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ORIGINAL RESEARCH

MRI Determination of Knee Effusion Volume: A Cadaveric Study

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ABSTRACT

Background: There is currently limited literature on quantitative determination of knee effusion volume using magnetic resonance imaging (MRI).

Purpose: To describe a method of knee effusion volume determination using MRI generated models and to demonstrate accuracy of this technique.

Materials and methods: Using axial T2-weighted turbo spin echo and sagittal SPACE sequences, MRIs of three cadaver knees with multiple saline loads were obtained. Effusions models were created and effusion volumes were estimated using the Rhinoceros software. Estimated and known effusion volumes were compared using a bivariate correlation analysis.

Results: The SPACE sequence and T2WTSE estimates were highly correlated with the known volumes ($R = 0.996$ and 0.993 respectively, $p < 0.001$).

Conclusion: MRI-generated models of knee effusions provide accurate estimates of knee effusion volumes.

Clinical relevance: MRI determination of knee effusion volume may provide a useful clinical outcomes tool.

Keywords: Effusion, Magnetic resonance imaging, Knee.

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INTRODUCTION

Joint effusions are associated with trauma, infection and both inflammatory and noninflammatory arthropathies. The ability to determine effusion volume may be useful as a clinical outcomes assessment tool. The effectiveness of interventions designed to address intra-articular pathology and inflammation could be assessed by comparing knee effusion volumes prior to and after intervention. While magnetic resonance imaging (MRI) has long been established as a means of qualitatively assessing joint effusions,[1,2] to date, there are a limited number of reports describing the quantitative determination of knee effusion volume using MRI.[3,4]

With recent hardware and software improvements, volume imaging of the knee has become more practical. However, most sites still perform two-dimensional (2D) imaging. Typically, such protocols contain slice spacing of 10 to 50%. Presumably such spacing would result in less accurate estimation of effusion volume.

Three-dimensional (3D) models of joints based on 2D MRI acquisition have been developed as tools to assess, among other things, joint surface contact stresses, cartilage surface area, and anterior cruciate ligament positions.[5-7] One such tool used to create these 3D models is Rhinoceros (McNeel and Associates, Seattle, WA). Rhinoceros creates a 3D model based on 2D semiautomated manual tracings of objects on 2D MRI slices. The 3D model is generated based on knowledge of the MRI slice thickness.

To our knowledge, the use of the Rhinoceros software to determine the volume of knee effusions has not previously been described. Automated volume segmentation has been demonstrated to be accurate in the measurement of volume of organs, tumors, lymph nodes, and pulmonary nodules using various imaging modalities.[8-15] Volume segmentation has specifically been used to accurately determine knee effusion volumes based on T2 MRI images with good interobserver reliability.[3,4] Similar technology has been used to determine intra-articular fluid volume of the first metatarsal phalangeal joint.[16] The purpose of this study is to determine whether 3D modeling of 2D image acquisitions will provide sufficient accuracy for assessing knee effusion volumes using the Rhinoceros software.

MATERIALS AND METHODS

Three cadaveric knees were imaged on a 3.0 Tesla scanner (Trio TM, Siemens, software version VB 17) using an 8 channel receive only coil (*in vivo*). All knees were frozen then thawed over night for a period of approximately 15 hours. An 18 gauge plastic angiocatheter was inserted into the knee joint superolaterally prior to all imaging and secured with tape. A stopcock was attached directly to the entrance to the angiocatheter so that a single puncture site in the capsule could be used for creation of progressively larger knee effusions. Each knee was imaged with the protocol listed below before the addition of fluid in order to determine the native effusion volume. The imaging protocol was then repeated following there infusions of additional saline. The effusion was increased incrementally from 20 cc to 40 cc and finally to 60 cc.

The protocol consisted of axial T2 weighted turbo spin echo (T2WTSE) and sagittal SPACE (Sampling Perfection

with application optimized contrast using different angle evolutions) sequences. The T2WTSE images were similar to our clinical protocol on this scanner and utilized the following parameters: TR/TE: 3640/56 msec, average: 1, flip angle: 120°, Turbo factor: 9, slice thickness: 3 mm, slice gap: 0.3 mm. FOV: 140 mm with 50% phase oversampling, matrix: 320 × 224, fat suppression: SPAIR and weak, bandwidth: 260 Hz/Px. The SPACE images were acquired using the following parameters: TR/TE: 1100/43 msec, average: 1, Turbo factor: 49, slice thickness: 0.6 mm, slice gap: 0 mm. FOV: 160 mm, matrix: 320 × 285 fat suppression: SPAIR and strong, bandwidth: 460 Hz/Px.

The Rhinoceros software was then used to trace any intra-articular fluid collections using a semiautomated propagation tool. The tracings were performed on the 3 mm slices for both the axial T2 images as well as the sagittal SPACE sequence images. By means of a pixel intensity gradient matrix, semiautomated edge detection software written in Mathematica 6.0 (Wolfram, Champaign, IL) was used to outline synovial fluid on each axial MRI. Spline curves were used to segment the edges of the synovial within each image and used to create a 3D model of the volume of synovial fluid within each joint. All tracings were performed by a sports medicine fellowship trained orthopaedic surgeon.

