Morphological size evaluation of the mid-substance insertion areas and the fan-like extension fibers in the femoral ACL footprint

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ARTHROSCOPY AND SPORTS MEDICINE

Morphological size evaluation of the mid-substance insertion areas and the fan-like extension fibers in the femoral ACL footprint

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Abstract

Purpose The purpose of this study was to evaluate the detailed anatomy of the femoral anterior cruciate ligament (ACL) insertion site, with special attention given to the morphology of the mid-substance insertion areas and the fan-like extension fibers.

Methods Twenty-three non-paired human cadaver knees were used (7 Males, 16 Females, median age 83, range 69–96). All soft tissues around the knee were resected except the ligaments. The ACL was divided into antero-medial (AM) and postero-lateral (PL) bundles according to the difference in macroscopic tension patterns. The ACL was carefully dissected and two outlines were made of the periphery of each bundle insertion site: those which included and those which excluded the fan-like extension fibers. An accurate lateral view of the femoral condyle was photographed with a digital camera, and the images were downloaded to a personal computer. The area of each bundle, including and excluding the fan-like extension fibers, was measured with Image J software (National Institution of Health). The width and length of the mid-substance insertion sites were also evaluated using same image.

Results The femoral ACL footprint was divided into four regions (mid-substance insertion sites of the AM and PL bundles, and fan-like extensions of the AM and PL bundles). The measured areas of the mid-substance insertion sites of the AM and PL bundles were 35.5 ± 12.5, and 32.4 ± 13.8 mm^2, respectively. Whole width and length of the mid-substance insertion sites were 5.3 ± 1.4, and 15.5 ± 2.9 mm, respectively. The measured areas of the fan-like extensions of the AM and PL bundles were 27 ± 11.5, and 29.5 ± 12.4 mm^2, respectively.

Conclusion The femoral ACL footprint was divided into quarters of approximately equal size (mid-substance insertion sites of the AM and PL bundles, and fan-like extensions of the AM and PL bundles). For clinical relevance, to perform highly reproducible anatomical ACL reconstruction, the presence of the fan-like extension fibers should be taken into consideration.

Keywords Anterior cruciate ligament · Anatomy · Femoral · Fan-like extension · Mid-substance

Abbreviations

ACL Anterior cruciate ligament
AM Antero-medial bundle
PL Postero-lateral bundle

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Introduction

Although anatomical anterior cruciate ligament (ACL) reconstruction has been performed widely in the past decade [1–7], reports vary as to the exact anatomy of the ACL [8–19], and the optimal placement of anatomical tunnels in anatomical ACL reconstruction remains unclear. It has been reported that in order to reproduce native ACL kinematics, femoral tunnel placement is one of the critical points of the surgery [2–5, 20]. However, reports on femoral ACL footprint morphology and tunnel position vary according to the measurement methods used [3, 8–15, 18, 19, 21–23]. One possible explanation for this variation in femoral ACL footprint measurement is the inclusion or exclusion of the fan-like extension fibers [9, 14, 15]. In previously reported anatomical studies of the ACL, some authors included the fan-like extension fibers within the femoral ACL footprint [8, 10, 12, 24], and others did not [11, 17, 25]. One of the final purposes of anatomical ACL reconstruction is the restoration of native anatomy [24, 26, 29, 30]. Recently, Smigielski et al. reported that the mid-substance insertion site of the ACL footprint has a narrow and thin structure when compared with previously reported ACL morphology [25]. However, they did not provide the accurate area of the mid-substance insertion site. It is essential to establish in detail the anatomy of the femoral ACL footprint, especially the morphology of the mid-substance insertion site and fan-like extension fibers.

The purpose of this study was to establish the accurate morphology of the mid-substance insertion site and the fan-like extension fibers in the femoral ACL footprint.

The hypothesis of this study was that a characteristic morphology of the femoral ACL footprint would be revealed in measurements which included the fan-like extension fibers.

Materials and methods

This study was approved by the ethics committee of Nihon University school of medicine (IRB number 20-14). Twenty-three (23) non-paired formalin fixed Japanese cadaveric knees were used (7 Males, 16 Females, median age 83, range 69–96). Knees with severe osteoarthritic changes were not included in this study.

Evaluation of the ACL insertion site

All surrounding muscles, and other soft tissues around the knee were resected before ACL dissection. Knees were cut at approximately 200 mm proximal to the femur and distal tibia. All soft tissues were carefully dissected. AM and PL bundles were identified according to the difference in tension patterns during complete knee range of motion. With the knee at 90° of flexion, relaxed fibers of the ACL were regarded as the PL bundle [29–31]. After identification of each bundle, particular care was taken to ensure that the posterior structures were carefully resected in order to simulate accurate ACL dissection: the posterior joint capsule, menisco-femoral ligaments, posterior cruciate ligament (PCL) and synovial tissues. When the surrounded synovial tissues were dissected carefully, fibers of the ACL could be revealed. After soft tissue resection, the ACL was cut into half. On the femoral side, the femur was split along the sagittal plane through the most superior point of the anterior outlet of the intercondylar notch with an oscillating saw to expose the femoral attachment of the ACL. The outline of the whole femoral ACL footprint was marked first with colored ink, and the mid-substance insertion site of the femoral ACL footprint was then marked [11]. As reported by Mochizuki et al. [15], there existed a fold between the mid-substance insertion site and the fan-like extension fibers, and the fold could be detected macroscopically. Following the identification of the AM and PL bundle mid-substance fibers, the mid-substance insertion site and the fan-like extensions were divided according to AM and PL bundles and marked [14, 15]. Referring to the mid-substance tissue of the ACL, the border between the mid-substance insertion and the fan-like extension fibers was clearly distinguished [11, 14, 15]. An accurate lateral view of the femoral condyle was photographed with a digital camera (Casio, Co. Ltd., Tokyo, Japan) [11]. The images were downloaded to a personal computer, and the footprint area was calculated after adjusting the computer images to the actual knee size using Image J software (National Institute of Health) [32, 33]. The accuracy of the area measurement was less than 0.1 mm^2 (Fig. 1). The following areas were calculated: the whole ACL area, the whole mid-substance insertion area, the fan-like extension area, the whole AM area, the mid-substance insertion area of the AM bundle, the whole PL area, and the mid-substance insertion area of the PL bundle.

