ACL reconstruction and the implication of its tibial attachment for stability of the joint: anthropometric and biomechanical study

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Abstract The planar topography of the anterior cruciate ligament (ACL) insertion was investigated and correlated to the use of the double-bundle/double tibial tunnel ACL reconstruction technique within the ACL tibial insertion area. The anteroposterior and mediolateral length of the tibial ACL attachment and the distances of the tibial insertion area from the anterior and posterior tibial borders were measured and the stability of the joint was tested using the double-bundle/double tibial tunnel ACL reconstruction technique. The anteroposterior length, 19.54 mm in men and 17.36 mm in women, of the ACL insertion, averaged approximately 40% of the total intercondylar anteroposterior dimension of the plateau. This broad distribution of insertion fibres ensures ligament tension and hence joint stability. The reported anteroposterior broad insertion of ACL fibres to the tibia is not sufficiently reproduced by the use of one or more bundles having a common tibial tunnel for the ACL reconstruction. In our view, this might be better achieved with two different bundles, with separate tunnels, and independent tensioning in different knee angles. This technique might achieve better results in human knee stability as opposed to other reported techniques.

Résumé Une étude topographique de l'insertion du ligament croisé antérieur a recherché une corrélation

avec la technique du double tunnel/ double brin au niveau de la zone d'insertion tibiale. Les dimensions antéro-postérieure et médio-latérale de l'insertion tibiale ainsi que les distances entre les bords antérieur et postérieur du tibia et cette zone d'insertion étaient étudiées. La stabilité articulaire était testée après reconstruction par la technique du double brin avec double tunnel. La longueur antéro-postérieure de l'insertion - 19,54 mm chez l'homme et 17,36 chez la femme - représente approximativement 40% de la dimension antéro-postérieure du plateau tibial dans la région intercondylienne. Cette distribution étendue de l'insertion des fibres assure la tension ligamentaire et en conséquence la stabilité articulaire. Cette insertion étendue n'est pas reproduite par l'utilisation d'un ou plusieurs brins passés dans un seul tunnel tibial. Nous pensons que cela peut être atteint en utilisant 2 brins et 2 tunnels avec une mise en tension indépendante dans les différentes positions du genou. Cette technique devrait donner de meilleurs résultats que les techniques habituellement proposées.

Introduction

Anatomical studies show that the anterior cruciate ligament (ACL) consists of fibres of different lengths arranged in two, or according to others in three bundles [1, 2, 7, 12], and that the area of ACL attachment to the tibia has a long anteroposterior axis with respect to the mediolateral axis [2, 7, 17]. The sagittal cross section has a fan [2, 7], or rather triangular shape, resembling the capital Greek letter delta “Δ.”

According to Girgis et al. [7] and Arnoczky et al. [2], the anteroposterior length of the ACL insertion averages

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29.3 mm (range: 23.0–38.0 mm), while the distance between the anterior insertion edge and the anterior intra-articular tibial border averages 15.2 mm (range: 10.0–20.0 mm).

The equivalent measurements of Odensten and Gillquist [17] were 17 ± 3 mm and 14.5 ± 4 mm, respectively, a mediolateral insertion breadth of 11 ± 2 mm and also the fact that they were unable to distinguish recognisable bundles.

The attached areas of the ACL, both on the femur and the tibia, are responsible for the different lengths of the anterior and posterior fibers of the ACL. This difference in fibre length may be of significance for the knee joint stability throughout the flexion-extension range of motion [7]. Investigators cited by Frank and Jackson [5] have agreed that the anatomical attachment or the “over-the-top” placement of the graft have almost the same action. On the other hand, the only statement concerning tibial attachment is that it should not be too anterior, because of the possibility of impingement in the notch [5].

Materials and methods

Fifty-five tibial condyles were measured, after removal, during total knee arthroplasty, in patients suffering from osteoarthritis (50 patients) and rheumatoid arthritis (5 patients) (Table 1).

The patients were 30 females and 25 males averaging 69.7 years of age (67.4 years for women and 72.1 years for men). After removal, each specimen was preserved in formalin until measurement. For measurement, the menisci and the posterior cruciate ligament (PCL) were removed. Using a Vernier caliper (Mitutoyo 536-134), the following dimensions were measured and their values recorded, rounded to the nearest millimeter:

- Anteroposterior insertion length (insertion AP: I-AP)
- Mediolateral insertion breadth (insertion ML: I-ML)
- The distance between the anterior insertion edge and the anterior intra-articular tibial border (insertion to anterior border: I-AB)

Table 1 Overview of the dimensional findings

Dimensions (mm)	Males		Females	
	Range	Mean	Range	Mean
I-AP	14–25	19.54	11–22	17.36
I-ML	9–17	12.12	8–18	12.05
I-AB	8–15	11.52	7–20	10.53
I-PB	11–19	14.62	8–20	12.70

- The distance between the posterior insertion edge and the posterior tibial border (insertion to posterior border: I-PB)

The various recognisable areas in the upper surface of the tibial condyles were also investigated. The most constant guide point on the tibial condyles is the notch of the posterior tibial margin, where the fibres of the posterior cruciate ligament are inserted into the bone. This distance was also measured in both men and women.

