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INTER-OBSERVER REPRODUCIBILITY OF QUANTITATIVE MENISCUS ANALYSIS USING CORONAL MULTIPLANAR DESS AND IWTSE MR IMAGING

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Abstract

The objective of this study was to determine the inter-observer reproducibility (IOR) of quantitative measures of meniscus size and position, and to compare the IOR and agreement between a double echo steady state (DESS) water excitation and an intermediately-weighted turbo spin-echo (IWTSE) sequence. Eight knees (4 healthy, 4 with radiographic knee OA) from the Osteoarthritis Initiative cohort were studied. Manual segmentation of the menisci was performed by 3 observers and quantitative measures of meniscus size and position (i.e. extrusion) computed using image analysis software. The root mean square IOR error (e.g. 5.4% for medial meniscus volume with DESS and 8.4% with IWTSE) was found considerably smaller than the inter-subject variability (average ratio approximately 1:3). The lowest IOR error for meniscus extrusion was obtained for the central 5 coronal slices across the tibial surface. Quantitative meniscus measures from DESS and IWTSE were highly correlated ($r=0.71$ to 0.99 for the medial meniscus).

Keywords

meniscus; quantitative; inter-observer reproducibility; magnetic resonance imaging

INTRODUCTION

The menisci are semicircular, intra-articular, fibro-cartilaginous structures thought to play an important role in the incidence, progression and clinical manifestation of knee osteoarthritis (OA) (1). Meniscal tears (and meniscectomy) may predispose the onset of knee OA (2) and are highly prevalent in the general population (3). They also have been suggested to promote cartilage loss (4), but it is controversial whether meniscus extrusion (scored by visual inspection) is associated with structural progression of knee OA (4,5). Also, it is currently debated whether the meniscus undergoes hypertrophy in early phases of OA (6,7).

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Conflict of interest statement:

Felix Eckstein is CEO and co-owner of Chondrometrics GmbH, a company providing MR image analysis services. He provides consulting services to MerckSerono, Novartis and Sanofi Aventis. Wolfgang Wirth and Martin Hudelmaier are partially employed by Chondrometrics GmbH, and Wolfgang Wirth is a co-owner of Chondrometrics GmbH. Kristina Siorpaes, Andrea Wenger and Katja Blöcker have no conflict of interest.

Meniscus extrusion and size are difficult to grade objectively by visual inspection (8), because complex three-dimensional (3D) geometric features are evaluated that extend over a series of two-dimensional images. Therefore, interest has been in developing 3D measures from MRI for use in scientific studies (9–11), and a recent report proposed several quantitative outcomes of meniscus size and position relative to the tibial surface (6). The inter-observer reproducibility (IOR) of such quantitative measures has, however, not been determined. Also, quantitative measures (of meniscus size and extrusion) have not been compared between a high resolution double echo steady state sequence (DESS) (12,13) with water excitation, as currently acquired in the Osteoarthritis Initiative (OAI: <http://oai.epi-ucsf.org/datarelease/>) (14), and an intermediately-weighted turbo spin-echo (IWTSE) sequence. This is important before further use of the DESS for meniscus segmentation can be recommended, since the IWTSE has been commonly used for clinical delineation and evaluation of the meniscus (15).

The objective of this study was therefore a) to determine the IOR of quantitative measures (size and position) of the medial and lateral meniscus in relation to the inter-subject variability of the same measures, b) to compare IOR errors between anatomical subregions (anterior and posterior horn, body, central part of the body) in relation to the inter-subject variability, and c) to compare the IOR errors and the agreement between the DESS and the IWTSE MRI sequence.

Methods

Study participants

Images of the right knees of eight participants from the OAI were studied (public-use 0.F.1 and 0.E.1. data set, <http://oai.epi-ucsf.org/datarelease/>) (14). All images had been acquired using a 3 Tesla Magnetom Trio scanner (Siemens Erlangen, Germany) and a quadrature transmit-receive knee coil (USA Instruments, Aurora, OH) (14). Four subjects (2 men, 2 women; age 53.5 ± 5.7 years; BMI 26.3 ± 4.3) were from the healthy reference cohort and had no history of pain, aching or stiffness in either knee in the past year, and no radiographic findings of femorotibial OA. Also, they were not exposed to risk factors of knee OA, including obesity, knee surgery or injury, family history of knee replacement, hand OA, and repetitive knee bending during daily activities. The other 4 subjects (2 men, 2 women; age 63 ± 12.0 years; BMI 27.5 ± 5.0) had symptomatic, radiographic knee OA (2 Kellgren Lawrence grade [KLG] 2, and 2 KLG 3) with frequent pain (on most days of a month in the past 12 months) in the right knee.

