Use of magnetic resonance imaging to determine laterality of meniscal size in healthy volunteers

Mohammad Hamdan, Bassem Haddad, Ula Isleem*, Rami Yaghi, Salsabiela Bani Hamad, Rahaf Al-Balkhi, Rami Afifi, Saif Aldeen Alryalat, Fadi Hadidi, Aws Khanfar, Amjad Shatarat

1 Jordan University Hospital, Department of Orthopaedic Surgery, Queen Rania Street, Amman, Jordan, 2 University of Jordan, Faculty of Medicine, Queen Rania Street, Amman, Jordan, 3 Jordan University Hospital, Department of Ophthalmology, Queen Rania Street, Amman, Jordan, 4 University of Jordan, Department of Anatomy, Queen Rania Street, Amman, Jordan

* ulaisleem289@gmail.com

Abstract

Introduction

The menisci are responsible for several functions. They are shock absorbers during dynamic loading on the knee and provide a broader surface area on which to distribute stress evenly to the tibia and femur. These functions allow for smoother movement and greater stability of the knee joint. Meniscal injury can be a great impediment to the function of the knee. Therefore, in the case of meniscal injury, our main concern is the relief of patient symptoms, followed by consequent restoration of meniscal function to the greatest of our ability.

To prevent the long terms effects of a meniscectomy, meniscal allograft transplantation (MAT) was developed. The potential of using the size of the contralateral healthy menisci, to determine the size of the menisci to be replaced, will be discussed.

Methods

Knee MRIs done on healthy patients in the past 5 years were reviewed. Magnetic Resonance Imaging was performed using a 3-T scanner. Each individual was examined with knee joints in full extension. Measurements were performed two separate times, two weeks apart. A mean of three measurements was made during each session to reduce error.

Thirty-eight normal bilateral knee joints MRIs remained (16 males, 22 females). Participants were sampled from the institutional Picture Archiving and Communication System (PACS). Age, gender, and the medial meniscal and lateral meniscal size of both knees were recorded. The laterality of the menisci was compared between both knees in each patient.

Results

A total of 38 patients were included in this study, with a mean age of 37.39 (±9.50) years. They were 16 (42.1%) men and 22 (57.9%) women. We didn't find any significant difference
in the mid-coronal section between left and right knees meniscal measurements. None of the measurements were significantly different between men and women. There was no significant difference in the medial mid-sagittal section or lateral mid-sagittal section between left and right knee meniscal measurements.

Conclusion
The results obtained in this study may support the use of MRI of the bilateral knee to obtain an appropriately sized allograft.

Introduction
The menisci are crescent-shaped fibrocartilage structures which cover around two-thirds of their corresponding tibial plateau, on the medial and lateral aspects of the knee. The horns of the medial meniscus usually insert into the flat intercondylar region of the tibial plateau anteriorly, and just anterior to the insertion of the posterior cruciate ligament, posteriorly. The anterior horn of the lateral meniscus attaches on the tibia, just posterior and lateral to the anterior cruciate ligament, while the posterior horn attaches between the posterior cruciate ligament and the posterior horn on the medial meniscus [1].

The menisci are responsible for several functions. They are shock absorbers during dynamic loading on the knee and provide a broader surface area on which to distribute stress evenly to the tibia and femur. These functions allow for smoother movement and greater stability of the knee joint [2]. These functions can be attributed to the composition of the menisci, primarily type 1 collagen fiber bundles, which give them their characteristic tensile strength and stiffness [3]. For these reasons, meniscal injury can be a great impediment to the function of the knee. Therefore, in the case of meniscal injury, our main concern is the relief of patient symptoms, followed by consequent restoration of the meniscal function to the greatest of our ability.

In the setting of degenerative or irreparable tears in the meniscus, a total or subtotal meniscectomy may be the only definitive treatment.

To prevent the long terms effects of a meniscectomy, meniscal allograft transplantation (MAT) was developed. A meta-analysis study performed in 2014, showed that all studies describing MAT demonstrated postoperative clinical improvement in patients who underwent this procedure, regardless of the type. It also showed that the most common mode of imaging was radiographic. [4] In this study, bilateral Magnetic Resonance Imaging (MRI) of the knees were used to compare the laterality of the menisci in both knees. The potential of using the size of the contralateral healthy menisci, to determine the size of the menisci to be replaced, will be discussed.