The 2D tracings were used to create a 3D model, the volume of which was determined based on the surface area of the 2D tracings and the slice thickness. The native effusion volumes were then subtracted from the calculated effusion volumes to generate the estimated effusion volumes for comparison to the known saline loads. The T2 and SPACE sequence estimates were then compared to the known saline load volumes using a bivariate correlation analysis.

RESULTS

The estimated effusion volumes calculated using the space sequences and the T2 images are summarized in Table 1.

Both the SPACE sequences and T2 images showed excellent correlation with the known saline loads with R values of 0.996 and 0.993 respectively. These correlations were significant with p-values less than 0.0001. The mean discrepancy between the known saline load and the SPACE sequence estimates was 0.66 cc. The mean discrepancy between the known saline loads and the T2 estimates was 0.67 cc. No significant difference between the T2 and SPACE sequence discrepancies were noted.

DISCUSSION

There are few studies on the use of MRI to calculate knee effusion volumes. Two studies using automated volume segmentation software have demonstrated excellent accuracy in estimating knee effusion volumes.[3,4] This study was performed on a limited number of cadaveric knees using the Rhinoceros software, but demonstrated excellent correlation between the estimated volumes and the known effusion volumes.

There are several strengths to this study. First of all, several measures were taken to ensure that the created effusion volume was nearly identical to the saline load injected into the knee. To ensure no leakage from the entry point for injection, the angiocatheter was inserted into the knee superolaterally in a single pass, then never removed through the entire imaging process. The angiocatheter was then connected to a stop cock to eliminate the possibility of any retrograde leakage. Finally, each study was evaluated for any leakage of fluid external to the joint capsule on the

Table 1: Comparison of saline load and estimated effusion volumes (SPACE and T2)

Saline load (cc)		*SPACE sequence estimate (cc)*	*T2 estimate (cc)*
Knee 1	60	58.14	56.9
	40	38.46	40.76
	20	20.11	22.7
Knee 2	60	57.42	57.59
	40	41.50	35.69
	20	21.30	19.40
Knee 3	60	61.30	60.15
	0	37.42	39.58
	20	19.83	18.50
Overall	60	58.95	58.21
	40	39.13	38.67
	20	20.41	20.20
Correlation		R = 0.996, p < 0.0001	R = 0.993, p < 0.0001

MRI. None of the knees demonstrated any significant leakage at any point during the imaging process.

While no interobserver or intraobserver correlations were reported, the single observer did determine the estimates for effusion volumes on two types of series-T2WTSE axial and SPACE sequence sagittal images. These estimates serve as internal controls for one another and are nearly identical with very similar R-values for correlation with the known saline load. In contrast to the study by Heuck et al[3] which notes an overestimation of effusion volume on a single cadaveric specimen, we did not find that the estimation based on the sagittal series resulted in over-estimation. In fact, the estimates obtained from the axial T2 images and the sagittal SPACE sequences were nearly identical. This may be due to the fact that a 3T magnet and 3 mm slice thickness rather than a 1.5T magnet and 5 mm slice thickness were used in our study.

All observations were made by a sports medicine trained orthopaedic surgeon. A sports medicine trained orthopaedic surgeon or a musculoskeletal trained MRI radiologist are likely to have the necessary knowledge of anatomy, pathology, and imaging to recognize what spaces an effusion occupies as it grows in size and correctly include this in their measurements. For instance in one case, a Baker's cyst enlarged as the effusion was successively increased, requiring inclusion of this fluid volume in the initial estimate of the native effusion as well as the estimates of subsequent effusions. Further research would be necessary to determine the accuracy that other types of observers would have in making these estimates as well as confirming inter- and intraobserver reproducibility.

A significant weakness is that the observer was not blinded to the saline loads injected into the cadaver knees. The rhinoceros program, however, does not indicate the total volume of the effusion tracing until this is calculated by the observer after the effusion tracing has been completed. Thus, the possibility of bias on the part of the observer affecting the estimate of the volume of the effusion is minimized.

This study suggests that the effusion volume in a knee can accurately be estimated using MRI and the Rhinoceros program to create a 3D model based on 2D acquisition. Our data is in agreement with previous studies in the literature that have demonstrated accurate assessment of knee effusion volumes based on 2D MRI acquisition. There are several potential clinical implications of this research. MRI determination of effusion volume may prove to be a useful outcome in research on the effectiveness of interventions aimed at reducing intra-articular inflammation and swelling.

CONCLUSION

2D images of knee effusions generated by MRI can be used to accurately estimate knee effusion volumes using the Rhinoceros software. Further studies will have to be performed to confirm if MRI determination of knee effusion volume will be a useful outcome measure for assessing the efficacy of interventions in patients with intra-articular inflammation and swelling.

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