MR imaging and segmentation

To determine the IOR of meniscus measurement, two MR sequences from the OAI imaging protocol (14) were used:

1. A 3D double oblique coronal multi-planar reconstructions of the sagittal DESS: repetition time=16.3ms, echo time=4.7ms, flip angle=25°, reconstructed slice thickness=1.5mm, in-plane resolution $0.37\text{mm} \times 0.7\text{mm}$, interpolated to $0.37\text{mm} \times 0.37\text{mm}$; Fig. 1a) (12,13).
2. A two-dimensional coronal IWTSE sequence (repetition time=3700ms, echo time=29ms, slice thickness=3mm, in-plane resolution $0.36\text{mm} \times 0.36\text{mm}$; Fig. 1b). Before segmentation, the IWTSE images were interpolated once (between planes) to match the 1.5mm slice thickness of the DESS.

The surface of the medial and lateral tibial plateau (ACdAB = area of the cartilage surface [AC] in regions with cartilage covering, and denuded areas of bone (dAB) in areas of full thickness cartilage loss) (6,16), and the tibial (TA), femoral (FA) and external areas (EA) of

the medial meniscus and lateral meniscus (Fig. 1) were segmented manually by three operators (K.S., A.W., K.B.), using Chondrometrics image analysis software (Chondrometrics GmbH, Ainring, Germany) (6). Segmentation of the coronal images was restricted at the anterior and posterior ends to slices, in which both the tibial cartilage and the meniscus could be reliably identified, without strong partial volume effects. The slice numbers, in which the medial meniscus and the lateral meniscus had to be segmented, were initially determined by the supervisor (F.E.). These slice numbers were known, but the three operators were blinded to the segmentations of the other operators throughout the study. Internally (i.e. towards the intercondylar eminence), the borders of the menisci were defined by the operators by using the margin of the tibial ACdAB, because of the lack of an intrinsic anatomical landmark between meniscus and the transverse ligament or the menisco-femoral ligament.

The three readers had been trained initially using a set of eight other OAI participants (4 healthy control and 4 OA knees), in which the above segmentation rules were established based on consensus between the readers and the supervisor (F.E.). To assist the segmentation, series of coronal anatomical knee joint sections were displayed by the software and figures published in articles on sectional anatomy of the knee were used as additional references (17–20).

3D morphometric analysis

A series of 3D parameters describing meniscus size and position were computed after segmentation (6). The nomenclature in the current paper was adopted from the previous report (6), which in turn was based on an expert proposal for quantitative cartilage measures (16). The total meniscus surface (TotA) was computed from the sum of the tibial, femoral, and external surface areas (TA, FA and EA). Further, the mean (Th.Me) and maximum average thickness (Th.Mav, also named meniscus height by other authors (5)), the volume (V), and the mean (Wid.Me) and maximum width (Wid.Max) of both menisci were computed.

As measures of meniscus position, the coverage of ACdAB by TA (ACdAB.Cov in %), and the area of the TA not covering the ACdAB (TA.Uncov in %) were determined (6). Also, the mean (Ex.Me) and maximal meniscal extrusion (Ex.Max), defined as the (mean or maximal) distance between the external margin of ACdAB and that of TA was computed (6). The distance between the internal margin of the meniscus (intersection of TA and FA) and the external border of ACdAB was described as the mean (OvD.Me) and maximum overlap distance (OvD.Max) between the meniscus and the tibial plateau.

Measures of thickness and extrusion were also determined for meniscus subregions, specifically the anterior horn, posterior horn and meniscus body, as described previously (6). In addition, the extrusion and overlap distance were also computed for the central 5 image slices and for the most central image slice, which was defined as the middle between the most anterior and most posterior slice selected for the analysis. This analysis covered the central part of the meniscus body.