Materials and methods
After acquiring the approval of the Institutional Review Board (IRB) of the Jordan University Hospital and the University of Jordan-Faculty of Medicine, knee MRIs done on healthy patients in the past 5 years at Jordan University Hospital were reviewed. Informed consent was waived by both IRBs due to the fact that the images did not include identifying patient information. All images were received with anonymization of the patient name and file number. All
images followed a standard protocol. Magnetic Resonance Imaging was performed using a 3-T scanner.

Coronal images were taken parallel to the axis of the tibial plateau. For the T2 weighted fat-suppression coronal STIR cuts, the repetition time was 4,330 ms, an echo time of 20.0 ms, a slice thickness of 3.0 mm, and an interslice gap of 0.5 mm. Sagittal images were taken perpendicular to the tibial plateau. For the T2 weighted fat suppression sagittal STIR cuts, the repetition time was 4,412 ms, and echo time of 21 ms, a slice thickness of 3.0 mm, and an interslice gap of 0.4 mm. The field of view for both types of cuts was 16 × 16 cm.

Each individual was examined with knee joints in full extension. By using mid-coronal images, the medial meniscus and lateral meniscus length, width, and lateral eminence were measured (Fig 1). The distances from the medial eminence to the meniscocapsular junction of the MM and from the lateral eminence to the meniscocapsular junction of the LM were also measured. Mid-sagittal images were used to measure the height and width of the anterior and posterior horns of each meniscus, as well as the whole length spanning from the most anterior margin of each meniscus to the most posterior (Figs 2 & 3). Measurements were performed two separate times, two weeks apart. A mean of three measurements was made during each session to reduce error.

**Inclusion and exclusion criteria**

Only patients who had normal bilateral knee MRIs were selected. Individuals under 18 and above 50 years were excluded from the study, in addition to those who had a history of meniscal tear or repair. Patients with pathologies that were suspected to reduce the accuracy of these
measurements were also excluded. Such pathologies included a discoid meniscus, fractures of the lower limb, rheumatoid arthritis, trauma of the knee with associated bone bruising, osteoarthritis of the knee, and signs of degeneration.

Thirty-eight normal bilateral knee joints MRIs remained (16 males, 22 females). Participants were sampled from the institutional Picture Archiving and Communication System (PACS). Age, gender, and medial meniscal and lateral meniscal size of both knees were recorded. The laterality of the menisci was compared between both knees in each patient.

**Statistical analysis**

SPSS version 21.0 (Chicago, USA) was used in our analysis. The mean (± standard deviation) was utilized to describe continuous variables (i.e. age and measurements). Count (frequency) was utilized to describe other nominal variables (i.e. gender). Paired-sample t-test was used to compare right and left meniscal measurements. An independent sample t-test was performed to analyze the mean difference between measurements and gender, and data were presented in mean (95% confidence interval (CI)). The correlation between each measurement with age was determined using Pearson’s correlation coefficient. All underlying assumptions were met unless otherwise indicated. We adopted a p-value of 0.05 as a significant threshold.

**Results**

A total of 38 patients were included in this study, with a mean age of 37.39 (±9.50) years. They were 16 (42.1%) men and 22 (57.9%) women.
We didn’t find any significant difference in the mid-coronal section between left and right knees meniscal measurements. The mean difference in measurements ranged from as low as 0.009 (95% CI -0.38 to 0.36) in MMH to as high as 0.44 (95% CI -0.59 to 0.50) in LMW. Table 1 details the measurements in the mid-coronal view. None of the measurements correlated with age or gender.

There was no significant difference in the medial mid-sagittal section between left and right knee meniscal measurements. The mean difference in measurements ranged from as low as 0.04 (95% CI -0.46 to 0.39) in posterior MMH to as high as 0.39 (95% CI -0.07 to 0.85) in anterior Medial Meniscal Width (MMW). Table 2 details the measurements in the lateral mid-sagittal view. We found that age significantly (p = 0.043) correlated with left posterior MMW with a negative correlation coefficient of -0.303. None of the measurements were significantly different between men and women.