The center position of each bundle was calculated automatically by the image J software. The length of the ACL footprint was calculated as an orientation line through the centers of the AM and PL bundles (whole, mid-substance, and fan-like extension fibers). The width of each bundle's insertion site was calculated as the greatest length of line perpendicular to the ACL length line.

Statistical analysis

Data are presented as mean and standard deviation. Considering the mean and standard deviations in the width of the ACL footprint, the sample size of 22 could address the question with power 0.90. Comparison of each bundle's area both including and excluding the fan-like extension fibers, was performed using Mann–Whitney's U test. It was assumed that there was statistical significance when $P < 0.05$. All statistical data were calculated with SPSS 19.0 (SPSS Inc., Chicago, IL, USA).

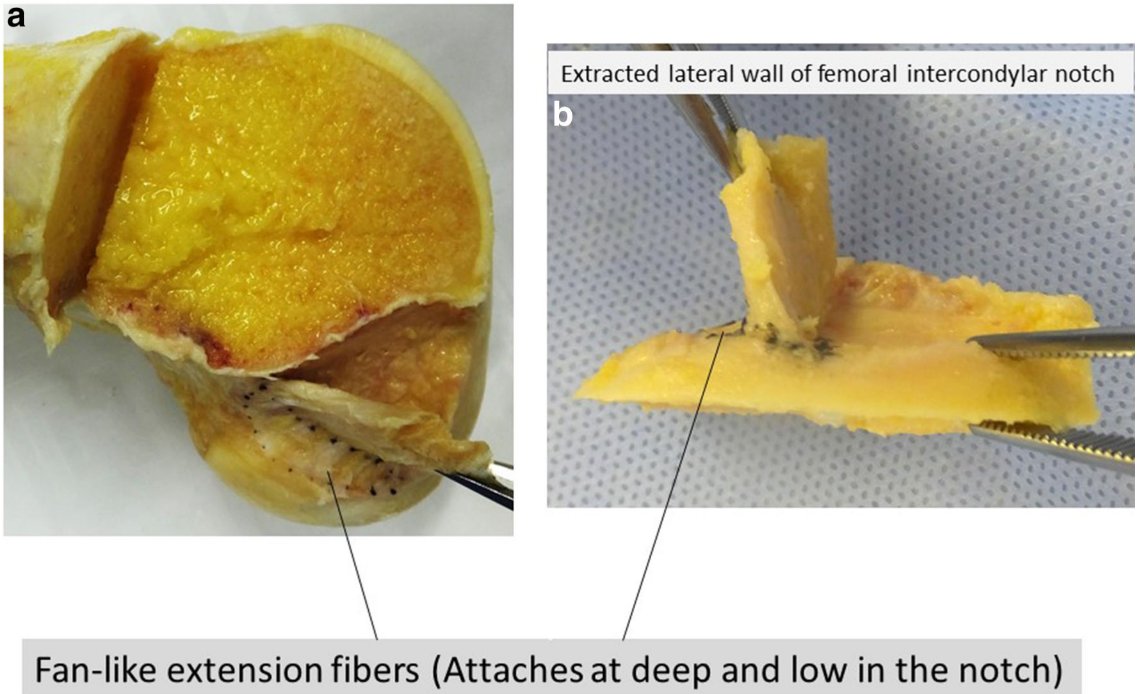

Fig. 1 Mid-substance insertion sites and fan-like extension fibers of the femoral ACL footprint. In all knees, the femoral insertion site of the ACL was divided into mid-substance insertion site and fan-like extension fibers (**a**, **b**). When extracted the lateral wall of intercondylar notch, the correlation between mid-substance of the ACL and the lateral wall was looked like "T" shape

Results

ACL footprint size and area

In all knees, the mid-substance insertion site and the fan-like extensions were successfully divided. Fan-like extension fibers existed at the low and deep lesion of the medial wall of the lateral femoral condyle, and the mid-substance of the ACL was attached relatively high in the notch (Fig. 1). ACL mid-substance was divided into AM and PL bundles according to the difference in tension patterns, and the femoral ACL footprint was divided into four regions (mid-substance insertion sites of the AM and PL bundles, and the fan-like extensions of the AM and PL bundles) (Fig. 2).

The measured areas of the whole femoral ACL footprint, the mid-substance insertion site, and the fan-like extension were 125 ± 47, 67 ± 21, and 59 ± 31 mm^2, respectively. Mid-substance insertion site was significantly smaller than the whole femoral ACL footprint ($P < 0.05$). Each area of divided femoral ACL footprint was described in Table 1.

The length and width of the ACL femoral footprint

The length and width of each lesion of the femoral ACL footprint (Fig. 3) was described in Table 2.

Discussion

The most important finding of this study was that when the ACL footprint was evaluated according to AM and PL bundles and taking into account the presence of the fan-like extension fibers, the femoral ACL footprint could be divided into four parts, the area, length, and width of which were approximately the same.