Statistical analysis

To determine the IOR, the mean, standard deviation (SD) and coefficient of variation expressed as a percentage (CV%) across the three observers was determined first for quantitative measures of the size and position of the total meniscus, and second for measures in anatomical subregions. As suggested by Glüer et al. (21), the root mean square (RMS) SD and CV% were then calculated across the eight knees as well as for healthy and OA knees separately. Because mean extrusion measures may be close to zero and because the relation

of the variation to the mean extrusion may therefore lead to extremely high or ill-defined values, only the RMS SD was given for extrusion measures (21). For all other measures, the RMS CV% was reported. To provide a “standardized” measure of IOR that can be compared between different parameters, the IOR was related to the inter-subject variability across the 8 participants. A large ratio between the inter-subject variability and the IOR error indicates that the IOR error does not strongly affect the detection of inter-subject differences, whereas a small ratio indicate that it does. In a next step, the IOR and agreement was compared between the DESS and the IWTSE. Differences between both sequences (absolute and %), 95% confidence limits of agreement according to Bland and Altman (22), and the Pearson correlation coefficient were determined across the 8 knees studied.

Results

IOR for quantitative measures of the total meniscus

The IOR error was generally smaller than the inter-subject variability. In the medial meniscus (Table 1), the mean ratio of the two above measures was 1: 3.1 for DESS) and 1:3.3 for IWTSE. In the lateral meniscus (Table 2), the ratio was 1:2.4 for DESS) and 1:3.5 for IW TSE. IOR errors did not show obvious differences between healthy and OA knees: With the DESS, 10 (of the 20 examined) quantitative measures showed smaller IOR errors for the medial meniscus in healthy knees than in OA knees, and 10 the opposite. Laterally, six quantitative measures showed smaller IOR errors in healthy than in OA knees in the lateral meniscus and 14 the opposite.

Medially, IOR errors of IWTSE were larger than those of DESS for 6, and lower for 4 of the 10 size-related meniscus measures. With regard to the 10 position-related meniscus measures IOR errors of IWTSE were larger than those of DESS in 4, and lower in 6 (Table 1). IOR errors of mean extrusion were smaller in the central 5 slices than in the central slice or across the entire meniscus; IOR errors for meniscus/tibial overlap distance were smallest for the entire meniscus (Table 1). Similar observations were made for the lateral meniscus (Table 2): IOR errors of IWTSE were larger than those of DESS in 5, and lower in the other 5 size-related parameters. With regard to position-related parameters IOR errors of IWTSE were larger than those of DESS in 5, lower in 4, and the same in 1 (of 10) measures..

IOR for quantitative measures of the meniscus subregions

In subregions of the medial and lateral meniscus, IOR errors for measures of thickness and extrusion tended to be greater in the posterior horn than in either the anterior horn or meniscus body (Tables 1&2). IOR errors for extrusion of the meniscal body were substantially (x2–3) greater when using the subregional method for determining the meniscus body than when assessing the central 5 slices (Tables 1&2).

Agreement between DESS and IWTSE

Measures of ACdAB and meniscus size were generally greater when measured using the DESS than when measured with IWTSE; the mean differences and 95% confidence limits of agreement being shown in Tables 3 and 4. The percent coverage of the tibial plateau by the meniscus was also larger for DESS than for the IWTSE measurements (40.5% versus 37.0% medially, and 52.6% versus 45.9% laterally):. No obvious differences, however, were identified for other measures of meniscus position. Measures of meniscus thickness were similar between DESS and IWTSE in the anterior horn and body of the menisci; however, they tended to be greater with the DESS in the posterior horn of the medial meniscus (Tables 3&4). Measurements with IWTSE and DESS were highly correlated across the 8 participants: Pearson correlation coefficients ranged from $r=0.71$ (OvD.Max) to $r=0.99$ (OvDCent5 and ACdAB) for measures of the total medial meniscus (Table 3). In the lateral

meniscus the correlations tended to be somewhat smaller but were 0.68, except for Wid.Max and mEx.Max (Table 4).

Discussion

This is the first study to examine the IOR of quantitative measures of medial and lateral meniscus size and position, the IOR of meniscus subregions, and to compare the IOR and such quantitative measures directly between two MRI protocols (DESS versus IWTSE). We find that IOR errors were similar for the DESS and the IWTSE, and generally lower than the inter-subject variability

Lower standardized IOR errors were observed for measures that covered larger areas, likely because of the more favourable relationship of the size of the structure/measure compared with the voxel size. As an exception to this, IOR errors of meniscus extrusion were lower for the central 5 slices (across the tibial ACdAB) than for the entire meniscus or for the subregional analysis of the meniscus body, as defined by the size of the total meniscus. This is likely due to difficulties in segmenting the meniscus and tibial ACdAB at their anterior and posterior ends in coronal images. Although a limitation of the use of the central 5 slices is that they cover a relatively greater proportion of the meniscus in small, and a relatively smaller portion of the meniscus in large joints, this likely has only have relatively small effects on measures of meniscus extrusion.

