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A 3D MRI Study of Changes in the Meniscus of the OA Knee: Data from the Osteoarthritis Initiative

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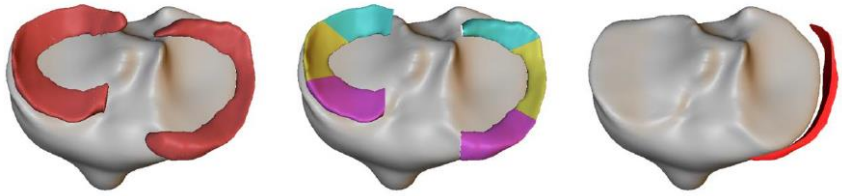
Purpose: The meniscus is crucial to the normal functioning of the knee, and damage or compromise to the meniscus is an important component in the development of knee osteoarthritis (OA). Quantitative measurement of the damage to the meniscus is likely to serve as a useful biomarker of OA progression. In principle, the meniscus is a simple shape; however damage to the meniscus may appear as loss of meniscal volume, extrusion of the meniscus, or a general failure of meniscal competence, resulting in the spreading of the surface. This study employed statistical shape modelling to study a number of potential measures of meniscal deterioration within a one-year period. Additionally, statistical models were used to visualise the areas of the menisci which underwent most change.

Methods: 88 subjects with medial OA were identified from the NIH-OAI dataset. Subjects had K-L scores of 2 or 3; medial JSN > lateral JSN, medial osteophytes and ≥1° of varus mal-alignment: 43 were female. Baseline and 12 month DESS images were manually segmented for the white meniscus of the medial and lateral menisci. Segmenters were blinded to time point but not to subject, using EndPoint software (Imorphics, UK). Segmented contours were converted to 3-D surfaces using a marching quads algorithm, followed by quadratic smoothing. Bone surfaces in the tibia were identified by automated segmentation using active appearance models (AAMs). A dense set of anatomically corresponded points was automatically identified on the tibia bone surfaces, allowing mapping of meniscal change both within and across subjects, by using the tibia as a reference surface. Several measurements were taken (see Figure 1): (a) the total volume of the entire meniscus including the meniscal attachment, (b) the trimmed menisci: the volume of the meniscus, after the attachments are systematically removed, (c) the height (thickness) of the meniscus above the tibia in the anterior, central and posterior sections of meniscal contact, (d) the volume of medial meniscal extrusion beyond the edge of the medial plateau, performed on medial side only, (e) the area of the meniscal window, and the proportion of that window to the area normally covered by cartilage (tAB). Change from baseline for each measure was measured using a paired students t-test. Population maps of the average height of the menisci above the tibia were prepared, and areas of most significant change identified.

Results: Measures of meniscal volume change were mostly not significant, with the exception of the trimmed lateral meniscus. Change in the extruded volume of medial meniscus was also not significant. (Table 1). Change in the size of the medial meniscal window, either measured in mm2 or as a percentage of tAB were highly significant; the lateral meniscal window showed no change. Change in meniscal height above the tibia (meniscal thickness) was significant in the posterior regions of both the lateral and medial menisci, and is visualised in Figure 2. The area which showed the most significant change in height was at the posterior of the medial meniscus.

Conclusions: Quantitative assessment of the menisci is desirable in studies of knee OA, and it is important to select a responsive measure which is biologically meaningful. Measures of meniscal volume and meniscal extrusion are very noisy, due to the many shapes which the damaged meniscus may adopt. Extrusion of menisci in this cohort, measured using careful 3D measurements did not show significant change, which is disappointing. The primary location of meniscal change in the posterior medial meniscus indicates that searching for meniscal extrusion at the most medial point of the tibia may not be the best approach. The most promising measure of meniscal change from this study is the meniscal window, measured either as an area, or as a proportion of the cartilage plate. This measure is very responsive, and should be easier to perform for research groups without access to specialist 3D measurement. Additionally, measurements of meniscal height over the tibia, used in a similar manner to the method used for articular cartilage thickness measurement, appears to provide a promising measure of change.



Complete menisci (medial on right)

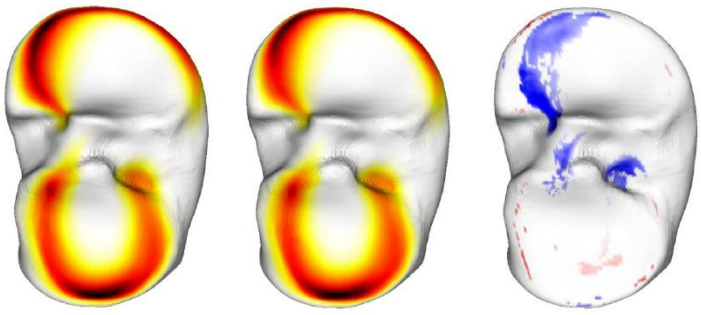
Anterior (magenta), central (yellow) and posterior (cyan) regions of menisci

Medial meniscus extruded volume (red)

Figure 1 - Meniscal measurement strategies: figure show (from left to right), total meniscus volume, sections used for meniscal height (thickness) and extruded volume.

Meniscus	Measure	0 months	12 months	Change	p value	SRM
Medial Meniscus	Total Volume (mm^3)	2566	2522	-43	0.223	-
Lateral Meniscus	Total Volume (mm^3)	2478	2476	-3	0.877	-
Medial Meniscus	Trimmed Volume (mm^3)	2345	2338	-7	0.815	-
Lateral Meniscus	Trimmed Volume (mm^3)	1582	1626	+46	0.002	0.34
Medial Meniscus	Extruded Volume (mm^3)	925	956	+34	0.130	-
Medial Meniscus	Meniscal Window Area (mm^2)	789	814	+25	$<10^{-4}$	-0.51
Lateral Meniscus	Meniscal Window Area (mm^2)	532	532	0	0.888	-
Medial Meniscus	Meniscal Window Area %	67.7	69.3	+1.66	$<10^{-4}$	-0.45
Lateral Meniscus	Meniscal Window Area %	51.7	51.6	+0.1	0.725	-
Medial Meniscus	Anterior Thickness (mm)	0.69	0.70	+0.01	0.755	-
Medial Meniscus	Central Thickness (mm)	0.87	0.83	-0.04	0.050	-0.21
Medial Meniscus	Posterior Thickness (mm)	2.07	1.96	-0.10	0.002	-0.34
Lateral Meniscus	Anterior Thickness (mm)	1.72	1.76	+0.04	0.036	0.23
Lateral Meniscus	Central Thickness (mm)	1.84	1.86	+0.02	0.288	-
Lateral Meniscus	Posterior Thickness (mm)	1.40	1.46	+0.06	0.0005	0.38

Table 1 – Change in various meniscal measures over 12-month period. Change for each measure was assessed using a pairwise Student's t-test. SRM = standardised response mean (mean change/SD of change)



Baseline mean meniscal height above tibia (thickness)

12 month mean meniscal height above tibia (thickness)

Areas of most significant change (blue loss of height)

Figure 2 – Change in meniscal height above the tibia at baseline and 12 months, with most significant area of change shown at right