Anatomical ACL reconstruction has become the favored method over non-anatomical isometric reconstruction, and many anatomical studies have been conducted concerning ACL morphology [8–11, 13–19, 32]. However, a great variation exists among these studies regarding the position and the size of the ACL insertion site [8–11, 13–19, 34]. In particular, the morphology of the femoral insertion site of the ACL remains unclear. Some authors have reported that the femoral ACL insertion site attaches very low in the notch [8, 12, 17, 23, 24]. The resident's ridge is often thought to be the upper limit of the femoral ACL insertion site in the notch [23]. However, other authors have reported that the center position of the femoral ACL footprint is relatively high in the notch [3, 9, 11, 14, 15]. Mochizuki et al. reported that the ACL attaches high in the notch beyond the residents' ridge [15]. One possible explanation for this variation in the ACL femoral insertion site concerns the presence of fan-like extension fibers. Mochizuki et al. [14, 15], and Hara et al. [9] reported that the femoral

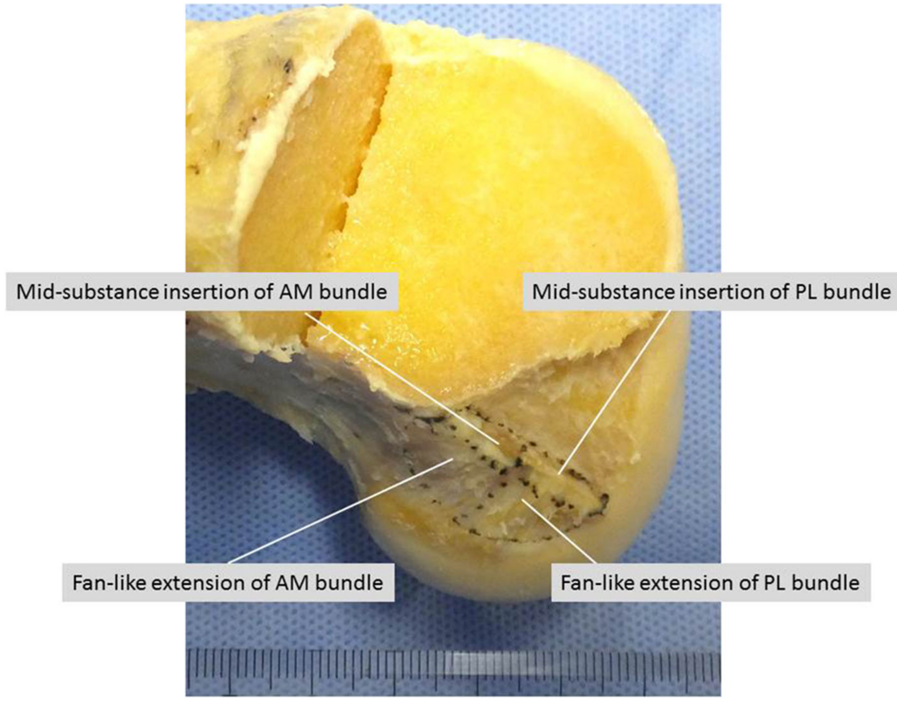

Fig. 2 The femoral ACL footprint is divided into four parts. According to the difference in tension patterns, the ACL was divided into antero-medial (AM) and postero-lateral (PL) bundles. The femoral ACL footprint was divided into four parts (mid-substance insertion sites of the AM and PL bundles, and fan-like extensions of the AM and PL bundles)

Table 1 Measurement of the femoral ACL footprint area

Whole femoral footprint area	125 ± 47 mm^2
Whole mid-substance insertion area	67 ± 21 mm^2
Whole fan-like extension area	59 ± 31 mm^2
Whole AM footprint area	64 ± 23 mm^2
Mid-substance insertion area of AM	35 ± 12 mm^2
Fan-like extension area of AM	29 ± 18 mm^2
Whole PL footprint area	63 ± 25 mm^2
Mid-substance insertion area of PL	32 ± 14 mm^2
Fan-like extension area of PL	30 ± 13 mm^2

ACL footprint consists of two different structures. One is the relatively narrow direct insertion area of the ACL mid-substance fibers, and the other is the fiber that adhere to the intercondylar notch. They termed these adhered fibers "fan-like extension fibers". As shown in the Fig. 1, when the medial wall of the lateral femoral condyle was extracted, the correlation of ACL mid-substance and the medial wall of the lateral femoral condyle appeared as a "T" shape (Fig. 1). If the ACL mid-substance was attached deep and low in the notch and the fan-like extension fibers did not exist, the correlation would appear as an "L" shape. In previous anatomical studies of ACL morphology, because the presence of the fan-like extension fibers had yet to be established, some authors included the fibers within the femoral ACL footprint [8, 10, 12, 24], and others did not [6, 9, 11, 14, 15, 25], which may account for such a

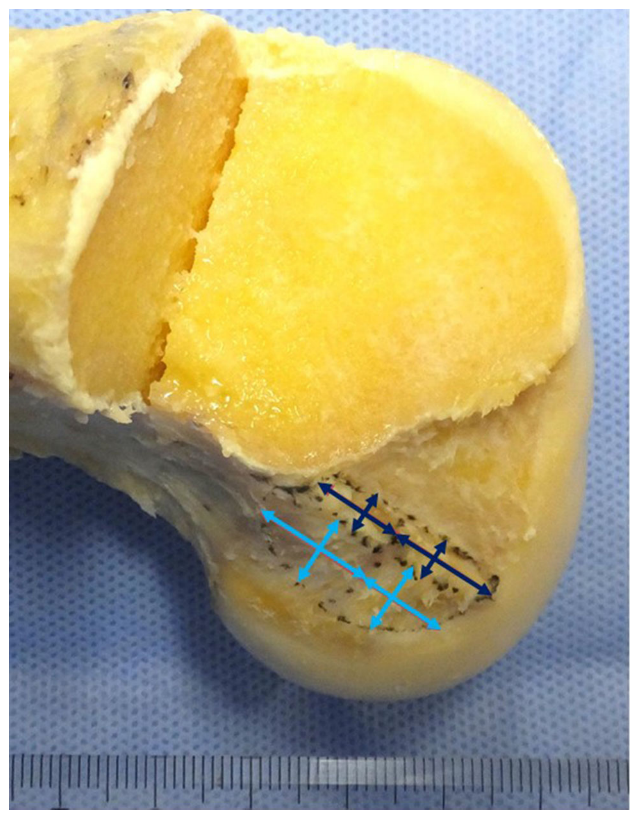

Fig. 3 The length and width measurement of mid-substance insertion and fan-like extension fibers. The length of the ACL footprint was calculated as an orientation line through the centers of the AM and PL bundles (Whole, mid-substance, and fan-like extension fibers). The width of each bundle's insertion site was calculated as the greatest length of line perpendicular to the ACL length line

