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Incidence and Patterns of Meniscal Tears Accompanying the Anterior Cruciate Ligament Injury: Possible Local and Generalized risk factors

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ABSTRACT

AIM OF THE WORK:
Injury to the anterior cruciate ligament (ACL) is frequently accompanied by tears of the menisci. Some of these tears occur at the time of injury, but others develop over time in the ACL deficient knee. The aim of this study was to evaluate the effects of the patient characteristics, time from injury (TFI) and posterior tibial slope (PTS) on meniscal tear patterns. Our hypothesis was that meniscal tears would occur more frequently in ACL deficient knees with increasing age, weight, TFI, PTS, and in male patients.

METHODS:
362 ACL injured patients were analyzed, and details of meniscal lesions were collected. The medial and lateral tibial slopes (MTS, LTS) were measured via computed tomography. Patient demographics, TFI, MTS, and LTS were correlated with the diagnosed meniscal tears.

RESULTS:
113 patients had a medial meniscus (MM) tear, 54 patients had a lateral meniscus (LM) tear, 34 patients had tears of both menisci, and 161 patients had no meniscal tear. The most common tear location was the posterior horn (PH) of the MM, followed by tear involving the whole MM. Patient age, BMI, and TFI were significantly associated with the incidence of MM tear. Female patients had a higher incidence of injury than males in all tear sites except in the Body and PH. Male patients had more vertical and peripheral tears. The median MTS & LTS for patients with MM tears were 7.0°and 8.7° respectively, while those of patients with LM tears were 6.9° and 8.1°. Steeper LTS was significantly associated with tears of LM and of both menisci.

CONCLUSION:
Older age, male sex, increased BMI and prolonged TFI were significant factors for the development of MM tears. An increase in the tibial slope, especially of the lateral plateau, seems to increase the risk of tear of the LM and of both menisci.

LEVEL OF EVIDENCE: level III

KEY WORDS: Knee, ACL Injury, Meniscus tear, Tibial slope, Time from injury.

INTRODUCTION

The anterior cruciate ligament (ACL) is the primary restraint to anterior tibial translation (ATT), providing 85% of the total restraining force to anterior drawer [5]. Isolated ACL tears are uncommon, with approximately 50% accompanied by meniscal tears due to the close anatomic and functional relationships of these structures [10].

The menisci are important structures within the knee, with complex biomechanical functions. They are thought to carry 40 - 70% of the load across the knee, and they have a role in shock absorption, proprioception, and enhancement of stability [30].

Preservation of meniscal tissue and function is paramount for long-term joint function, especially in active patients. Early repair of tears of the posterior horn (PH) of the lateral meniscus (LM) significantly improve loading profiles in the lateral compartment, and may help to prevent the cartilage degeneration and osteoarthritis associated with partial meniscectomy [10].

Understanding the demographic and morphometric differences in ACL deficient patients with meniscal lesions becomes more important in injury prevention and treatment. Many studies have analyzed predictors of these injuries and demonstrated an association between meniscus tears and male sex, obesity, increased age, varus malalignment and increased time from injury (TFI) [7, 10, 12, 26, 31, 37].

A limitation of these studies is that meniscus tears were considered a binary finding (i.e. tear vs. no tear). However, different patterns of meniscal tears in ACL injured subjects may be associated with different demographic and historical risk factors. Identification of such risk factors may help physicians recognize patients at risk of more significant or irreparable meniscal tears.

Furthermore, patients may present with knee pain and isolated meniscal tears, without any history of trauma, implying other causative factors. One may hypothesize that the bony morphology of the knee, including the posterior tibial slope (PTS), may contribute to the development of meniscal tears.

The purpose of this study to document the incidence and distribution of meniscal lesions accompanying ACL tears in a large patient cohort, and to test for associations between these lesions and patient age, gender, Body Mass Index (BMI), time from injury (TFI) and medial and lateral tibial slope (MTS & LTS).

Our hypothesis was that meniscal tears would occur more frequently in ACL deficient knees with increasing age, weight, TFI, PTS, and in male patients. We further hypothesized that increased PTS and TFI would be associated with more significant meniscal lesions.

MATERIALS & METHODS

STUDY DESIGN

A retrospective cohort study was performed to analyze the association between different patterns of meniscal tears in ACL-injured subjects, and potential demographic and historical risk factors. As all data were collected retrospectively from medical records, Institutional Review Board approval was not required at our institution.