Measurements with the DESS and with the IWTSE showed differences with regard to meniscus size (but not extrusion). However, measures of size and extrusion generally showed high linear relationships (i.e. correlations) between DESS and IWTSE, particularly in the medial meniscus.

Limitations of the study include the relatively low number of knees examined. However, with 8 knees studied by three observers, the analysis involves 16 degrees of freedom (21), and therefore the true IOR error should not be underestimated by more than 40% in the current analysis (21). Further, the study is limited to examining only one aspect of measurement error, i.e. the IOR; other factors that affect reproducibility (i.e. short- and long-term intra-observer reproducibility, repositioning, day-to-day variation in patient conditions, MRI equipment drifts, etc.) were not examined. The strength of the study is that two MRI sequences were used and compared directly, one that has been traditionally used in context of meniscus diagnostics and scoring (IWTSE) (15), and one with a combined T2/T2* weighted signal and high spatial resolution (DESS) that has been validated in context of quantitative cartilage imaging (12,13). Validation in context of cartilage imaging is important, since the evaluation of meniscus extrusion greatly depends on accurate detection of the external border of the tibial ACdAB. The DESS was used, because it provides clearer delineation of the tibial ACdAB and a lower slice thickness than the non-fat suppressed clinical IWTSE. Although not evident from the IOR reported here, the three readers reported greater subjective ease in identifying the external border of the tibial ACdAB from the DESS compared with IWTSE, likely due to its lower slice thickness, lower partial volume, and a higher contrast-to-noise ratio for cartilage and surrounding tissues in the joint periphery. In this context it is worth noting that previously another T2*-weighted gradient echo sequence (CISS) has been reported to provide satisfactory (intra-reader) test-retest reproducibility, and good agreement between MRI-based meniscal volume measurements and water-displacement of surgically removed menisci in cadaver specimens (10).

Because the segmentations made here were manual, we assume that if alternative tools would have been used for the segmentation, this would have yielded similar results of IOR, as long as long as the readers are responsible for the segmentation. We are, however, not

aware of other software products that are capable of computing a similar wealth of quantitative morphological parameters from meniscus segmentations.

The method evaluated here is not meant to improve (or replace) the qualitative evaluation of meniscal tears, which must be performed by an experienced radiologist and should rely on IWTSE sequences (15). However, the technique proposed can potentially provide a more objective measure of size and extrusion, because complex 3D geometric features extending over a series of two-dimensional images are evaluated quantitatively, which is challenging based on visual scoring alone. For instance, a recent paper (4) showed that quantitative outcomes of cartilage morphology (after segmentation) were more sensitive in revealing relationships between risk factors and structural progression of knee OA than a qualitative approach using semi-quantitative scoring of cartilage status (8).

Geometric measures of meniscus size and extrusion may, for instance, be of interest in context of the design of patient-specific meniscus transplants, in predicting the onset and/or the progression of symptomatic or structural knee OA,. As mentioned in the introduction, recent studies hypothesized that meniscus hypertrophies in early radiographic OA (6,7), and contradictory results have been reported whether or not meniscus extrusion is related to structural progression of knee OA (4,5).. The value of the method and work presented here is primarily for scientific studies of the contribution of the meniscus to (early) knee OA. Promising advances have been recently made in this area by the use of MRI, but there still exists uncertainty about the role of the meniscus in knee OA pathophysiology (1). Reliable quantitative measures of meniscus size and position may thus become a valuable tool in addressing open scientific questions in the above context.

In conclusion, we find the IOR errors of quantitative 3D measures of meniscus size and extrusion to be within acceptable limits and considerably smaller than the inter-subject variability. The lowest IOR error of meniscus extrusion was obtained when analyzing the central 5 coronal slices across the tibial ACdAB. The above findings were consistent between the IWTSE and the DESS sequences, and measurements from both MRI protocols were highly correlated.