Table 2 Measurement of the femoral ACL footprint length and width

Whole femoral footprint length and width	15 ± 3/10 ± 2 mm
Whole mid-substance insertion length and width	15 ± 3/5 ± 1 mm
Whole fan-like extension length and width	13 ± 3/5 ± 2 mm
Whole AM footprint length and width	8 ± 2/9 ± 2 mm
Mid-substance insertion length and width of AM	7 ± 2/5 ± 2 mm
Fan-like extension length and width of AM	7 ± 2/4 ± 1 mm
Whole PL footprint length and width	7 ± 2/9 ± 2 mm
Mid-substance insertion length and width of PL	7 ± 2/5 ± 1 mm
Fan-like extension length and width of PL	7 ± 2/4 ± 1 mm

wide variation in the reports of femoral ACL footprint size. As recently described by Mochizuki et al. [15] and Smigielski et al. [25] and confirmed in this study, the insertion site of ACL mid-substance fibers is narrow, and the area is small. Likewise, in the present study, the entire mid-substance femoral insertion area of the ACL was only 67 mm^2, and the mid-substance width was only 5 mm. Although Mochizuki et al. described the femoral ACL footprint in detail, they did not report the area, length or width. They also did not evaluate AM and PL bundle morphology. Smigielski et al. reported the narrow and thin structure of the ACL mid-substance insertion site [25]. They evaluated the ACL area and width 2 mm from the femoral insertion site, and therefore, their results (56.6 mm^2 area and 3.54 mm width) were smaller than the results of this study. However, the area and width measurements of this study were similar to the results of Smigielski et al. [25]. Revealing the correct size of the ACL footprint is critical to the reproduction of accurate anatomy in ACL reconstruction [27, 28]. This study revealed a significant distinction between the ACL mid-substance insertion site and the fan-like extension fibers. In the authors' opinion, anatomical ACL reconstruction is better suited to the reproduction of the mid-substance insertion site of the ACL. If the femoral ACL tunnels are placed deeper and lower in the femoral inter condylar notch than the mid-substance insertion, then the ACL reconstruction reproduces the fan-like extension fibers (Fig. 4). Recently, Kawaguchi et al. reported that among ACL fibers, those attached close to the AM bundle mid-substance insertion resisted to 66–84% of anterior tibial drawer force, and the posterior lesion those close to the fan-like extension fibers had minimal role to stabilize the knee [32]. The function of the fan-like extension fibers should be revealed in the future plans.

The main limitations of this study were (1) the ACL dissection was performed only by macroscopic evaluation. Although the dissection was made by experienced surgeons, this might allow for human error and bias. Although the border between the mid-substance insertion and fan-like extension fibers of the ACL could be determined

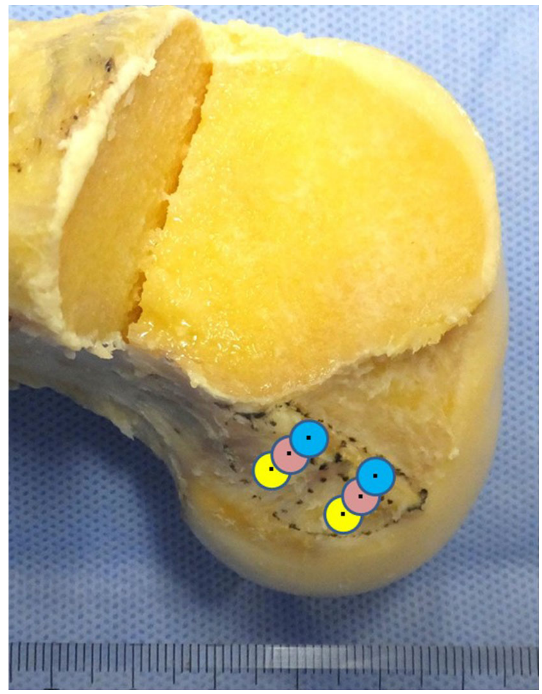

Fig. 4 Femoral ACL tunnels position reproducing mid-substance insertion, center of the whole ACL footprint, and the fan-like extension fibers. When reproducing the mid-substance insertion in the ACL reconstruction, femoral tunnels position would be like *blue circles*. When reproducing the center of the whole ACL insertion, the tunnels position would be like *pink circles*. When reproducing the fan-like extension fibers, the tunnels position would be like *yellow circles*

clearly by macroscopic evaluation, and the significant correlation between the macroscopic border and the histological border has been previously reported [4], more detailed histological evaluation should be performed in future plans. (2) Only Japanese subjects were included in this study. Ethnicity might be a potential influence and should be taken into consideration in future studies. (3) The average age of the cadavers used was significantly older than the average age of patients that undergo ACL reconstruction. Even though no specimens had severe osteoarthritic changes, the ages of the specimens should be considered in such an anatomical study. (4) Our sample size was not large ($n = 23$) but was similar to previous studies [11, 15, 29]. However, due to anatomical variation and in order to accurately define the ACL anatomy, a study with a larger sample size is needed. (5) The ACL footprint was only evaluated using a two-dimensional technique. The ACL is attached three-dimensionally to the bone [24] and might be better evaluated three-dimensionally. (6) The ACL morphology including fan-like extension fibers might be influenced by the formalin fixation. The studies using fresh cadavers should be performed in the future plans.

For clinical relevance, the knowledge of the detailed morphology of the femoral ACL footprint taking into consideration the presence of the fan-like extension fibers makes it possible for surgeons to perform more accurate reproducible anatomical ACL reconstruction.