PATIENTS SELECTION

All patients undergoing ACL reconstruction in our institution between 2012 and 2015 were recruited to this study.
The pre-operative clinical notes were reviewed to collect patient age, gender, BMI and TFI data.
The pre-operative clinical and radiological examination findings, as well as the intra-operative findings, were also reviewed. All data were recorded on evaluation forms.

Patients with either partial or complete ACL rupture in the affected knee, as established by arthroscopy, were included in the study. Exclusion criteria were patients less than 18 years old, a history of previous surgery involving partial meniscectomy, other ligamentous lesions, or signs of osteoarthritis.
Seven patients were also excluded due to incomplete or ambiguous documentation of meniscal status.

A total of 362 consecutive patients with partial or complete rupture of ACL injury were included, and were divided into 4 groups according to the involved meniscus; Group 1 with medial meniscal (MM) tear, Group 2 with lateral meniscal (LM) tear, Group 3 with tears of both menisci, and Group 4 with no meniscal tear.

MENISCAL TEAR CLASSIFICATION

In all patients, meniscal lesions were confirmed arthroscopically using a standard probe and documented according to the ISAKOS classification [2]. Tears were documented occurring in the medial or lateral meniscus. In addition, each meniscus was subdivided into three parts: the anterior horn, the body and the posterior horn.
We further categorized the type of meniscal tear as Vertical, Horizontal, Peripheral (Meniscocapsular & Ramp lesions), Oblique, Flap, Radial or Complex. Other variations such as bucket-handle and degenerative tears were also recorded.

TIBIAL SLOPE MEASUREMENT

The archived computed tomography (CT) scan images were analyzed and morphometric measurements were performed using a picture archiving and communication system (PACS, Centricity, GE Healthcare, Waukesha, Wisconsin) workstation with standard features, including the ability to adjust windows, change the zoom, and apply electronic calipers.

The MTS and the LTS were measured by two blinded radiologists using the modified midpoint method previously published by **Lustig** et al. [24]. Three sagittal slices were selected corresponding to the midsagittal, the mid-medial compartment sagittal (B), and the mid-lateral compartment sagittal cut (C) (**Fig. 1**). All sagittal slices were selected manually, and digital measurements were performed twice for each patient two weeks apart to assess the intra-observer reliability.

The proximal tibial anatomical axis (PTAA) was selected to establish the PTS. This axis has been shown to have the best correlation with the tibial shaft anatomic axis and reflect most accurately the mechanical axis of the tibia [39].
The PTAA was established on the mid-sagittal cut by a line joining the midpoint between the anterior and posterior tibial cortices at the level of the tibial tuberosity and at another level 5 cm more distal. The angle subtended between the tibial axis to the horizontal was then calculated (PTTA-H Angle) **(Fig. 2)**. This angle was then used to transfer the calculated tibial axis to the medial and lateral sagittal cuts to assess the MTS and LTS respectively. The tibial slope in each compartment were measured as the angle between a line perpendicular to PTAA and a line connecting the superior points of the anterior and posterior corresponding tibial plateau **(Fig. 3)**. A posterior inclination was assigned a positive value, while an anterior inclination was assigned a negative value.

STATISTISTICAL ANALYSIS

Statistical analysis was performed using SPSS for Windows (version 11.5; SPSS, Chicago, IL, USA). Microsoft Excel was used to calculate statistical values and to create diagrams. Continuous variables were calculated as mean ± standard deviation and categorical variables were reported as count and percentages. The assumption of normality was assessed with Kolmogorov–Smirnov tests. Inter and Intra-observer reliabilities were tested by means of Intra Class Correlation Coefficients (ICC). The Wilcoxon rank sum test and the Chi2 test were used to test the difference between the continuous and categorical variables. Kruskal-Wallis ANOVA test and post-hoc tests were used to test the effects age, sex, BMI, TFI, MTS and LTS on the incidence, sites and types of meniscal tears. The results of correlations and risk analysis were calculated separately, where the probability of this result, assuming the null hypothesis, was less than 0.05.

RESULTS

The distribution of age, BMI, LTS, MTS and TFI were tested using a one-sample Kolmogorov-Smirnov test. All variables were normally distributed except TFI ($p < 0.001$).
The means, standard deviations (SD) and ranges are shown in **Table (1)**.