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Figure 1. Coronal MR images of the femorotibial joint

a) Multiplanar reconstruction of a sagittal double echo steady state (DESS) sequence with water excitation.

b) Intermediately-weighted turbo spin-echo (IWTSE) sequence

The images show the segmented medial (MM) and lateral meniscus (LM), specifically the tibial area (TA=green), the femoral area (FA=magenta) and the external area (EA=turquoise) of the meniscus. The images also show the segmentation of the tibial ACdAB (=blue).

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Table 1

Inter-observer reproducibility (IOR) for quantitative measures of the medial meniscus position and size obtained from coronal multiplanar reconstruction of double echo steady state (DESS) imaging and intermediately-weighted turbo spin-echo (IWTSE) in relation to the inter-subject (IS) variability.

Parameter	DESS			IWTSE			Ratio IS/IO
	Mean	IS CV% or SD	IOR RMS CV% or SD	Ratio IS/IO	Mean	IS CV% or SD	IOR RMS CV% or SD
Total Size							
ACdAB [mm ²]	1062	20.0	3.77	5.3	1027	20.6	3.41
TA [mm ²]	484	17.2	4.95	3.5	427	13.8	5.83
FA [mm ²]	542	16.3	4.74	3.4	485	15.2	6.11
EA [mm ²]	350	30.7	10.3	3.0	324	29.7	10.9
TotA [mm ²]	1376	19.3	5.22	3.7	1236	16.6	6.74
Th.Me [mm]	2.48	12.5	4.33	2.9	2.48	13.5	6.82
Th.Mav [mm]	6.09	14.5	7.69	1.9	5.82	16.1	6.52
V [mm ³]	1731	25.0	5.44	4.6	1554	23.7	8.39
Wid.Me [mm]	8.30	11.4	5.52	2.1	7.96	12.9	4.03
Wid.Max [mm]	14.8	14.9	5.90	2.5	13.6	16.4	5.28
Total Position							
ACdAB.Cov [%]	40.5	16.4	5.33	3.1	37.0	22.0	4.39
TA.Uncov [%]	14.8	11.3	2.6	4.3	14.3	14.0	1.62
mEx.Me [mm]	1.53	1.50	0.50	2.9	1.60	1.51	0.48
mEx.Max [mm]	6.83	1.50	1.30	1.2	6.04	1.47	0.81
mEx.Cent [mm]	1.96	1.14	0.31	3.7	1.94	1.25	0.39
mEx.Cent5 [mm]	1.92	1.21	0.25	4.9	1.87	1.14	0.27
OvD.Me [mm]	-9.72	-14.9	4.69	3.2	-9.42	-20.5	6.60
OvD.Max [mm]	-2.80	-40.4	34.8	1.2	-3.14	-48.1	42.1
OvD.Cent [mm]	-5.43	-40.6	18.6	2.2	-5.54	-47.8	10.0
OvD.Cent5 [mm]	-5.71	-39.0	14.8	2.6	-5.80	-45.8	10.2
Anterior horn							
Th.Me [mm]	2.25	13.8	3.44	4.0	2.32	10.8	7.81
Th.Mav [mm]	5.99	10.0	4.50	2.2	5.97	11.2	5.10

DESS		IW TSE					
Parameter	Mean	IS CV% or SD	IOR RMS CV% or SD	Ratio IS/IOR	IS CV% or SD	IOR RMS CV% or SD	Ratio IS/IOR
mEx.Me [mm]	2.58	1.20	0.50	2.4	1.09	0.55	2.0
mEx.Max [mm]	5.24	0.70	0.46	1.6	0.79	0.41	1.9
Body							
Th.Me [mm]	2.38	17.2	5.00	3.4	15.7	6.94	2.3
Th.Mav [mm]	5.89	13.9	7.42	1.9	15.0	5.41	2.8
mEx.Me [mm]	1.57	1.60	0.64	2.5	1.40	0.58	2.4
mEx.Max [mm]	5.14	0.91	0.59	1.6	0.85	0.45	1.9
Posterior horn							
Th.Me [mm]	2.62	11.2	6.12	1.8	17.2	9.15	1.9
Th.Mav [mm]	6.27	15.1	10.7	1.4	22.5	8.70	2.6
mEx.Me [mm]	0.08	2.62	1.06	2.5	2.82	0.62	4.5
mEx.Max [mm]	6.71	1.64	1.36	1.2	2.14	2.14	1.0

Values given in italics are standard deviations (SD), all other values are coefficients of variation (CV%)

