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Musculoskeletal Imaging ORIGINAL ARTICLE

Feasibility of a double-bundle anterior cruciate ligament reconstruction can be predicted by anthropometric and skeletal parameters: An MR imaging study

Evangelia E. Vassalou[1,2], Georgios Tzoanos[3], Michael Hantes[4], Nikolaos Tsavalas[5,6], Apostolos Karantanas[2,7]

[1]*Department of Medical Imaging, Sitia General Hospital, Greece*
[2]*Department of Medical Imaging, Heraklion University Hospital, Crete, Greece*
[3]*Consultant Orthopaedic Surgeon, Tzoanos Sports Clinic, Heraklion, Crete, Greece*
[4]*Department of Orthopaedic Surgery, Larissa University Hospital, Greece*
[5]*Consultant Radiologist, Iasis Private Hospital, Chania, Greece*
[6]*Consultant Radiologist, Asklepieion Private Hospital, Heraklion, Crete, Greece*
[7]*Department of Radiology, University of Crete*

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ABSTRACT

Purpose: To evaluate the rate of anatomic restrictions on MR imaging which may prevent anterior cruciate ligament (ACL) double-bundle reconstruction (DBr) technique. The hypothesis was that some patients may not meet the criteria for this procedure.

Material and Methods: From November 2013 to June 2016, 680 consecutive knee magnetic resonance (MR) imaging studies, from 656 patients (322 males and 334 females; age range 2-85 years; mean age 44.5 years; SD ± 18.8) were retrospectively reviewed. Exclusion criteria included: (i) pres-

CORRESPONDING AUTHOR, GUARANTOR

Corresponding author: Evangelia E. Vassalou
Department of Medical Imaging, Heraklion University Hospital, Voutes 71110, Heraklion, Crete, Greece; Sitia General Hospital, 72300, Greece,
E-mail: vassalou.e@hotmail.com
Guarantor: Apostolos H. Karantanas
Department of Medical Imaging, Heraklion University Hospital, Voutes 71110, Heraklion, Crete, Greece, E-mail: akarantanas@gmail.com

ence of non-anatomic parameters (open physes, severe osteoarthritic changes, multiligamentous injuries), (ii) previous ACL reconstruction and (iii) incomplete MR imaging examination. Following the exclusion of 128 patients (139 MR imaging studies), 528 patients (541 MR imaging studies) comprised the study group. The femoral notch width (FNw) was measured on coronal T1-w whereas the ACL tibial insertion site (TIS) length was measured on sagittal fat-suppressed proton density MR images. A TIS length and an FNw of less than 14 mm and 12 mm respectively were regarded abnormal.

Results: Ninety-eight patients (18.5%) proved to be improper candidates for DBr technique. Ninety of them (91.8%) were not suitable due to short TIS length, 8 (8.2%) due to narrow FNw and 2 (2%) due to coexistence of both the above anatomic limitations. The number of female patients showing anatomic restrictions was significantly higher compared to that of male patients ($p<0.00001$).

Conclusions: A significant number of patients do not meet the criteria for DBr technique due to anatomic restrictions. MR imaging can identify them pre-operatively and prevent failure of a demanding procedure.

Level of evidence: III, retrospective comparative study

KEY WORDS

anterior cruciate ligament; double-bundle reconstruction; single bundle reconstruction; MR imaging; knee joint

Introduction

Our understanding of the anatomy and function of the anterior cruciate ligament (ACL) has evolved continuously during the last years [1]. Advancing knowledge has led to the development of modern techniques that aim in anatomic reconstruction of the native ligament. Anatomic ACL reconstruction is defined as the functional restoration of the ligament with regard to its native dimensions, collagen orientation and insertion sites [2]. It represents a common procedure, with an estimated 100,000 procedures performed per year in the United States alone [3].