Conclusion

In conclusion, the femoral ACL footprint was accurately divided into mid-substance insertion areas and fan-like extensions. Taking into consideration the presence of the fan-like extension fibers, the mid-substance insertion site of the ACL is relatively narrow and thin in structure.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest on this study.

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Ethical approval This study has been approved by the ethics committee. The no.: 20-14.

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学位論文審査　　補足資料
学籍番号 2015026　外科系整形外科学　駿河誠
指導教員　德橋泰明

本資料は提出論文に関して、専門外の研究者においても幅広く読まれることを前提に、より理解しやすいように補足資料として作成したものである。

以下 6 項目は予備審査会でご指摘いただいた項目である。ご指摘いただいた点の解答は本文中にアンダーラインで示した。

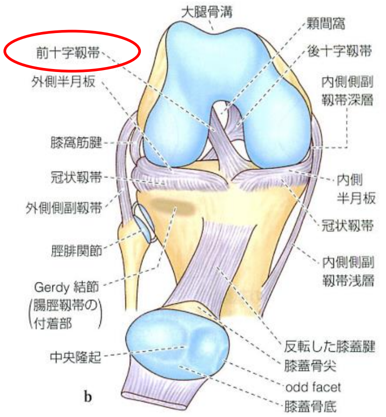
① 膝の解剖図を含めた靱帯損傷の治療法と現在行っている著者らの手術法を解説すること．手術時大腿骨側の骨孔を作成するのにはどこを指標にしているか記載すること．
② 現在 ACL 再建を行う上でどのような問題があって，この研究を企画したかを記載すること
③ この研究結果によって ACL 再建術式の何が改善されるかを記載すること．
④ 本研究が今までにない独創的なものである点を説明すること．
⑤ AM bundle と PL bundle 線維の fan-like extension fiber の境界はどのように判断したかを述べること．
⑥ Mochizuki T, et al.: Knee Surg Sports Traumatol Arthrosc. 2014 と Kawaguchi Y, et al:　Arthroscopy. 2015 の論文を考察で引用し，本研究との違いを明確に述べること．

前十字靱帯(Anterior Cruciate Ligament; ACL)について

1. 膝関節の解剖学①

・膝関節は主に ACL、後十字靱帯、内側側副靱帯、外側側副靱帯の 4 つの靱帯によって制動されている。
・ACL は膝関節の中心に位置する靱帯で、大腿骨外顆の顆間壁後上方に発し，脛骨顆中央部に付着する長さ平均 3.8cm,中央部での幅平均 1.1cm の帯状靱帯である。
・大腿骨に対し脛骨の前方変位および回旋を制動し、膝関節の安定化に非常に重要な機能を持つ靱帯である。

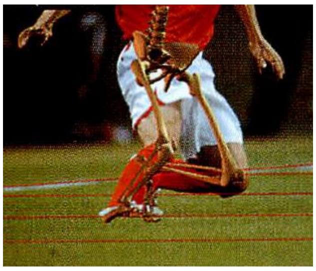
Fisher et al. JBJS Am, 1991



標準整形外科第 12 版, 医学書院, 2014

2. ACL 損傷

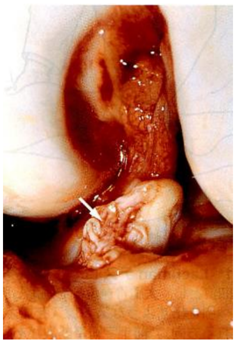
バスケットボールやスキー、ラグビーなどのスポーツで多く生じる外傷である。受傷機転は非接触型と接触型に大きく大別され、非接触型の受傷が多いのが特徴的である。非接触型はジャンプの着地、急なストップ動作などで膝を内側に捻ることで生じ、接触型は外側からタックルを受けたり、交通外傷などで生じる。側副靱帯や半月板損傷を合併することが非常に多い。



Koga, Am J Sports Med, 2010

3.　ACL 損傷の症状

受傷時は激痛とともにブツッという断裂音 popping を体感することが多い。数時間以内に関節が腫脹し関節血症を認める。大腿骨側付着部で断裂は起こることが多いことが報告されている。急性期を過ぎると膝の不安定感や急な方向転換時などの膝くずれなどを生じる。



標準整形外科第 12 版, 医学書院, 2014

4.　ACL 損傷の治療

保存療法および手術療法に大別されるが近年では手術療法が一般的である。

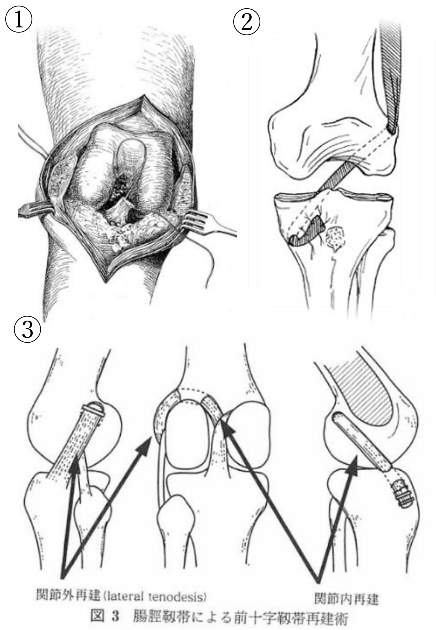
保存療法は主に活動性の低い中高年に適応となり四頭筋訓練による膝関節の安定化などのリハビリテーションや装具療法を行う。

手術は鏡視下 ACL 再建術が施行される。手術が一般的となってきた背景としては、①損傷靭帯の治癒能が低い②保存的治療ではスポーツに復帰できる率が低い③放置すれば二次的に半月損傷を合併、変形性関節症へと進展する④近年の手術手技の向上により靭帯再建術の成績が良好であるということが挙げられる。