DESS: double echo steady state; IW TSE: intermediately-weighted turbo spin-echo; IOR: inter-observer reproducibility; RMS: root mean square; IS: inter-subject; ACdAB: area of the cartilage surface [AC] in regions with cartilage covering, and denuded areas of bone (dAB) in areas of full thickness cartilage loss; ACdAB.Cov: area of the ACdAB covered with meniscus in percent; TA: tibial area; FA: femoral area; EA: external area; Th.Me: mean thickness of the meniscus; Th.Mav: maximal average of thickness of the meniscus; TotA: total surfaces of meniscus; V: volume; Wid.Me: mean width of the meniscus; Wid.max: maximal width of the meniscus; TA.Uncov: tibial area of the meniscus not covering the ACdAB in percent; mEx.Me: mean external extrusion; mEx.Max: maximal external extrusion; mEx.Cent: extrusion in the most central slice; mEx.Cent5: extrusion in the central 5 slices reflecting the meniscus body; OvD.Me: mean overlap distance; OvD.Max: maximal overlap distance; OvD.Cent: overlap distance in the most central slice; OvD.Cent5: overlap distance in the central 5 slices reflecting the meniscus body;

Table 2

Inter-observer reproducibility (IOR) for quantitative measures of the lateral meniscus position and size, obtained from coronal multiplanar reconstruction of double echo steady state (DESS) imaging and intermediately-weighted turbo spin-echo (IWTSE) in relation to the inter-subject (IS) variability.

DESS				IWTSE				
Parameter	Mean	IS CV% or SD	IOR RMS CV% or SD	Ratio IS/IO <i>R</i>	Mean	IS CV% or SD	IOR RMS CV% or SD	Ratio IS/IO <i>R</i>
Total Size								
ACdAB [mm ²]	957	20.9	3.53	5.9	879	24.4	5.25	4.6
TA [mm ²]	519	20.5	7.89	2.6	432	31.6	9.62	3.3
FA [mm ²]	600	21.3	9.88	2.2	478	32.4	10.5	3.1
EA [mm ²]	403	24.1	12.0	2.0	359	25.7	7.78	3.3
TotA [mm ²]	1523	21.3	9.41	2.3	1268	29.0	9.06	3.2
Th.Me [mm]	2.66	18.2	5.20	3.5	2.58	19.5	5.92	3.3
Th.Mav [mm]	6.60	14.48	9.18	1.6	6.66	16.8	4.22	4.0
V [mm ³]	2027	33.6	9.90	3.4	1655	37.2	10.0	3.7
Wid.Me [mm]	8.40	12.8	6.50	2.0	7.75	16.4	5.19	3.2
Wid.Max [mm]	12.0	13.6	8.60	1.6	11.7	16.7	5.22	3.2
Total Position								
ACdAB.Cov [%]	52.6	8.91	8.76	1.0	45.9	24.2	5.72	4.2
TA.Uncov [%]	7.20	5.13	1.94	2.6	9.56	11.9	3.3	3.6
mEx.Me [mm]	-1.02	1.94	0.65	3.0	-1.40	2.52	0.73	3.4
mEx.Max [mm]	8.31	1.01	0.91	1.1	6.30	1.86	0.42	4.4
mEx.Cent [mm]	1.49	0.79	0.42	1.9	1.40	0.98	0.25	4.0
mEx.Cent5 [mm]	1.47	0.74	0.28	2.6	1.40	0.90	0.17	5.3
OvD.Me [mm]	-14.6	-14.0	4.77	2.9	-13.5	-24.9	7.31	3.4
OvD.Max [mm]	-6.99	-32.3	15.5	2.1	-6.80	-42.7	15.5	2.8
OvD.Cent [mm]	-8.00	-26.4	13.0	2.0	-8.01	-37.1	21.8	1.7
OvD.Cent5 [mm]	-8.30	-21.2	9.56	2.2	-8.22	-33.3	11.2	3.0
Anterior horn								
Th.Me [mm]	2.30	21.0	9.49	2.2	2.33	25.0	6.62	3.8
Th.Mav [mm]	6.00	19.5	8.06	2.4	6.62	21.1	7.49	2.8