ACL consists of two bundles, namely the anteromedial (AMb) and posterolateral (PLb). These bundles exhibit variable tension, i.e. the AMb tightens with knee joint flexion and relaxes with extension whereas the PLb laxes with flexion and tightens with extension. In addition, the AMb acts as a restraint to anterior translation of tibia during flexion whereas the PLb prevents anterior tibial translation during extension but also prevents internal rotation at 90° of flexion. According to a recent meta-analysis, it has been shown that no more than 60% of patients make a full recovery after the traditional single-bundle reconstruction (SBr) of the ACL [4]. An explanation for this rate of failure may be related to the fact that as SBr reconstructs only a single ACL bundle, it impairs restoring the ability for rotational stability and consequently recovery of the complex functional anatomy of the intact ACL.

Current trends in ACL reconstruction have been towards anatomical reconstruction of the native size and location of the ACL regarding both the AMb and PLb [5, 6]. In this regard, double-bundle reconstruction (DBr) technique has gained popularity. Patient's native anatomy, individualised approach, placement of the tunnels and grafts into native footprints and proper tensioning are important prerequisites for a positive clinical outcome [7].

Magnetic resonance (MR) imaging has been shown to play an important role in the preoperative planning as it can identify anatomic restrictions in performing DBr technique [8]. In detail, a tibial insertion site (TIS) smaller than 14 mm and a femoral notch width (FNw) of less than 12 mm in diameter have been reported as contraindications for performing a DBr technique [2, 9, 10]. In addition, the presence of open physes, severe osteoarthritis, bone bruising and multiligamentous injuries represent additional contraindications for DBr [11]. However, to the best of our knowledge, there are limited data on the preoperative utilisation of MR imaging in assessing the TIS and FNw diameter [10, 12].

The hypothesis of the present study was that a subgroup of patients would not meet the criteria for per-

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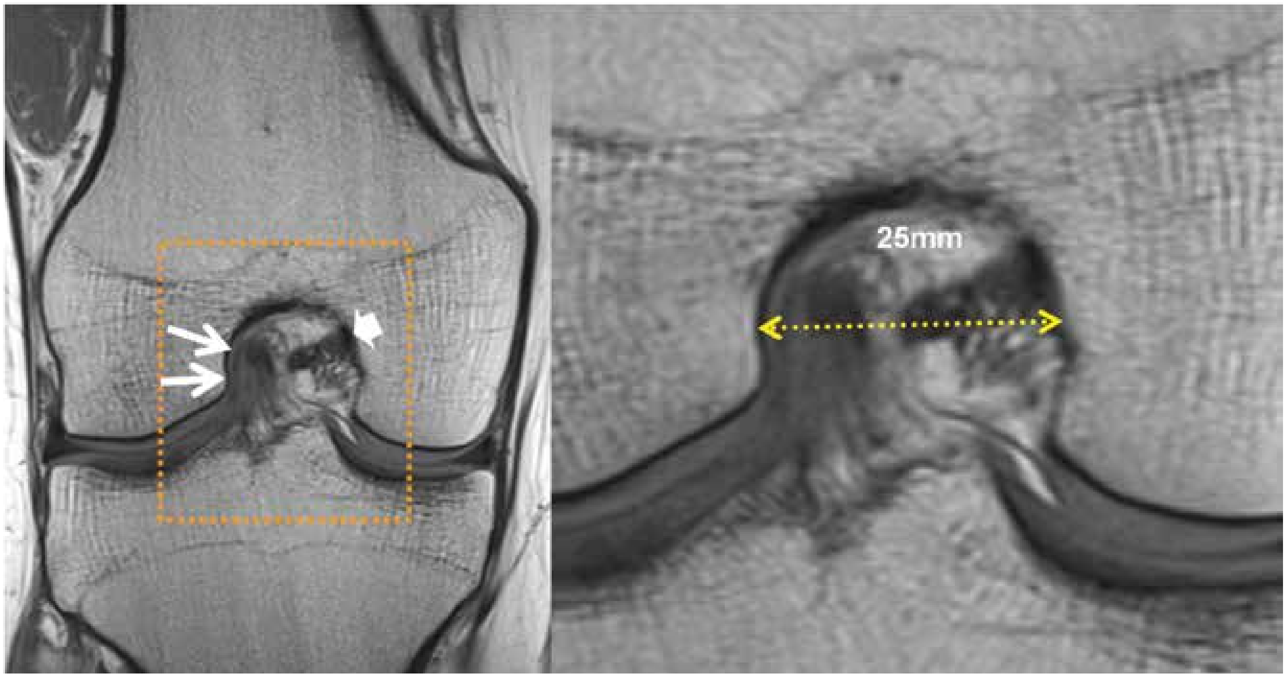