DISTRIBUTION OF MENISCAL LESIONS:

From 362 patients (238 male and 124 female), there were 113 patients with an isolated MM tear (group 1), 54 patients with an isolated LM tear (group 2), 34 patients with tears of both menisci (group 3), and 161 patients with no meniscal tear (group 4) (**Fig. 4**).
The most common tear location of the MM was the posterior horn (PH), followed by tears of the whole meniscus. Similarly, tears of the LM tended to be distributed more posteriorly and involve mainly the PH, followed by the tears involving both the PH and body. Tears of the anterior parts of the menisci were seen least frequently. The distribution of meniscal tears across the different anatomical regions is shown in **Figure 5.**

TYPES OF MM TEARS (Groups 1&3):

After evaluating all 147 MM tears, the most common tear type was a vertical tear (33%), followed by bucket-handle tears (18%). We noted an equal proportion of peripheral and complex tears (12% each), while the degenerative tears represented the least common type (1%) **(Fig. 6a)**.

TYPES OF LM TEARS (Groups 2&3):

In 88 LM tears, vertical tears were observed in 27. In comparison with MM tears, there were less of bucket-handle tears (5%) but more horizontal tear amongst the LM tears than the MM (18% vs. 6%). As in the MM, the degenerative tears represented the least tear type (2%). Oblique tears had the same distribution for both sides (6%) **(Fig. 6b)**.

PATIENT AGE

The median age of the patients with MM tears was 32.9 years while that of patients with LM tears was 29.7 (ns).
There were a significant relationship between patient age and the incidence of MM tears, with older patients having more MM tears ($p = 0.002$). However, there was no such relationship for the other groups.

GENDER

Using Chi2 test, there were significant associations between sex and the incidence of MM tears ($p = 0.034$), the incidence of the LM tears ($p = 0.002$), and the incidence of both menisci tears ($p = 0.005$). Male patients predominated in all groups. The percentages of male and female patients having these tears were 44.5% and 33.1% (MM), 28.1% and 14.5% (LM), and 12.2% and 3.2% (both) respectively.

We also found a significant associations between sex and tear sites (*p* = 0.002). Female patients had a higher incidence of injury to all tear sites except the Body and posterior horn, and posterior horn tears. The percentages of male and female patients having tears in the different sites were 1.8% and 2.4% for anterior horn tears, 0.9% and 2.4% for body tears, 16.0% and 12.2% for posterior horn and body tears, 70.7% and 43.9% for posterior horn tears, and 10.4% and 39.0% for entire meniscus tears respectively.

Finally we found an association between sex and the type of the meniscal tear (*p* < 0.001). Male patients had more vertical, peripheral, and oblique tears, while females had a higher percentage of horizontal, flap, bucket-handle, degenerative, radial and complex tears. The distribution of the tear types between male and female patients are shown in **Table (2**).

BMI

The median BMI for the patients with MM tears was 24.2 while that of patients with LM tears was 23.8 (ns). BMI had a significant effect on the incidence of MM tears (*p* = 0.029), with patients with higher BMI having a higher incidence. Conversely, no effect of the BMI on the incidence of meniscus tears in the other groups. BMI did not affect the tear sites or types in any groups.

TIME FROM INJURY

The median TFI for patients with MM tears was 5.9 months while that for patients with LM tears was 4.7 months (ns).
TFI had a significant effect on the incidence of MM tears, with patients having a longer time to surgery more likely to have MM tears at the time of surgery (*p* = 0.031). Similar results were seen in group 2, however, this did not reach statistical significance (*p* = 0.056).

TFI did not influence tear site or type, with the exception of MM tear types. In this group, the Dunn and Sidák's post hoc test revealed that TFI was significantly higher for radial type (median = 18.73) than for peripheral (4.53) and oblique (3.55) types (*p* = 0.022).

TIBIAL SLOPE

Repeated measures analysis of variance showed strong agreement between the two raters for both the medial and lateral slopes (ICC 0.83 and 0.88 for MTS &LTS respectively). Intra-observer reliability was also high for all measurements (0.89 - 0.93).