Parameter	DESS			IW TSE			Ratio IS/IO	IS CV% or SD	IO RMS CV% or SD	Ratio IS/IO	IS CV% or SD	IO RMS CV% or SD	Ratio IS/IO
	Mean	IS CV% or SD	IO RMS CV% or SD	Mean	IS CV% or SD	IO RMS CV% or SD							
mEx.Me [mm]	0.01	2.53	1.03	-0.63	2.86	1.00	2.5	2.86	1.00	2.9	2.86	1.00	2.9
mEx.Max [mm]	4.63	2.49	1.96	4.53	2.71	1.59	1.3	2.71	1.59	1.7	2.71	1.59	1.7
Body													
Th.Me [mm]	2.70	20.3	5.85	2.82	20.3	6.17	3.5	20.3	6.17	3.3	20.3	6.17	3.3
Th.Mav [mm]	6.71	14.7	5.80	7.19	14.7	5.40	2.5	14.7	5.40	2.7	14.7	5.40	2.7
mEx.Me [mm]	-1.20	2.21	0.83	-1.58	2.60	0.79	2.7	2.60	0.79	3.3	2.60	0.79	3.3
mEx.Max [mm]	4.20	2.77	1.27	3.58	2.68	0.60	2.2	2.68	0.60	4.5	2.68	0.60	4.5
Posterior horn													
Th.Me [mm]	2.90	18.0	10.0	2.54	20.9	7.17	1.8	20.9	7.17	2.9	20.9	7.17	2.9
Th.Mav [mm]	6.50	15.5	12.8	6.28	18.0	5.48	1.2	18.0	5.48	3.3	18.0	5.48	3.3
mEx.Me [mm]	-1.69	1.38	1.26	-2.35	1.83	0.75	1.1	1.83	0.75	2.4	1.83	0.75	2.4
mEx.Max [mm]	8.00	1.17	1.47	3.36	4.17	1.16	0.8	4.17	1.16	3.6	4.17	1.16	3.6

Abbreviations are the same as in Table 1

Table 3

Agreement between quantitative measures of the medial meniscus position and size obtained from coronal multiplanar reconstruction of double echo steady state (DESS) and intermediately-weighted turbo spin-echo (IWTSE) MRI sequences (n=8).

Parameter	Diff	Diff%	Lower	Upper	Correlation
95%CL					
95% CL (r)					
Total Size					
ACdAB [mm ²]	35.5	3.50	-24.2	95.1	0.99
TA [mm ²]	57.2	13.4	-37.8	152	0.83
FA [mm ²]	57.2	11.8	-30.5	145	0.87
EA [mm ²]	26.1	8.00	-22.0	74.1	0.98
ToT A [mm ²]	140	11.4	-80.0	361	0.92
Th.Me [mm]	0.01	0.22	-0.14	0.15	0.98
Th.Mav [mm]	0.27	4.61	-0.38	0.92	0.94
V [mm ³]	176	11.3	-109	461	0.95
Wid.Me [mm]	0.34	4.27	-0.61	1.29	0.89
Wid.Max [mm]	1.19	8.75	-0.89	3.26	0.89
Total Position					
ACdAB.Cov [%]	3.45	9.31	-1.52	8.42	0.96
TA.Uncov [%]	0.52	3.66	-8.51	9.55	0.96
mEx.Me [mm]	-0.07	-4.42	-1.52	1.38	0.89
mEx.Max [mm]	0.79	13.0	-1.13	2.70	0.79
mEx.Cent [mm]	0.02	1.00	-0.78	0.82	0.95
mEx.Cent5 [mm]	0.05	2.42	-0.55	0.64	0.97
OvD.Me [mm]	-0.30	3.18	-1.90	1.30	0.93
OvD.Max [mm]	0.34	-10.8	-1.78	2.46	0.71
OvD.Cent [mm]	0.11	-2.03	-1.32	1.54	0.97
OvD.Cent5 [mm]	0.09	-1.55	-1.10	1.28	0.99
Anterior horn					
Th.Me [mm]	-0.06	-2.79	-0.43	-0.30	0.81
Th.Mav [mm]	0.02	0.29	-0.94	0.97	0.72
mEx.Me [mm]	0.66	34.14	-0.89	2.20	0.78