5.　ACL 再建術

ACL 損傷に対する手術は 1900 年代初期より行われていた。

当初は靭帯を縫合する手術などが行われていたが成績が悪く、自家腱を移植する ACL 再建術が行われるようになった。1917 年に Hey Groves が初めて腸脛靭帯を用いた ACL 再建術を報告し、以後本邦でも腸脛靭帯を膝の裏を通して再建する守屋法などが多く行われていた。近年では、解剖学やバイオメカニクスの研究が進んできたことと、手術器具、関節鏡、インプラントの発達によって、大腿骨及び脛骨に骨孔を作成して屈筋腱や膝蓋腱を移植し、正常靭帯に近い靭帯を模倣する鏡視下 ACL 再建術が主流となっている。



①　Perthes, Zentralbl Chir(German), 1926

②　Hey Groves, Lancet, 1917

③　蟹沢, 守屋ら, 整形災害外科, 1998

6. <u>現在の一般的な鏡視下 ACL 再建術の術式(ハムストリング腱を用いる場合)</u>
<u>（当院でも同様の手法を用いている）①</u>

①腱の採取
脛骨内側部に皮膚切開を加えて半腱様筋腱を採取する。

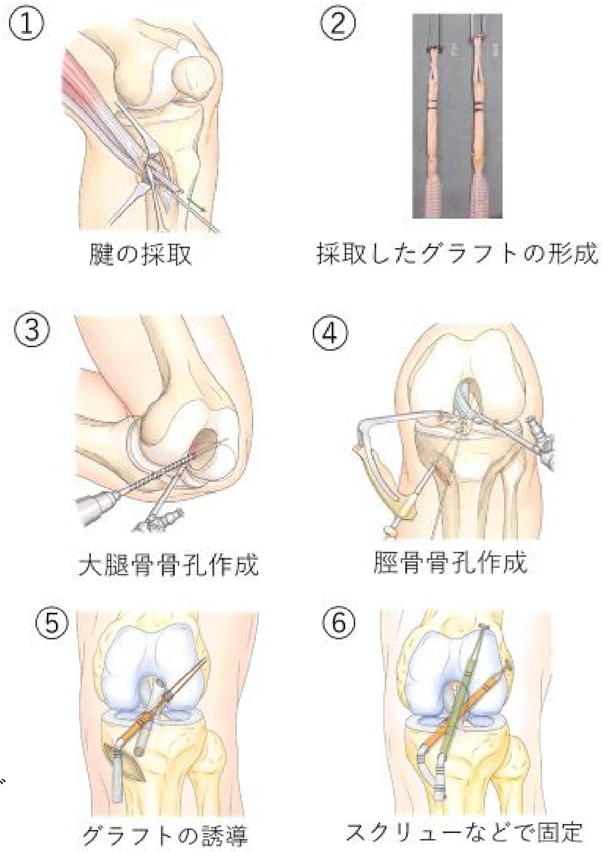
②採取した腱の形成
採取した腱を形成して、人工靭帯と金属のボタンをつける。

③大腿骨孔の作成
関節鏡補助化にドリルで大腿骨顆間窩の後外側壁に骨孔を作成する。

④脛骨骨孔の作成
関節鏡補助下にガイドを用いて、脛骨側も骨孔作成をする。

⑤グラフトの誘導
糸を用いてグラフトを骨孔の中に誘導する。

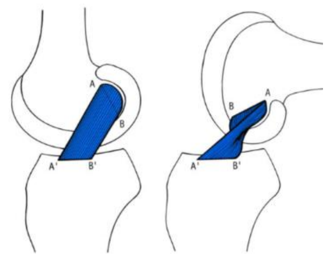
⑥スクリューなどによる固定
大腿骨側はボタンで固定され、適切なテンションでグラフトはスクリュー固定する。



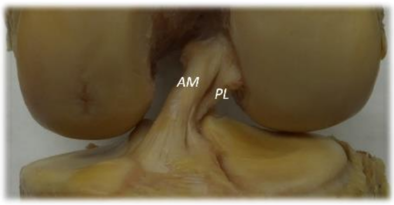
北村、宗田ら, OS NEXUS 5, 2016

7. ACL の解剖研究

1975 年 Girgis らは、ACL は外観上 1 本のファイバーに見えるが屈曲位と伸展位でテンションのかかり方が違う前内側線維束(Anteromedial bundle; AM)と後外側線維束(Posterolateral bundle; PL)の 2 種類のファイバーから成ることを報告した。
膝屈曲位で AM bundle は緊張し、PL bundle は弛緩する。

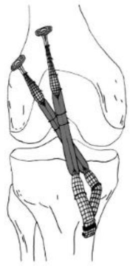


Girgis FG, Clin Orthop Relat Res,1975



8. ACL 二重束再建術

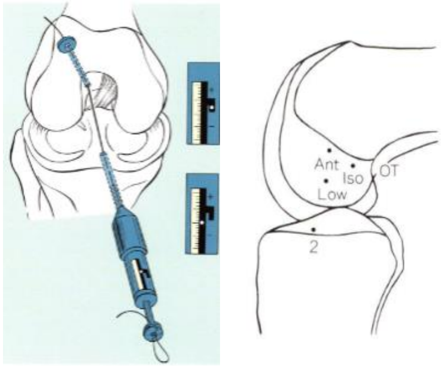
1999 年宗田らは、より正常靭帯に近い再建をするために大腿骨と脛骨に 2 つずつ骨孔を作成することで AM と PL を模倣する二重束再建術を報告した。現在当院でも二重束再建を行っている。



Muneta et al, Arthroscopy, 1999.

