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Original article

X-ray microtomography-based measurements of meniscal allografts

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A R T I C L E I N F O

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A B S T R A C T

Background: X-ray microcomputed tomography (XMT) is a technique widely used to image hard and soft tissues. Meniscal allografts as collagen structures can be imaged and analyzed using XMT. The aim of this study was to present an XMT scanning protocol that can be used to obtain the 3D geometry of menisci. It was further applied to compare two methods of meniscal allograft measurement: traditional (based on manual measurement) and novel (based on digital measurement of 3D models of menisci obtained with use of XMT scanner).
Hypothesis: The XMT-based menisci measurement is a reliable method for assessing the geometry of a meniscal allograft by measuring the basic meniscal dimensions known from traditional protocol.
Materials and methods: Thirteen dissected menisci were measured according the same principles traditionally applied in a tissue bank. Next, the same specimens were scanned by a laboratory scanner in the XMT Lab. The images were processed to obtain a 3D mesh. 3D models of allograft geometry were then measured using a novel protocol enhanced by computer software. Then, both measurements were compared using statistical tests.
Results: The results showed significant differences ($P < 0.05$) between the lengths of the medial and lateral menisci measured in the tissue bank and the XMT Lab. Also, medial meniscal widths were significantly different ($P < 0.05$).
Discussion: Differences in meniscal lengths may result from difficulties in dissected meniscus measurements in tissue banks, and may be related to the elastic structure of the dissected meniscus. Errors may also be caused by the lack of highlighted landmarks on the meniscal surface in this study.
Conclusion: The XMT may be a good technique for assessing meniscal dimensions without actually touching the specimen.
Level of evidence: Level IV.

1. Introduction

Meniscal allograft transplantation is suggested as a means to normalize contact pressures following meniscectomy. Allografts are obtained from deceased donors. An important criterion determining the use of meniscal allografts is their size [1]. In a standard clinical procedure, dissected meniscal allografts are not imaged before transplantation. Grafts are assessed visually rather than by use of other methods, such as imaging techniques [1,2]. Typically, they are harvested, prepared and sterilized. All dimensions of allografts are measured using a sliding or digital caliper and cotton thread or steel wire (to measure circumference) [3,4]. However, this way of proceeding may cause some errors, such as discrepancies between different tools measurements of the same menisci dimensions. Besides, when measuring circumference, tissue banks use their own tools, which are not standardized. Additionally, when the meniscus is not attached to the tibial plateau, measurement of its length may be hindered due to the fact that it is possible to change the distance between its horns.

The preservation of the allograft's shape and position seems necessary in order to make highly detailed measurements. One technique that can be successfully used to provide high-resolution images of meniscal allografts is X-ray microcomputed tomography (XMT).

XMT is a non-destructive imaging method where individual projections recorded from different angles are used to reconstruct the axial cross-sectional images of the scanned object [5]. Reconstructed images can be synthesized to generate a three-dimensional (3D) image, which facilitates quantitative analysis of the geometric properties of the 3D object without physically

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contacting the samples [6]. XMT can be successfully used for soft tissue imaging [7].

The aim of this study was to present a scanning protocol that could be used to obtain 3D quantitative data of menisci and to compare two methods of meniscal allograft measurement. One method takes a "traditional" measurement of the menisci using standard instruments, and the other uses XMT-based visualization and computer programs.

2. Materials and methods

2.1. Preliminary test

All of the menisci were received from the Katowice Tissue Bank (Poland). Thirteen menisci in total were harvested from cadaveric knees (male menisci only, mean age 42.4, 30–61 years, six lateral and seven medial menisci). All menisci were harvested without bone plugs. They were cleaned, packaged in plastic bags and then frozen below −40 °C. The donor's meniscal qualification test was performed according to Polish Transplantation Act DU2005.169.1411 [8].

One of the 13 menisci was chosen randomly to find out which parameters and conditions should be used to obtain the best image quality. A right lateral meniscus was scanned using various parameters and conditions. The scanning was performed by XMT scanner Phoenix v|tome|x s (GE Sensing & Inspection Technologies, Wunstorf, Germany).