Fig. 1. *Slice selected for femoral notch width measurements (mid-coronal T1-weighted SE image) at the level of proximal decussation of the two ligaments: anterior cruciate ligament is longitudinal (arrows) and the posterior cruciate ligament is seen on end (short arrow).*

forming a DBr technique of a torn ACL. Our purpose was to evaluate the incidence of anatomic restrictions on MR imaging, by means of TIS and the FNw length, which may be used to identify the subgroup of patients which do not represent suitable candidates for a DBr technique. In addition, any significant difference regarding the incidence of these restrictions between males and females was investigated.

Material and Methods

Patients

No ethical committee approval was required, since the study was retrospective. A routine written consent for each patient was obtained, which is readily available.

From November 2013 to June 2016, 680 consecutive knee MR imaging studies from 656 patients (322 males and 334 females; age range 2-85 years; mean age 44.5 years; SD ± 18.8) with various knee pathologies were retrospectively reviewed. Exclusion criteria included: (i) presence of non-anatomic parameters (open physes, severe osteoarthritic changes, multiligamentous injuries), (ii) previous ACL reconstruction and (iii) incomplete MR imaging examination. Severe arthritic changes were described as grade 3 or greater according to the International Cartilage Regeneration & Joint Preservation Society (ICRS) classification system [13], while multiligamentous injuries were classified according to Schenck classification [14]. Based on the above criteria 128 patients (139 MR imaging studies) were excluded from the study. Of the excluded patients, 56 patients (38 males and 18 females; age range 2-20 years; mean age 13.7 years) were found to have open physes, 53 (19 males and 34 females; age range 37-81 years; mean age 64.4 years) severe osteoarthritic changes, 5 patients (4 males and 1 female; age range 22-37 years; mean age 28.6 years) suffered multiligamentous injuries and 4 patients (4 males; age range 26-35 years; mean age 29 years) had previous ACL reconstruction. Eleven patients with incomplete MR imaging examinations were also excluded from the study. Consequently, 541 MR imaging studies from 528 patients (253 males and 275 females; age range 14-85 years; mean age 45.9 years; SD ± 16.6) comprised our study group.

Imaging

All MR examinations were performed on a 1.5 Tesla scanner (Vision Hybrid, Siemens Erlagen, Germany)