There was no significant difference in the lateral mid-sagittal section between left and right knee meniscal measurements. The mean difference in measurements ranged from as low as 0.13 (95% CI -0.62 to 0.35) in posterior Lateral Meniscal Height (LMH) to as high as 0.96 (95% CI -0.20 to 2.13) in Lateral Meniscal (LH) whole length. Table 3 details the measurements in the lateral mid-sagittal view. We found that men have significantly (p = 0.011) higher right LM anterior height compared to women with a mean height difference of 0.52 (95% CI -0.27 to 1.31). Men have also had significantly (p = 0.014) higher right LM anterior width compared to women with a mean width difference of 1.86 (95% CI 0.80 to 2.91). Age did not correlate with any of the measurements.
Discussion

MAT surgery is becoming the preferred treatment for symptomatic patients with a partial or total loss of the meniscus. These procedures are utilized to delay the early development of knee degenerative changes after total or partial meniscectomies. The classic indications for these surgeries include the absence of advanced degenerative changes in the knee and the correction of any concomitant pathology such as malalignment, localized osteochondral defect, or instability. However, these indications are being expanded to include patients with more prominent degenerative changes after studies have shown that 73.5% of patients can resume sporting activities postoperatively. There is, however, a 22.4% failure rate for the MATs [5].

Failure of meniscal allograft surgery is commonly caused by extrusion or tearing. Extrusion may become more likely if the menisci are oversized. On the other hand, an undersized

Table 1. Mean differences and the significance of the differences between left and right knee meniscal measurements in mid-coronal view. The minus sign here means that the left was more than the right.

| Pair | Right | Mean   | Standard Deviation | Mean difference | 95% Confidence interval | P value |
|------|-------|--------|--------------------|-----------------|-------------------------|---------|
|      | MMH   | 5.0371 | 1.12324            | -0.009          | -0.38 - 0.36            | 0.96    |
|      | LMMH  | 5.0461 | 0.90842            |                 |                         |         |
|      | MMW   | 8.4032 | 2.60581            | 0.54            | -0.48 - 1.56            | 0.29    |
|      | LMMW  | 7.8658 | 2.41042            |                 |                         |         |
|      | MM-MEW| 28.5524| 4.57837            | -0.60           | -1.49 - 0.29            | 0.18    |
|      | LMM-MEW| 29.1539| 3.99853           |                 |                         |         |
|      | LMH   | 5.6116 | 1.22198            | -0.12           | -0.99 - 0.33            | 0.33    |
|      | LLMH  | 5.7316 | .93774             |                 |                         |         |
|      | LMW   | 9.7968 | 2.89690            | 0.10            | -0.45 - 0.66            | 0.73    |
|      | LLMW  | 9.6992 | 2.85743            |                 |                         |         |
|      | LM-LEW| 30.2611| 3.83217            | 0.23            | -0.45 - 0.90            | 0.50    |
|      | LLM-LEW| 30.0355| 3.87666         |                 |                         |         |

MMH: Medial Meniscal Height; MMW: Medial Meniscal Width; MM-MEW: Medial Meniscal Medial Eminence Width; LMH: Lateral Meniscal Height; LMW: Lateral Meniscal Width; LM-LEW: Lateral Meniscal Lateral Eminence Width

Table 2. Mean differences and the significance of the differences between the left and right knee meniscal measurements in the medial mid-sagittal view.

| Pair | Right | Mean   | Standard Deviation | Mean difference | 95% Confidence interval | P value |
|------|-------|--------|--------------------|-----------------|-------------------------|---------|
|      | Anterior MMH | 4.9655 | 1.04964            | 0.24            | -0.09 - 0.56            | 0.17    |
|      | Anterior MMH | 4.7297 | 1.12912            |                 |                         |         |
|      | Anterior MMW | 8.6745 | 1.26929            | 0.39            | -0.07 - 0.85            | 0.09    |
|      | Anterior MMW | 8.2837 | 1.77826            |                 |                         |         |
|      | Posterior MMH | 6.0374 | 1.33294            | -0.04           | -0.46 - 0.39            | 0.89    |
|      | Posterior MMH | 6.0726 | 1.56879            |                 |                         |         |
|      | Posterior MMW | 13.7434| 3.39383            | -0.11           | -0.96 - 0.74            | 0.80    |
|      | Posterior MMW | 13.8518| 3.57912            |                 |                         |         |
|      | MM Whole length | 41.7797| 4.71250            | -0.25           | -1.29 - 0.78            | 0.62    |
|      | MM Whole length | 42.0345| 4.90259            |                 |                         |         |

MMH: Medial Meniscal Height; MMW: Medial Meniscal Width
Meniscal allograft may result in tears, as a result of increased contact pressures [6]. Therefore, the importance of having an accurate way to measure meniscal allografts is to preserve function and reduce failure rates of MAT.