The median MTS and LTS for patients with MM tears were 7.0° and 8.7° respectively while those for patients with LM tears were 6.9° and 8.1°, respectively (ns).
The LTS has a significant effect on the incidence of LM tears. Patients with LM tears demonstrated greater LTS (median= 9.5˚) compared to that of patients without tears (7.2˚) (*p* = 0.003). Similarly, the LTS has a significant effect on the incidence of both menisci tears (group 3), with patients in this group demonstrating greater LTS (9.3˚) compared to that of the patients without tears (7.5˚) (*p* = 0.007). The MTS did not influence the incidence of meniscus tears in any groups. Neither the MTS nor the LTS had an effect on the tear site or type in any group.

DISCUSSION

The overall incidence of meniscal tears in the present study was 55% (31% for MM, 15% for LM and 9% for both menisci). This finding is consistent with rates in the literature [14, 26, 31]. Various mechanisms affect the frequency of medial and lateral meniscal tears, including lower limb alignment**,** load distribution, and delay of intervention. The incidence of LM tears remained relatively unchanged with time, while MM tears increased with time.
Biomechanically, the MM is a secondary stabilizer of the knee against anterior displacement of the tibia in the ACL-injured knee, and is subjected to anteroposterior shear forces. On the other hand, the more mobile LM is less likely to undergo these shear stresses [23]. This may account for the high incidence of MM tears, but further studies are necessary to prove this theory.

The most common tear location in the MM in our study was the PH with the most common tear types being vertical tears was (33%), followed by bucket-handle tears (18%) and peripheral tears (12%). These findings in accordance with the current literature [35].
More bucket-handle tears were seen in the MM than in the LM. These findings are consistent with other studies which found that MM tears were likely to be bucket-handle type regardless of the chronicity of the injury [14, 15]. **Cerabona** et al. have theorized that the recurrent trauma sustained by the MM while acting as a cushion in the ACL-deficient knee leads to PH tears [6]. This may be due to its relative immobility, resulting in a decreased ability to absorb shear stresses during subluxation of the tibial plateau during the pivot shift [30].

Regarding LM tears, the most common site for the tears was also the posterior horn. The most common tear types were vertical (27%) and horizontal tears (18%).
Radial tears were also more common in the LM (12% vs. 8%). It has been reported that approximately 15% of meniscal tears are radial tears, with 20% of these tears occurring in the PH of the LM, which may be more susceptible to radial tears due to a lack of ligamentous support [16]. **Choi** et al. reported that more radial tears were found in female patients than horizontal tears [8].
Radial tears of the meniscus significantly impair the load-bearing function of the meniscus and cause the meniscus to be extruded under axial loads. If the meniscus is displaced, the incongruent bony articular surfaces come in direct contact, and subsequent damage to the articular cartilage will occur [4].

In our study, the LM showed more flap tears than the MM (7% vs. 4%). These results are supported by those of **Ghodadra** et al., who found that the full-thickness LM tears were more often flap-type tears [14].

Several factors are reported to increase the risk of meniscal tears in ACL-deficient patients. These include older age, male gender, increased bodyweight, time from injury, and repetitive activities [10, 12, 28, 29, 37].

We found increasing age to be associated with increased medial but not lateral meniscal tears regardless of location of tear. For the different lesion types, the age seemed homogenous. In

contrast, **Feucht** et al. observed higher risk for LM tears in younger patients [10], and other authors have found no correlation between age and meniscal injury [38].
There is general belief of a strong effect of aging on the menisci in the literature. These effects may include vascular changes [32], biochemical changes [36], and degenerative changes [18]. The patients in our study, however, were relatively young, and degenerative tears were uncommon.

We also observed increased meniscal injury in male patients across all groups. Other authors, however, have found no such association [11]. Male patients had a higher incidence of injury in the body and posterior horn of both menisci and show more vertical, peripheral tears than females. This observed injury pattern may be explained by a lesser degree of ACL resilience in women, leading to ACL rupture at smaller forces with less associated meniscal injury [33]. On other hand, the patterns could be due to less resilient meniscal tissue and contraction difference in quadriceps or hamstring muscles in males [17]. Further investigation is needed to clarify the tissue-level influence on this potential gender difference.