9. Isometric point

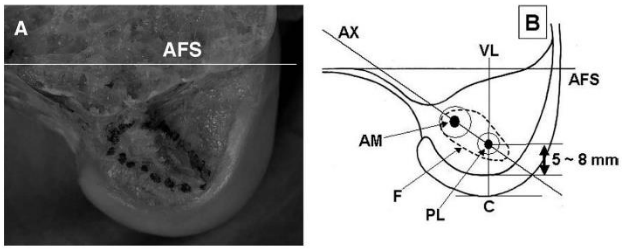
現在の技術では native な ACL と同等の機能が得られる手術方法は骨孔を作成して腱を移植する手術しかない。様々な解剖学の報告が出ているが最適な骨孔の作成位置に関しても未だ議論されている。以前は、膝を屈伸した際に再建靭帯の長さや張力をなるべく一定にすべきという考えのもとバイオメカニクスの研究で Isometric point と呼ばれる位置が同定され、この位置での骨孔作成が主流であった。Isometric point は右図の"Iso"に相当する場所で、anatomical な骨孔位置よりもやや前方で高い位置となる。そのため、膝を伸展したときに移植腱が顆間前方にぶつかってしまう(graft impingement)が生じるため、手術中に顆間前方の骨を削る(notch plasty)が必要であった。



Graf B et al, Personal Communication, 1987

10. 解剖学的 ACL 再建術

2004 年安田ら ACL の付着位置の解剖研究から、native な ACL の付着部に 2 つの骨孔を作成し、正常靭帯に近い靭帯を再建する解剖学的再建術を報告した。この報告以降、解剖学的な再建が本邦を中心に世界的に行われるようになった。

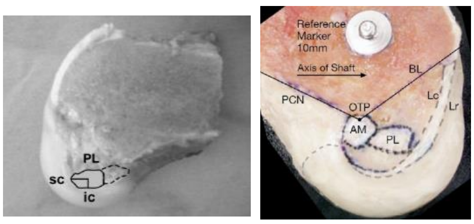


現在解剖学的 ACL 再建は形態的にも機能的にも native な靭帯を再現することと定義され、理想的な解剖学的再建を施行するための様々な手術方法が考案されている。

Yasuda K et al, Arthroscopy, 2004

11. ACL 大腿側付着部における解剖研究

ACL 大腿側付着部に関する解剖研究は過去にも多くの報告があるが、報告によって ACL の付着部として認識しているエリアは広く認識しているものや狭く認識しているものまであり、ばらつきがあった。このばらつきが生じる原因の一つに 2014 年に Mochizuki らが報告した fan-like extension fiber という新しい概念によるものが考えられる



Ferretti M, Arthroscopy, 2007

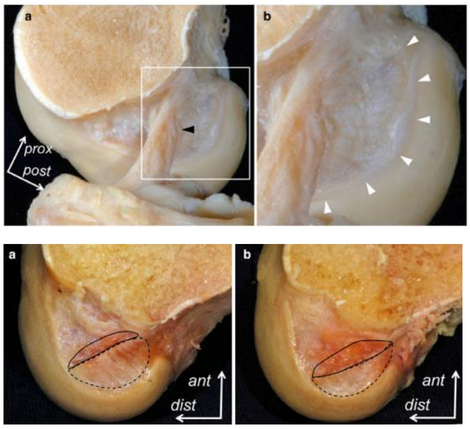
Siebold R, Arthroscopy, 2008

12. Fan-like extension fibers について⑥

望月らは ACL には線維が折れ曲がるところがあることに着目し、折れ曲がるところより後方の線維を fan-like extension fibers と呼称した。Fan-like extension fibers は膝の屈曲伸展をしても線維方向が変化しない特徴があり、後方の軟骨面まで扇状に広がっている。

fan like extension fibers に対して ACL の実質部のことを mid-substance と呼び、望月らはこの 2 つの領域に区別して、面積などの評価を行った。

本研究は、更にこれを AM と PL に分けて評価した初めての研究である。④⑥



Mochizuki T et al, KSSTA, 2014

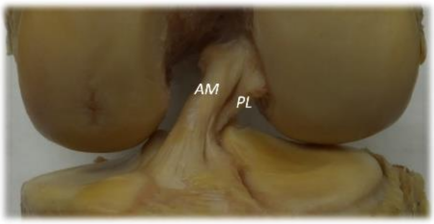
論文の補足説明

1. 現在 ACL 再建を行う上でどのような問題があってこの研究を企画したか。この研究結果によって ACL 再建術式の何が改善されるか。②③

   ACL 再建術は近年技術が向上し良好な成績が得られる手術となってきている。今後さらなる向上を目指すためには、より解剖学的な再建をする必要があると考えられている。解剖学的再建とは、機能的にも形態的にも native な ACL を再現することとされているが、現在の前十字靭帯再建は、得られるグラフトのサイズで再建される ACL のサイズが決定されており、native な ACL と比較するとサイズが太すぎたり細すぎたりしてしまう可能性がある。大腿側フットプリントのサイズを詳細に検討することで、将来的にはオーダーメイドの ACL 再建が可能になる可能性がある。

2. AM bundle と PL bundle 線維の fan-like extension fiber の境界はどのように判断したか⑤

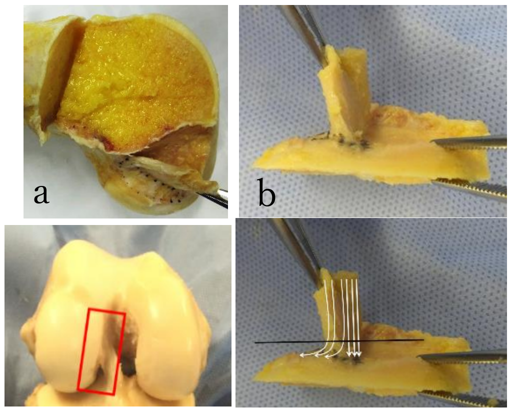
   膝を 90° 屈曲させると、AM bundle は緊張し、PL bundle は弛緩する。肉眼的に AM と PL の線維を同定して fanlike extension fibers まで追っていき、尖刃で線維を分けた。過去の報告も同様の手法を用いて行っている。