To determine the sizing of a meniscal allograft, preoperative imaging measuring the bony landmarks and points of insertion of soft tissue can be used. The standard method for determining the MAT size is the method developed by Pollard et al depending on x-ray measurements with a reported mean error of estimating the size of the native meniscus of less than 8.4% [7]. However, to determine the size of the allograft using this method, preoperative imaging measuring the bony landmarks and points of insertion of soft tissue are used. This method, however, may yield inaccuracies as a result of errors in magnification and incorrect identification of landmarks [5]. Studies have suggested that to preserve the anatomic and biochemical limitations of the original meniscus, the size should be accurate to at least 5mm [8]. Another study proposed a 10% limitation for the difference between the original meniscus and the allograft [9]. This limitation of size difference and the need for more accurate sizing of the allograft may justify the use of this more costly method of imaging, compared to the use of x-ray imaging. In addition, variations in points of insertion of soft tissue can be better viewed using MRI.

In our study, in the mid-coronal view, the greatest difference in size between the right and left menisci was 0.44 mm. When noting the mean differences between the left and right knee meniscal measurements in the medial mid-sagittal view, the mean differences between the menisci in both knees ranged from 0.04 to 0.39 mm. In the lateral mid-sagittal view, the differences in size ranged from 0.13 to 0.96 mm. The p-values for all these measurements were all over 0.05, with a confidence interval of 95%. These results correspond to those found in similar studies [9] [10] [11] [12]. The results obtained in this study support the use of MRI of the contralateral knee to obtain an appropriately sized allograft.

Of the limitations of this study was the sample size of 38 participants. If this study included a larger sample size, then the significance of the study could be enhanced. In addition, using contralateral knee MRI measurements in a knee with pathology may not be a useful or accurate method of determining meniscal size. Besides, the use of MRI measurements carries a much higher cost than the use of x-ray imaging, which may outweigh the potential benefits of this method. However, this is one of few studies studying the use of these measurements in the Middle Eastern patient population.

Table 3. Mean differences and the significance of the differences between left and right knee meniscal measurements in the lateral mid-sagittal view.

| Pair   | Right Anterior LMH | Left Anterior LMH | Mean difference | 95% Confidence interval | P value |
|--------|-------------------|------------------|----------------|-------------------------|---------|
| 1      | 4.7321            | 1.33722          | -0.18          | -0.51 - 0.15             | 0.31    |
| 2      | 4.9126            | 1.43220          | -0.13          | -0.62 - 0.35             | 0.46    |
| 3      | 6.2174            | 1.57665          | 0.15           | -0.27 - 0.58             | 0.64    |
| 4      | 6.0655            | 1.19097          | -0.13          | -0.62 - 0.35             | 0.46    |
| 5      | 9.5929            | 2.10319          | -0.13          | -0.62 - 0.35             | 0.46    |

LMH: Lateral Meniscal Height; LMW: Lateral Meniscal Width; LM: Lateral Meniscal

https://doi.org/10.1371/journal.pone.0228040.t003
Conclusion
The use of MRI to determine the size of contralateral meniscus was shown to be an accurate method of measurement. Due to the fact that failure of MAT is usually due to errors in sizing, this method may significantly improve the outcomes of this surgery, and therefore, justify the higher cost of this modality of imaging.

Supporting information
S1 File. MRI Measurements of the Knee. The measurements taken from the MRIs of the knees of healthy patients in cm.

Author Contributions

Conceptualization: Mohammad Hamdan, Bassem Haddad, Ula Isleem, Amjad Shatarat.
Data curation: Bassem Haddad, Rami Yaghi, Salsabiela Bani Hamad, Rahaf Al-Balkhi, Rami Afifi.
Formal analysis: Saif Aldeen Alryalat.
Funding acquisition: Mohammad Hamdan, Bassem Haddad, Ula Isleem.
Investigation: Bassem Haddad, Ula Isleem, Rami Yaghi, Salsabiela Bani Hamad, Rahaf Al-Balkhi, Amjad Shatarat.
Methodology: Ula Isleem, Rami Yaghi, Rahaf Al-Balkhi, Rami Afifi.
Project administration: Mohammad Hamdan, Bassem Haddad, Fadi Hadidi.
Resources: Rami Yaghi, Fadi Hadidi, Aws Khanfar, Amjad Shatarat.
Supervision: Fadi Hadidi, Aws Khanfar.
Writing – original draft: Ula Isleem.
Writing – review & editing: Ula Isleem.