In our study, increased BMI was also associated with an increased incidence of MM tears. Generally, obesity has an unfavorable effect on the knee joint, and previously BMI and weight equally predicted meniscal injury [3]. Consequently, **Ford** et al. [12] reported a significant correlation between meniscal tear and increasing BMI.
Chen, however, found no correlation between BMI and meniscal or chondral injury, and suggested that higher BMI patients may be less active and thus less at risk for further injury [7]. There is a potential biomechanical explanation for the relationship between BMI and meniscal tears, in that as the BMI increases, the torque in the knee joint during rotation may increase, and theoretically may cause more meniscal injury [8].

Increased interval between injury and surgery has also been shown to increase the frequency and severity of meniscal injuries [11].
Our study confirms that a delay in surgical treatment is associated with a higher incidence of MM tears. Our results are in accordance with the results of other studies that reported an increased incidence of MM tears in chronic (70-78 %) compared to acute injuries (30 - 45%) [9, 19, 20, 28]. Similarly, our study supports previous reports that LM tears remain fairly constant in respect to TFI [9, 11, 13]. These findings support the notion that most LM tears occur at the time of injury during the subluxation of the lateral compartment, while further MM tears occur due to the role of the MM as a secondary stabilizer in the ACL deficient knee. Anatomically, the MM is attached firmly to the joint capsule and also adherent to the inferior margin of the tibial plateau by the coronary ligament which may account for the increased incidence of MM tears in chronically ACL deficient knees.

Recently, a number of studies have investigated the association between the geometry of the proximal tibia and the risk of ACL injury [1, 22, 25], however, little information on the relationship between tibial slope and meniscal tear is available. In theory, a greater PTS will cause more anterior tibial translation under load, which may increase the forces in both the ACL and the menisci. More specifically in the lateral compartment, increased slope may cause a rotatory moment under load [34], to which the lateral meniscus is a stabilizer [27].

Markl et al. examined the rate of meniscal tears in found ACL deficient patients and noted increased rates of meniscal tears in with medial and lateral tibial slope greater than 10° (odds ratio 2.11 for medial and 3.44 for lateral slope), however in this small study of only 71 subjects these findings did not reach statistical significance **[25]**.

In the present study, the LTS was greater in the knees with LM or both menisci tears compared to that of patients without tears, but the MTS was similar in knees with and without MM tears. In contrast**, Khan** et al. observed a significant association between shallower MTS and tears of the PH of the MM. They hypothesized that entrapment of the PH horn of MM within a tight medial compartment could occur as a result of the shallower MTS **[21]**.

We suggest that PTS is one of the considerations in ACL injury to prevent secondary meniscal tears in patients with ACL injury. Increased slope, particularly in the lateral compartment, is a risk factor for lateral and both menisci tears, and when identified should prompt the clinical to consider early ACL reconstruction to prevent further meniscal injury.

The present study has several limitations. Firstly, the retrospective design of the study is an inherent limitation, as the clinical report was sometimes imprecise concerning the description of meniscal lesions.
Furthermore, this study focused on limited risk factors. We did not evaluate factors such as activity level or lower limb alignment which may affect the severity of meniscal injury in ACL injured patients.
Further prospective studies with greater sample sizes are needed to better understand the relationship between these parameters and tear types and sites. Biomechanical and kinematic studies are needed to further explore the association between tibial slope and meniscal tears.

CONCLUSION

Older age, male sex, increased BMI and prolonged TFI were significant factors for the development of MM tears. An increase in the tibial slope, especially of the lateral plateau, seems to increase the risk of tear of the LM and of both menisci. Therefore, it may be suggested that tibial slope could be one parameter to consider in ACL injured patients for recommending early reconstruction, in order to prevent secondary meniscal tears.

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Compliance with ethical standards :

Conflict of interest
AE, TL, AS, RD: no conflict of interest.
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Ethical approval :
All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. For this type of study, formal consent is not required.