Based on the authors' knowledge concerning XMT scanning of biological samples with low absorption of X-ray radiation, three configurations of scanning conditions and parameters were established. First, the meniscus was scanned in a plastic bag filled with solution of physiological saline. Then the meniscus was drained and scanned in a sterile plastic cup. The next scanning was performed after placing it in a new sterile plastic bag, but this time without fluid. All scanning parameters used in these three cases are shown in Table 1. The tested meniscus was scanned after thawing at room temperature.

After XMT scanning, the acquired two-dimensional projections were reconstructed using manufacturer software for data reconstruction (Datos 2.0). Then 3D models of each dataset were performed using a free program for data visualization (Drishti ver. 2.3.3) [9] to evaluate aspects such as problems with data segmentation and the influence of scanning conditions on the fidelity of shapes. Scanning in fluid gave the worst results and created many artifacts, which were difficult to remove using standard segmentation tools. This option was rejected as not useful for this study. The use of a plastic cup provided very good meniscal surface images, but there was a problem with segmentation of the border between the plastic cup's bottom and the meniscus body. The best option for further investigation was scanning a thawed meniscus in a plastic bag with no fluid. Plastic foil was thinner than the plastic cup and thus made the segmentation process easier.

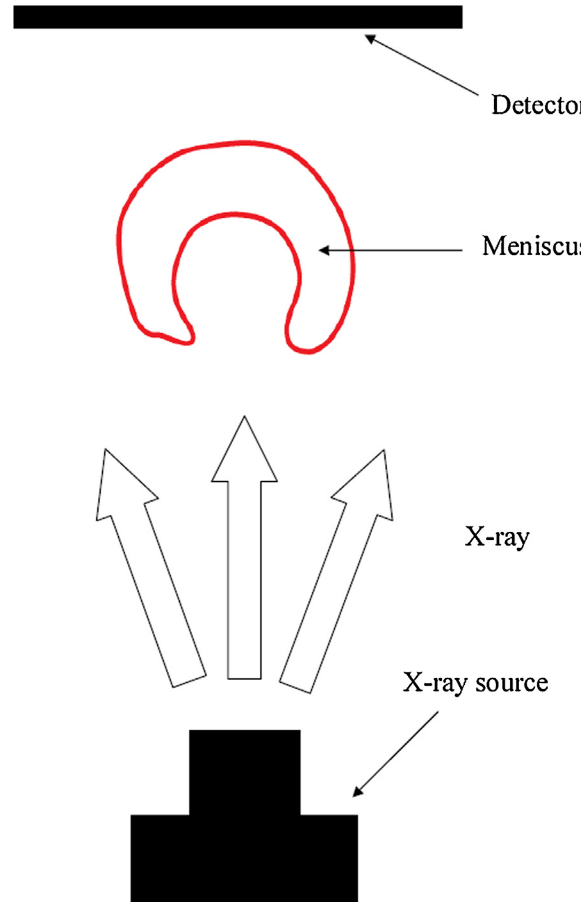

Fig. 1. Meniscus placement and orientation in XMT scanner.

2.2. Final test

2.2.1. Preparation of meniscal allografts

Before the scanning, the same thawing procedure was used for all investigated menisci. Menisci were thawed at room temperature for 30 minutes. Then the menisci were XMT-scanned without being removed from the plastic bag, and were put into the scanner in front of the X-ray source – with the middle of the meniscal body perpendicular to the X-ray source (Fig. 1).

2.2.2. XMT scanning parameters used in the final test

XMT scanning was performed using the scanning parameters chosen during the preliminary test (Table 2). Due to size differences between menisci, higher voxel size for all medial menisci was used.

2.2.3. Data reconstruction, segmentation and 3D visualization

After completion of the XMT scanning process, image reconstruction was performed using the same software as during the

Table 1
XMT scanning parameters established during preliminary test.

Parameters	The meniscus in plastic bag with fluid	The drained meniscus in plastic cup	The meniscus in plastic bag without fluid
Voltage (kV)	230	130	130
Current (μA)	200	130	130
Power (W)	46.0	16.9	16.9
Number of projections	1000	1000	1000
Resolution (μm)	29.492	29.492	29.492
Timing (ms)	131	131	131
Scan time (s)	286	286	286