In a previous experiment using 25 right porcine knees, we had investigated the reconstruction of the ACL, which was substituted by one bundle in the classic isometric placement (group A) and by two grafts in the form of a triangular double bundle, sharing a common origin at its anatomical insertion to the femur and having two different insertions (group B) at the anterior and posterior ends of the tibial ACL insertion area. The distance of these insertion points is the base of the triangular construction. The specimens were divided into two groups of 10 and 15 knees. In the first group (group A), 10 knees were used and the ACL was reconstructed with the so-called isometric placement of the graft (A technique). In the second group (group B), of the 15 knees the ACL reconstruction was done with the double-bundle technique (B technique). The distance between the two tendon grafts was increased progressively in the tibial condyles, so as to reproduce the wide, more than 15 mm, insertion of the normal ACL using two separate bundles (anteromedial and posterolateral). The tendon grafts were retained and stabilised in the tibia and in the femur with absorbable sutures by specifically manufactured buttons.

Results

In this series we have confirmed that the ACL is composed of two distinct bundles, the anteromedial and the posterolateral, possessing fibres of different length and having a broad attachment to the tibia.

According to the measurements in the study the anteroposterior length of the ACL insertion averages 19.54 mm (range: 14–25) in men and 17.36 mm (range: 11–22) in women. This length covers 42% of the total anteroposterior length of the tibial condyles in men and 43% in women (approximately 2/5) (Tables 3, 4).

The distances from the anterior and posterior borders of the tibia are 11.52 mm (range: 8–15) and 14.62 mm (range: 11–19) in men, respectively, and 10.53 mm (range: 7–20) and 12.70 mm (range 8–20) in women, respectively

Fig. 1 Representations of ACL tibial attachment area in males

(Figs. 1, 2). The mediolateral insertion breadth in men is 12.12 mm (range: 9–17) and in women 12.05 mm (range: 7–20) (Tables 2, 3).

Thus, the tibial attachment of the ACL represents quite a broad area, situated more anteriorly and slightly medially in the anteroposterior and mediolateral dimensions of the tibial condyles and also having an average distance from the insertion of the PCL of 14.62 mm and 12.70 mm for men and women, respectively (Figs. 1, 2).

In the above-mentioned experiments [19], we had investigated the anterior shift of the tibia in porcine knees, in both groups, in 30° (Noullis-Trillat-Lachmann test), in 60°, and in 90° (anterior drawer test) of flexion with the ACL intact, after its resection and following the reconstruction with the single-bundle technique (A technique) and also with the double-bundle technique (B technique). Each specimen was placed and measured in a specially

Fig. 2 Representations of ACL tibial attachment area in females

Table 2 Results expressed in absolute and as percentage values of the total anteroposterior length (males)

I-AB (mm)	I-AP (mm)	I-PB (mm)	T-AP (mm)	I-AB/ T-AP (%)	I-AP/ T-AP (%)	I-PB/ T-AP (%)
12	20	14	46	26	43	31
11	21	19	51	22	41	37
9	17	14	40	23	43	34
10	18	18	46	22	39	39
13	17	18	48	27	35	38
8	14	13	35	23	40	37
13	21	16	50	26	42	32
15	20	14	49	31	41	28
12	19	11	42	29	45	26
15	20	14	49	31	41	28
9	19	14	42	21	45	34
13	19	12	44	30	43	27
11	22	11	44	25	50	25
10	21	15	46	22	46	32
12	23	18	53	23	43	34
11	21	18	50	22	42	36
12	20	17	49	24	41	35
11	23	17	51	22	45	33
15	25	19	59	25	42	33
11	19	14	44	25	43	32
10	17	14	41	24	41	35
10	17	16	43	23	40	37
12	18	15	45	27	40	33
12	18	15	45	27	40	33
11	20	15	46	24	43	33
Mean				25	42	33
SD				3	3	4
Minimum				21	35	25
Maximum				31	50	39

constructed device similar to the KT-2000, on which a special clock was adapted, measuring the anterior shift.

The distance between the two different insertion points to the tibia proved to be of paramount importance for the triangular technique (B technique). Increasing the distance between graft insertions, the joint laxity was diminished, resembling normality, in distances more than 15 mm (Fig. 3).

Discussion

This anthropometric study on the topography of the ACL insertion has proved that the area covered by the ACL insertion on the tibial plateau is quite broad, supporting, although with some discrepancies, previous findings in this area [2, 7, 17].