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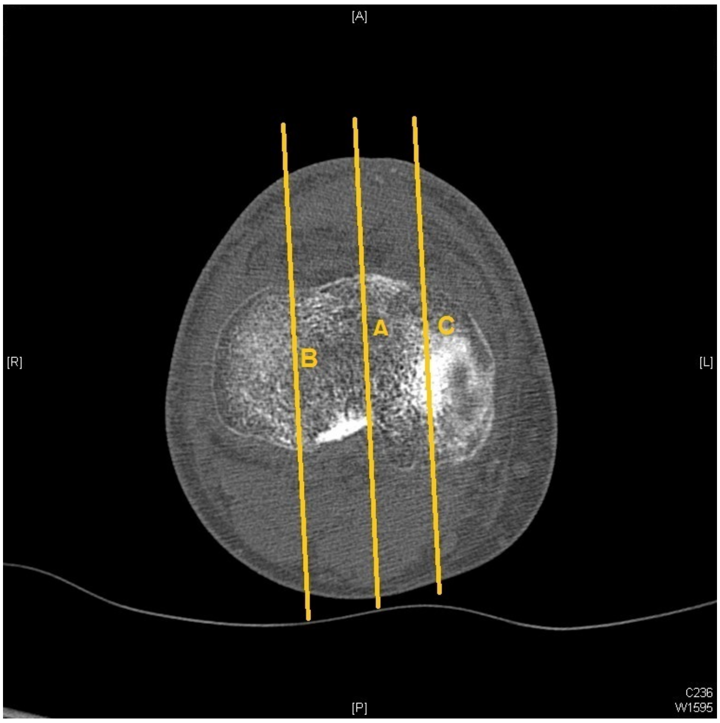


Fig.1: Three CT axial cuts of the tibia at superior joint line were taken to select the corresponding midsagittal (A), the mid-medial sagittal (B), and the mid-lateral sagittal images (C).

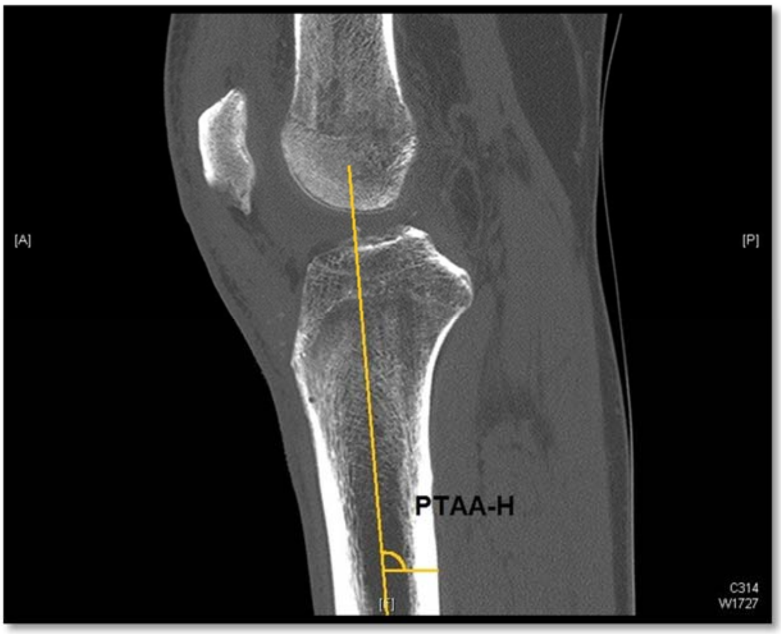


Fig.2: The PTTA was defined as a line through the midpoints between the two tibial cortices at the level of tibial tuberosity and at 5 cm more distal. The angle between the PTAA and the horizontal was also calculated (PTTA-H).

Fig. 3: Superimposition of the PTTA on each corresponding sagittal image by means of PTAA-H. Calculation of the MTS &LTS as the angle between a line joining the high points of the anterior & posterior tibial plateau and a line perpendicular to the PTTA.

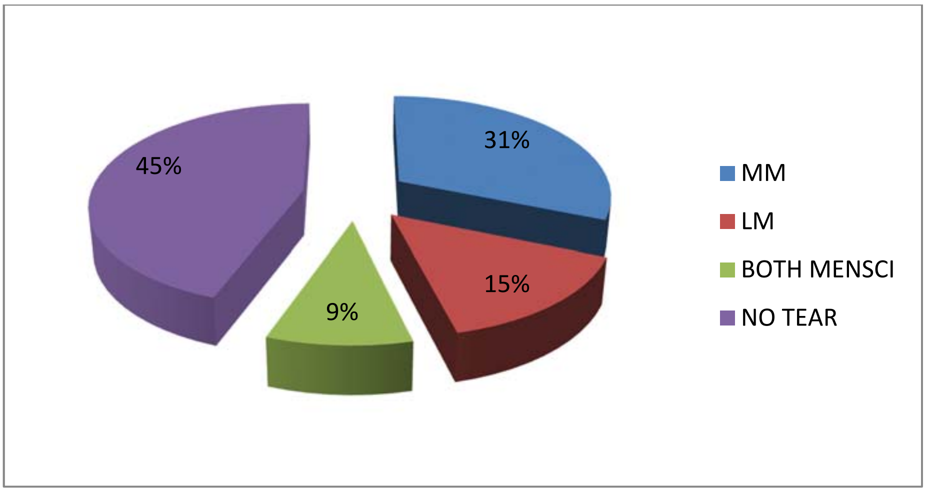


Fig.(4): Incidence of meniscal tears, MM: Medial meniscal tears, LM: Lateral meniscal tears.