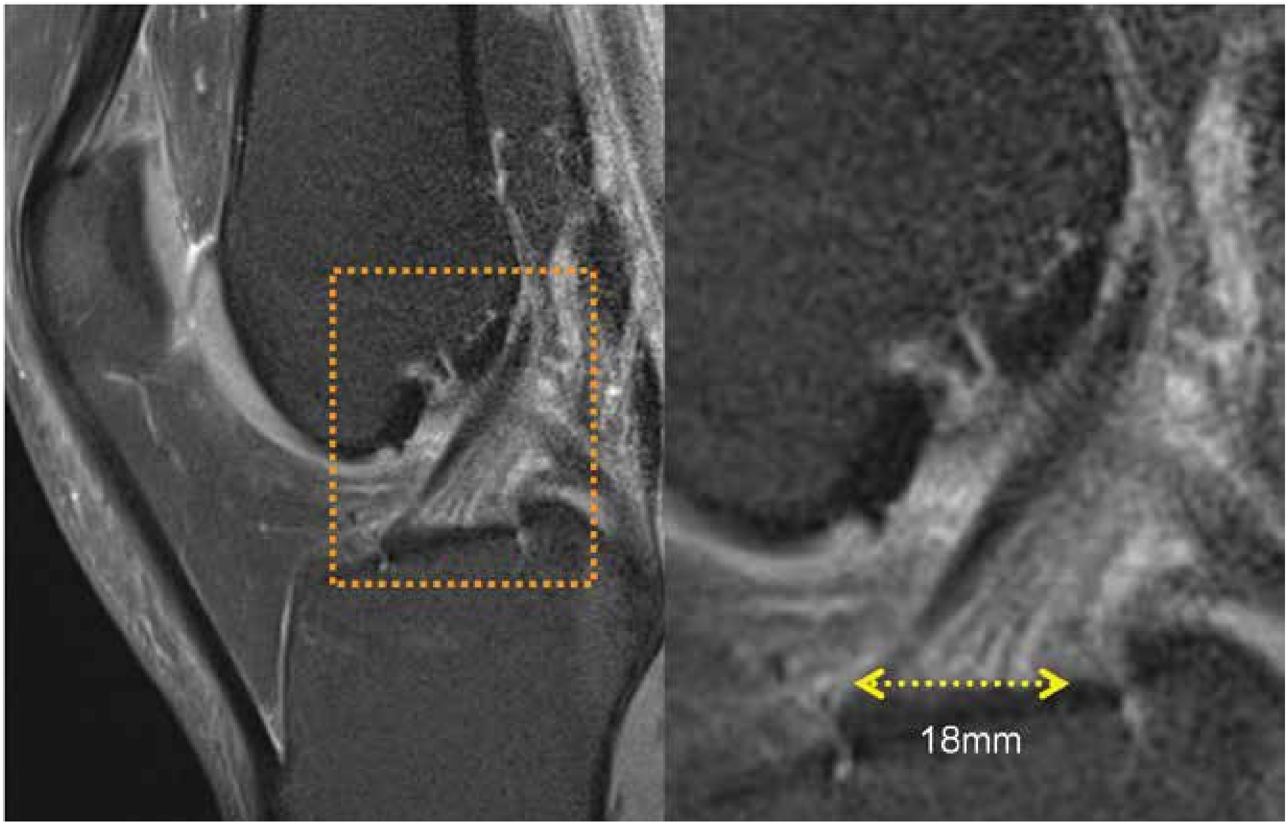

Fig. 2. *Example of tibial insertion site measurement at the point of maximum length on a sagittal fat-suppressed proton density MR image.*

using a phased-array knee coil. Each patient was positioned supine with the affected knee in 10-15° flexion and 15° external rotation. Axial fat-saturated turbo spin echo (TSE) proton density (PD, TR/TE, 3500/14 ms), sagittal fat-saturated TSE intermediate-weighted (IM-w, TR/TE, 2000/41 ms), sagittal T2*-w MEDIC and coronal T1-w spin echo (TR/TE, 450-500/14 ms) MR sequences, all with a slice thickness of 4 mm, were utilised for our study analysis. The sagittal plane was drawn perpendicular to a line connecting the posterior borders of the femoral condyles, according to the European Society of Musculoskeletal Radiology (ESSR) instructions [15]. MR imaging started above the trochlear groove and extended below the tibial tubercle. Images were reviewed and analysed on an EVORAD research RIS/PACS system (www.evorad.com).

