T-MRI, with 98 % for Tomosynthesis and 57 % for 3T-MRI.
3. Tomosynthesis is considered to offer significant utility for diagnostic imaging of TFCC tears before surgery.

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