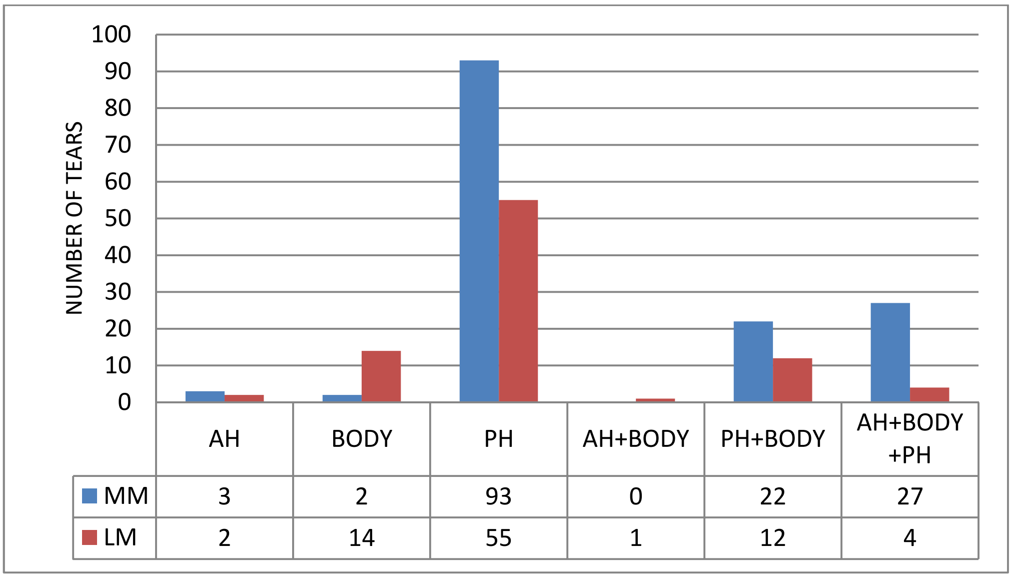
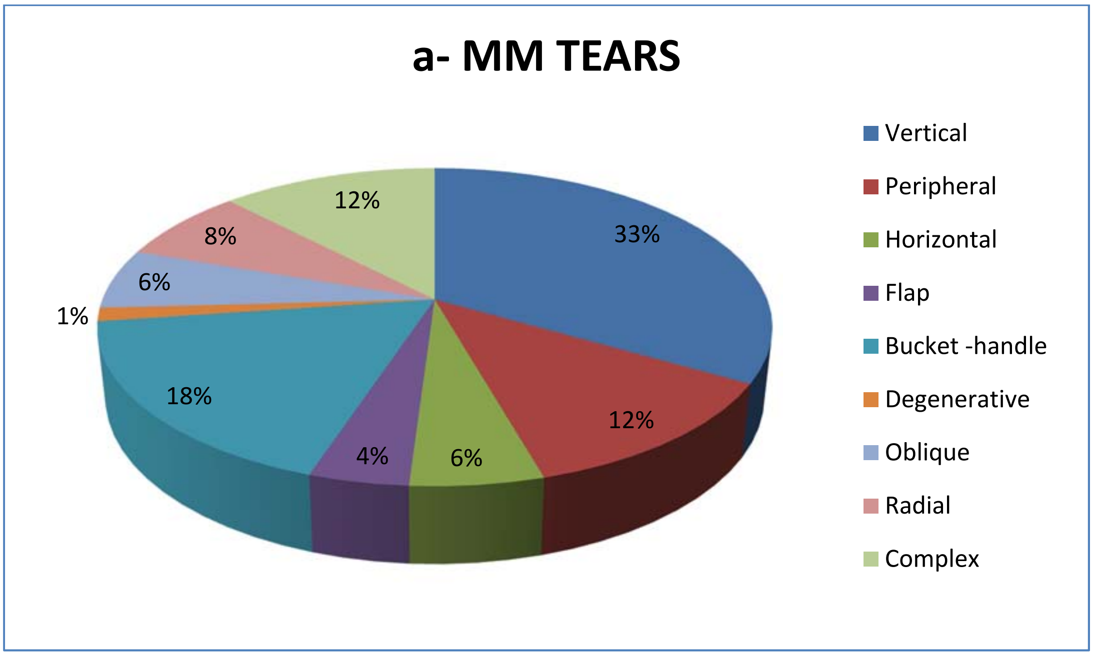