Measurements

All measurements were performed digitally on a computer workstation, by placing electronic calipers. In order to assess the FNw, T1-w spin echo images were used. A specific slice was chosen in each knee, the one where the two cruciate ligaments cross one another at the very nearest point to the mid-substance of the ACL [16]. On this slice, ACL is recognised as a longitudinal structure whereas posterior cruciate ligament (PCL) is seen on end (**Fig. 1**). In order to identify the suitable image for performing the measurements, the roof of the intercondylar notch was used as a key structure, since immediately posterior to its appearance the preferable image was recognised, as described above. Moreover, on the slice just anterior to the suitable one, ACL can be seen approaching its tibial insertion, while PCL is depicted close to its femoral insertion. In addition, on the first slice posterior to the image of preference, there is typically no notch roof found, ACL approaches its femoral insertion and PCL is prominently shown. After the identification of the right image, FNw was measured at the point of one half notch height, by placing the cursors at the appropriate position.

For the evaluation of ACL TIS length, sagittal fat sat-

Table 1. Demographics and distribution of patients according to anatomic restriction. TIS, tibial insertion site; FNw, femoral notch width.

	Males	*Females*	*Mean age (years)*	*Mean value (mm)*
Short TIS length	18	72	51.1	13
Narrow FNw	1	7	37	11.4
Short TIS length and narrow FNw	0	2	21.5	-

urated turbo-spin-echo IM-w images were utilised, selecting the slice where the ligament is shown to insert the tibia at its maximum length. TIS was measured at this point by placing the calipers at the appropriate position and obtaining the value in millimeters (**Fig. 2**) [17].

It is crucial to provide the anatomical criteria we used to identify the patients regarded as non-suitable for performing a DBr technique. A TIS length of less than 14 mm and an FNw of less than 12 mm were regarded as contraindication for DBr [2, 9, 10].

All measurements were conducted by two fellowship-trained musculoskeletal radiologists and one 5th-year radiology resident. All procedures were supervised by a senior musculoskeletal radiologist with 31 years of experience.

Statistical analysis

For the statistical analysis, MedCalc version 10.0 software (MedCalc Software, Mariakerke, Belgium) was used. Standard descriptive results were expressed as mean ± standard deviation. Correlation between parameters was assessed with Fisher's exact test, as appropriate. A p value of <0.005 was considered statistically significant.

Results

According to the measurements on the 541 knee MR imaging studies from 528 patients, 98 (18.5%) of them (19 males and 79 females; age range 17-82 years; mean age 50 years; SD ± 17.3) proved to be non-proper candidates for DBr technique. Of them, 90 (91.8%) patients (18 males and 72 females; age range 17-82 years; mean age 51.1 years; SD ± 16.8) were found to be not suitable due to short TIS length, 8 (8.2%) patients (1 male and 7 females; age range 19-74 years; mean age 37 years; SD ± 19.4) due to narrow FNW and 2 (2%) patients (2 females aged 19 and 24 years) due to coexistence of both the above anatomic limitations (**Table 1**).

The mean value of TIS length in the 541 knee MR imaging studies from 528 patients was 16.3 mm (range 10.1-26.3 mm; SD ± 5.6) while the mean value of FNw was 18 mm (range 10.5-24.6 mm; SD ± 11.9). The mean value of the short TIS length in the 90 patients was 13 mm (range 10.1-13.9 mm; SD ± 0.9) while the mean value of the narrow FNW in the 8 patients was 11.4 mm (range 10.5-11.8 mm; SD ± 0.4).

Additionally, gender-based analysis indicated that the number of female patients who potentially represent improper candidates for DBr technique due to anatomic restrictions (short TIS length and/or narrow FNw) was statistically significantly higher compared to the number of male patients (p<0.00001). Specifically, 18 out of 90 patients with short TIS length were males versus 72 females (p<0.00001). Similarly, 1 out of 8 patients with narrow FNW was male versus 7 females. However Fisher's exact test did not reveal a significant correlation regarding this measurement (p=0.0708).

Discussion

According to the results of the present study, 18.5% of individuals were shown to be improper candidates for DBr technique. Among them, 17% had short TIS length, 1.5% narrow FNw and in 0.4% of individuals both anatomic restrictions coexisted. The number of females showing anatomic restrictions was significantly higher compared to that of males (p<0.00001).