Parameter	Diff	Diff%	Lower	Upper	Correlation
			95%CL	95% CL	(r)
mEx.Max [mm]	0.58	12.45	-0.72	1.88	0.63 #
Body					
Th.Me [mm]	-0.08	-3.11	-0.24	0.09	0.98
Th.Mav [mm]	0.04	0.60	-0.64	0.71	0.92
mEx.Me [mm]	-0.38	-19.4	-2.05	1.30	0.85
mEx.Max [mm]	0.13	2.61	-0.40	0.66	0.96
Posterior horn					
Th.Me [mm]	0.06	2.46	-0.41	0.54	0.87
Th.Mav [mm]	0.38	6.39	-0.85	1.60	0.91
mEx.Me [mm]	0.22	-154	-2.56	3.00	0.87
mEx.Max [mm]	1.53	29.5	-2.09	5.15	0.57 #

Diff: difference of the DESS compared with IWTSE (DESS-IWTSE) in absolute units; Diff(%): difference in percent; 95% CL: 95% confidence limits of agreement as described by Bland & Altman (22); r: Pearson correlation coefficient for values obtained from the DESS and from the IWTSE; correlation coefficients marked with # were not significantly different from zero at $p < 0.05$; all other abbreviations are the same as in Table 1

Table 4

Agreement between quantitative measures of the lateral meniscus position and size obtained from coronal multiplanar reconstruction of double echo steady state (DESS) and intermediately-weighted turbo spin-echo (IWTSE) MRI sequences (n=8).

Parameter	Diff	Diff%	Lower	Upper	Correlation
			95%CL	95% CL	(r)
Total Size					
ACdAB [mm ²]	77.7	8.83	-131	286	0.88
TA [mm ²]	87.7	20.3	-97.6	273	0.74
FA [mm ²]	122.7	25.7	-107.	353	0.68
EA [mm ²]	44.4	12.4	-57.	146	0.86
Tot A [mm ²]	255	20.1	-249	759	0.74
Th.Me [mm]	0.08	3.25	-0.28	0.45	0.93
Th.Mav [mm]	-0.06	-0.97	-1.13	1.00	0.88
V [mm ³]	371.8	22.5	-362	1106	0.84
Wid.Me [mm]	0.68	8.79	-0.81	2.17	0.81
Wid.Max [mm]	0.74	6.35	-3.20	4.68	0.42 #
Total Position					
ACdAB.Cov [%]	6.70	14.6	-8.1	21.5	0.87
TA.Uncov [%]	-2.36	-24.7	-17.7	13.0	0.89
mEx.Me [mm]	0.37	-26.7	-1.51	2.26	0.94
mEx.Max [mm]	2.01	31.9	-2.74	6.75	-0.30 #
mEx.Cent [mm]	0.09	6.76	-0.87	1.06	0.87
mEx.Cent5 [mm]	0.08	5.42	-0.67	0.82	0.91
OvD.Me [mm]	-1.11	8.17	-5.26	3.05	0.81
OvD.Max [mm]	-0.19	2.77	-2.18	1.80	0.96
OvD.Cent [mm]	-0.02	0.20	-2.20	2.17	0.96
OvD.Cent5 [mm]	-0.13	1.58	-2.43	2.17	0.96
Anterior horn					
Th.Me [mm]	-0.05	-2.33	-0.66	0.55	0.85
Th.Mav [mm]	-0.20	-2.98	-1.20	0.81	0.93
mEx.Me [mm]	0.64	-102	-2.42	3.70	0.85

Parameter	Diff	Diff%	Lower	Upper	Correlation
			95%CL	95% CL	(r)
mEx.Max [mm]	0.10	2.18	-4.52	4.71	0.61 #
Body					
Th.Me [mm]	-0.16	-5.65	-0.41	0.09	0.98
Th.Mav [mm]	-0.49	-6.74	-1.09	0.12	0.96
mEx.Me [mm]	0.34	-21.2	-1.74	2.41	0.92
mEx.Max [mm]	0.65	18.2	-2.12	3.42	0.87
Posterior horn					
Th.Me [mm]	0.35	13.7	-0.34	1.03	0.79
Th.Mav [mm]	0.22	3.54	-1.38	-1.83	0.72
mEx.Me [mm]	0.66	-28.1	-2.76	4.08	0.46 #
mEx.Max [mm]	4.66	138	-5.03	14.4	-0.48 #

Diff: difference of the DESS compared with IWTSE (DESS-IWTSE) in absolute units; Diff(%): difference in percent; 95% CL: 95% confidence limits of agreement as described by Bland & Altman (22); r: Pearson correlation coefficient for values obtained from the DESS and from the IWTSE; correlation coefficients marked with # were not significantly different from zero at $p < 0.05$; all other abbreviations are the same as in Table 1