Our measurements differ from the previously reported investigations of ACL anatomy, both in anteroposterior length and the mediolateral breadth. According to the

Table 3 Results expressed in absolute and as percentage values of the total anteroposterior length (females)

I-AB (mm)	I-AP (mm)	I-PB (mm)	T-AP (mm)	I-AB/ T-AP (%)	I-AP/ T-AP (%)	I-PB/ T-AP (%)
7	14	12	33	21	42	37
11	22	13	46	24	48	28
14	11	13	38	37	29	34
11	14	11	36	31	39	30
20	14	8	42	48	33	19
10	14	16	40	25	35	40
11	20	10	41	27	49	24
8	16	13	37	22	43	35
10	16	12	38	26	42	32
12	17	16	45	27	38	35
9	18	18	45	20	40	40
10	17	10	37	27	46	27
10	18	11	39	26	46	28
8	21	15	44	18	48	34
13	16	13	42	31	38	31
8	14	13	35	23	40	37
10	16	13	39	26	41	33
10	16	10	36	28	44	28
9	18	17	44	20	41	39
11	20	20	51	22	39	39
10	14	9	33	30	42	28
8	14	12	34	24	41	35
9	19	12	40	23	48	29
10	21	8	39	26	54	20
14	21	10	45	31	47	22
7	20	14	41	17	49	34
12	19	11	42	29	45	26
11	21	13	45	24	47	29
13	20	14	47	28	43	29
10	20	14	44	23	45	32
Mean				26	43	31
SD				6	5	6
Minimum				17	29	19
Maximum				48	54	40

reported measurements the anteroposterior length of the ACL insertion averages 20 mm in men and 17 mm in women. This covers 42% of the total anteroposterior length of the tibial condyles in men and 43% in women (approximately 2/5). However, differences exist between

Table 4 Previously reported results in comparison with the results of the current study

	I-AP (mm)	I-AB (mm)
Girgis et al. [6]	30	15
Odensten et al. [16]	17	14.50
Current study mean males-females	18.45	11.02

the reported findings and those of previous researchers. We have confirmed the AP distances of Odensten and Gillquist, but our findings completely disagree with the AP findings of Girgis et al., while the ML distances in our study are slightly smaller, than in the measurements of the previous investigators [7, 17]. These are comparatively shown in Table 4.

The ACL is of major importance for the stability and function of the knee. Damage to this ligament substantially compromises the demanding daily requirements for the knee [9, 14]. Surgical intervention is the only efficient method to prevent gradual malfunction and deficiency of the joint after an ACL rupture [6]. It is suggested that the anteromedial bundle of the anterior cruciate is responsible for the anteroposterior drawer sign in flexion.

Various surgical techniques have been suggested, using autografts (patellar, semitendinosus, gracilis), allografts, synthetic materials, or combinations of these [3, 4, 10, 13, 15, 16, 18, 21, 23]. Postoperatively, all previously reported surgical techniques reveal an incidence of positive Noulis-Trillat-Lachmann test [13, 15, 18, 26]. The demonstrated anteroposterior broad insertion of ACL fibres to the tibia is not sufficiently reproduced by the use of one or more bundles, having a common

Fig. 3 Increasing the distance between graft insertions, the joint laxity was diminished, resembling the normal one, in distances more than 15 mm

tibial tunnel, even within the ACL tibial attachment, as far as the reconstruction is concerned. It seems, therefore, that regardless of the technique and the grafts used, the surgical aim is not always reached.

The fibres of the anterior cruciate ligament have different lengths and directions and are not all stretched at the same time during flexion-extension. The flexion angle is of paramount importance for the determination of the degree of tension developed in the fibers of the ACL. The normal ACL exhibits increased anterior translation forces in the first 30° of knee flexion and as the flexion angle increases, anterior translation forces decrease. In fact, the shape, the length, and the direction of the cruciate fibres compensate for the geometry of the femoral condyles and vice versa. The target of tensioning the various grafts is to restore anterior stability of the knee joint after ACL reconstruction.

Surgical reconstruction of a ruptured ACL is aimed at the prevention of joint instability, meniscal degradation, and osteoarthritis, offering the patient a stable joint with a full range of motion. Reconstruction of the ACL should not rely on an isometric placement of the graft, which, in our view, is not feasible, but it should reproduce the normal isometric tensioning throughout the joint's function, if possible.

Some researchers have reported the use of a double bundle, having a common femoral and tibial tunnel, in order to enhance its strength. The semitendinosus tendon has been used alone [11] or together with the patellar tendon [8, 19] or the gracilis tendon and bone graft [25]. The quadriceps tendon has also been used [22], as well as prosthetic grafts [24].

We have investigated in vitro the anteroposterior translation, following the restoration of the ACL with a double-bundle/double tibial tunnel technique. We have experienced positive results, especially when the two bundles are separated, at the proximities of anterior and posterior attachments of the wide tibial insertions of the ACL. We observed the best results when the distance between the two bundles was as far apart as possible, more than 15 mm within the insertion area of the ACL attachment to the tibia [20].

Conclusions

According to our philosophy, by exploiting the full anteroposterior ACL insertion length, using the double-bundle/double tibial tunnel technique, ACL reconstruction could have better results, particularly when the distance between insertions is as great as possible (more than 15 mm) within the ACL tibial attachment area [19]. This technique does not, of course, reproduce, but rather approximates to the natural ACL functional configuration,

and seems to maintain tension, while resisting anterior tibial translation throughout the full range of knee motion.

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