References
1. Fox AJ, Wanivenhaus F, Burge AJ, Warren RF, Rodeo SA. The human meniscus: a review of anatomy, function, injury, and advances in treatment. Clinical Anatomy. 2015 Mar; 28(2):269–87. https://doi.org/10.1002/ca.22456 PMID: 25125315
2. Walker PS, Arno S, Bell C, Salvadore G, Borukhov I, Oh C. Function of the medial meniscus in force transmission and stability. Journal of biomechanics. 2015 Jun 1; 48(8):1383–8. https://doi.org/10.1016/j.jbiomech.2015.02.055 PMID: 25888013
3. Danso EK, Oinas JM, Saarakkala S, Mikkonen S, Töyräs J, Korhonen RK. Structure-function relationships of human meniscus. Journal of the mechanical behavior of biomedical materials. 2017 Mar 1; 67:51–60. https://doi.org/10.1016/j.jmbbm.2016.12.002 PMID: 27987426
4. Rosso F, Biscicchia S, Bonasia DE, Amendola A. Meniscal allograft transplantation: a systematic review. The American journal of sports medicine. 2015 Apr; 43(4):998–1007. https://doi.org/10.1177/0363546514536021 PMID: 24928760
5. Stone KR, Freyer A, Turek T, Walgenbach AW, Wadhwa S, Crues J. Meniscal sizing based on gender, height, and weight. Arthroscopy: The Journal of Arthroscopic & Related Surgery. 2007 May 1; 23(5):503–8.
6. Prodromos CC, Joyce BT, Keller BL, Murphy BJ, Shi K. Magnetic resonance imaging measurement of the contralateral normal meniscus is a more accurate method of determining meniscal allograft size than radiographic measurement of the recipient tibial plateau. Arthroscopy: The Journal of Arthroscopic & Related Surgery. 2007 Nov 1; 23(11):1174–9.
7. Pollard ME, Kang Q, Berg EE. Radiographic sizing for meniscal transplantation. Arthroscopy: The Journal of Arthroscopic & Related Surgery. 1995 Dec 1; 11(6):684–7.

8. Shaffer B, Kennedy S, Klimkiewicz J, Yao L. Preoperative sizing of meniscal allografts in meniscus transplantation. The American journal of sports medicine. 2000 Jul; 28(4):524–33. https://doi.org/10.1177/03635465000280041301 PMID: 10921644

9. Dienst M, Greis PE, Ellis BJ, Bachus KN, Burks RT. Effect of lateral meniscal allograft sizing on contact mechanics of the lateral tibial plateau: an experimental study in human cadaveric knee joints. The American journal of sports medicine. 2007 Jan; 35(1):34–42. https://doi.org/10.1177/0363546506291404 PMID: 16923825

10. Yoon JR, Jeong HI, Seo MJ, Jang KM, Oh SR, Song S, Yang JH. The use of contralateral knee magnetic resonance imaging to predict meniscal size during meniscal allograft transplantation. Arthroscopy: The Journal of Arthroscopic & Related Surgery. 2014 Oct 1; 30(10):1287–93.

11. dos Santos Netto A, Kaleka CC, Toma MK, Silva JC, Cury RD, Fucs PM, et al. Should the meniscal height be considered for preoperative sizing in meniscal transplantation?. Knee Surgery, Sports Traumatology, Arthroscopy. 2018 Mar 1; 26(3):772–80. https://doi.org/10.1007/s00167-017-4461-6 PMID: 28233022

12. Kaleka CC, Netto AS, Silva JC, Toma MK, de Paula Leite Cury R, Severino NR et al. Which are the most reliable methods of predicting the meniscal size for transplantation?. The American journal of sports medicine. 2016 Nov; 44(11):2876–83. https://doi.org/10.1177/0363546516653203 PMID: 27422172