Fig.5: Distribution of the meniscal tears. AH: Anterior horn, PH: Posterior horn



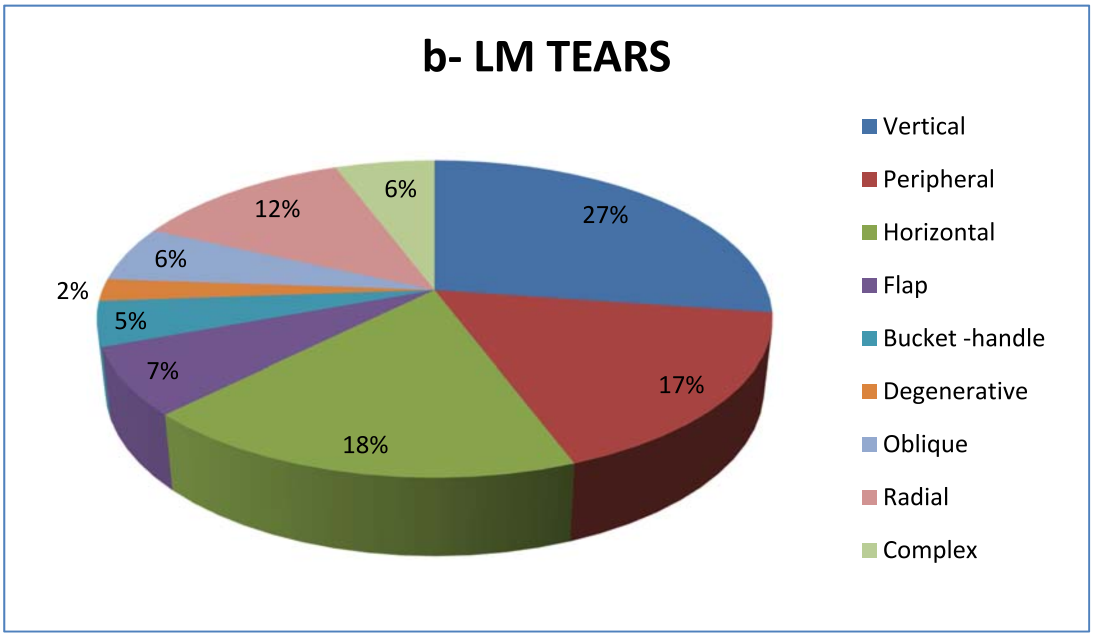


Fig. 6 a&b: Types of the meniscal tears. **a**: MM tears, **b**: LM tears.

Table (1): The means, standard deviations (**SD**) and ranges of all the variables for all patients. BMI: Body Mass Index, MTS: Medial Tibial Slope, LTS: Lateral Tibial Slope, TFI: Time From Injury.

PARAMETER	AGE(years)	BMI($kg/m^{2)}$	MTS(˚)	LTS(˚)	TFI(months)
MEAN	32.1	24.0	9.1	7.6	11.7
SD	11.0	3.4	3.5	3.6	24.6
RANGE	18.0 - 61.9	17.5 - 37.6	1 - 18.9	-1.1 - 17.9	0.37 - 256.4

Table (2): The distribution of the tear types between male and female patients.

TEAR TYPE	MALE-FEMALE %
Vertical	42.4% - 7.3%
Peripheral	14.1% - 7.3
Horizontal	4.7% - 7.3%
Flap	3.8% - 4.9%
Bucket-handle	9.4% - 39.0%
Degenerative	0.9% - 2.4%
Oblique	6.6% - 4.9%
Radial	6.6% - 9.7%
Complex	11.3% - 14.6%