Fundamental principles that should be considered when planning anatomic ACL reconstruction include:

(i) respecting the anatomy; (ii) replicating the native ACL insertion site to restore normal knee kinematics and (iii) individualising ACL surgery for each patient. With the current interest in anatomical ACL DBr techniques, it is critical to have a thorough knowledge on the anatomy of the size of the ACL insertion sites for the restoration of the native ACL anatomy.

TIS length has been reported to represent a significant parameter regarding the feasibility of DBr technique, with a length of more than 14 mm being accepted as optimal [2, 9, 10]. This is due to technical difficulties while placing the guide pins, especially the AMb pin, in the native femoral insertion site. A relatively short TIS length may induce improper positioning which may result in graft impingement. Additionally, in the presence of a TIS length of less than 14 mm, drilling two distinct tunnels while maintaining an osseous bridge of 2 mm in between them is not feasible [18]. For individualised approach to anatomical ACL reconstruction at this time, the size of the native ACL insertion can be accurately defined and measured intraoperatively [2, 8, 19]. To the best of our knowledge, there are no studies investigating the preoperative role of cross sectional imaging in identifying the subgroup of patients who do not meet the anatomic requisites for undergoing an ACL DBr technique.

Furthermore, one of the main elements of anatomic reconstruction surgery is to restore the native ACL insertion site. In this regard, the size of the ideal graft depends on the length of ACL insertion, as certain grafts may limit the ability for optimal restoration. The clinical significance of this fact is based on the new concept of "complete footprint restoration" which was introduced be Siebold et al [20]. According to this suggestion, higher percentage of individual footprint reconstruction is related to better biomechanical function and clinical stability [20]. The need to restore the bulk of the native ACL size is also supported by previous reports that showed higher rate of reconstruction failure with smaller grafts [21]. Contrary to DBr resulting in a footprint reconstruction of more than 97%, SBr technique restores only 70-79% of the native ACL insertion size [22]. Thus, SBr surgery should be retained for patients with relatively small and intermediate (14 to 15 mm) TIS length.

With regard to previous studies based mainly on arthroscopic and cadaveric measurements, the length of the ACL TIS has been reported to range between 9 and 21 mm [20, 23-33]. The length of the AMb and PLb insertion sites ranged from 5-12 mm and 5-10 mm, respectively [19, 23]. In accordance, the results of the present study showed a mean TIS length of 16.3 mm, ranging between 10.1 and 26.3 mm. From a practical point of view, considering the highly variable TIS measurement, individualised approach of each patient is suggested. In this regard, in patients with ACL tears who intent to undergo reconstruction of the ligament, preoperative MR imaging is recommended as a valuable tool aiding in more efficient preoperative planning.

Regarding FNw, it has been reported that in patients with a notch diameter of less than 12 mm, anatomic ACL SBr without notchplasty is recommended for preserving as much of the patient's native anatomy as possible [2, 10]. However, other studies support that small FNw do not appear to be a risk factor for higher rates of graft failure after anatomic and individualised ACL reconstruction [34].

This study has limitations. Firstly, only the TIS length of the native ACL has been evaluated. Although evaluation of the femoral insertion site is also significant for preoperative evaluation, this is an ongoing process which requires 3D isotropic MR imaging sequences which were not available at the time of the conduction of the study. Secondly, no control group, i.e. patients with abnormal TIS and/or FNw who underwent ACL DBr, was included. Such an inclusion would allow correlation of the clinical outcome between patients with and without anatomic restrictions (short TIS length, narrow FNw). Finally, we did not attempt to assess the TIS length in patients with complete distal ACL tear.

In conclusion, a significant number of individuals represent improper candidates for an ACL DBr technique due to anatomic restrictions. In this regard, MR imaging appears to be a valuable tool for defining these restrictions preoperatively. Identification of this subgroup of patients is critical for clinical decision making in order to prevent failure of a particularly demanding procedure. R

Conflict of interest

The authors declared no conflicts of interest.

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