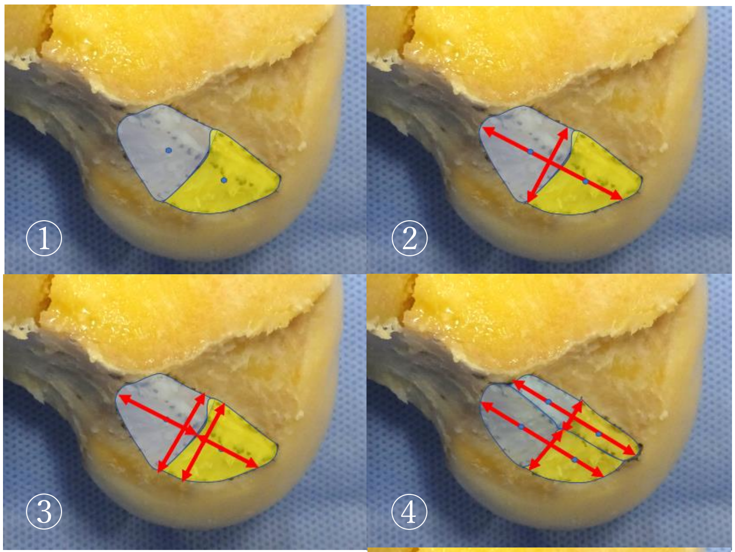
3. Fig.1 の解説

   図 a は ACL の折れ曲がる点を表したもので、この折れ曲がる点で mid-substance と fan-like extension fibers を分けた。Fan-like extension fibers は外側顆の深く低い位置（図中では左下の方向）に存在した。

   図 b は左下図の様に顆間窩外側壁を摘出して横から見た図である。ACL を折れまげて見ると、顆間窩外側壁と ACL は T 字状に観察される。ACL の線維は右下図の様に折れ曲がるところで後方へ線維を広げている構造をしていた。



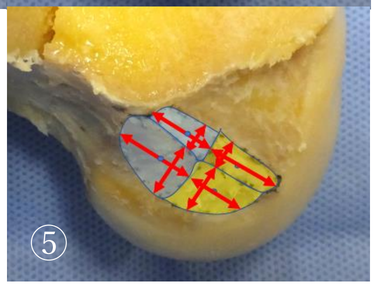
4. Fig.3 の解説



①画像解析ソフトの Image J を用いて AM と PL の領域をプロットすると、面積および中心点が算出される。

②Siebold の報告に準じて、それぞれの中心点を結ぶ線を ACL の軸として「長さ(length)」と定義した。
ACL の軸より垂線を引いて最も長いところの長さを「幅(width)」と定義した。

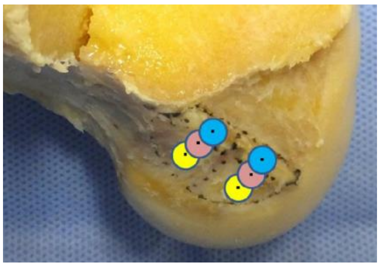
③同様に AM と PL の長さと幅をそれぞれ計測した。
④⑤同じ計算方法で mid-substance および fan-like extension fibers について長さ、幅、面積について計測した。

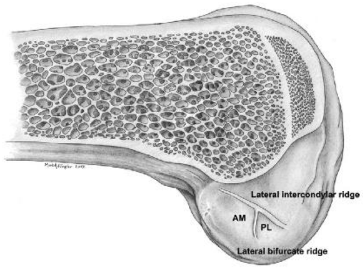


Siebold R, Arthroscopy, 2008

5. Fig. 4 の解説と骨孔位置について①

右図の 6 つの円は青は mid-substance、赤は ACL 全体、黄色は Fan like extension fibers の AM と PL の中心点である。現在、大きく分けて青の位置に骨孔を作成するか、黄色の位置に作成するかで議論が分かれている。当院では mid-substance の付着部に再建することが望ましいと考え、青の位置に骨孔を作成することを目標としている。
手術中は Lateral Intercondylar ridge（別名 Resident's ridge）と呼ばれる骨性隆起を指標に ACL の作成を行っている。① ACL の mid-substance は Lateral Inter condylar ridge のすぐ後方に存在することが報告されている。





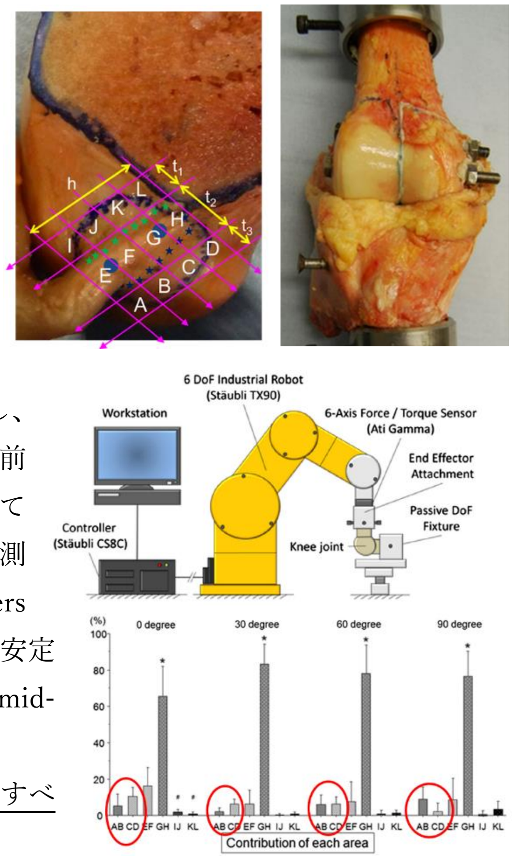
Ferretti M, Arthroscopy, 2007

6. Kawaguchi らの論文との相違⑥

本研究は解剖研究であるのに対して Kawaguchi らは ACL 大腿側付着部における、バイオメカニクスの研究を報告した。⑥ ACL 付着部前方にも fan like extension fibers が存在することを指摘し、anterior fan like extension fibers と呼称し、望月らが報告する fan like extension fibers は posterior fan like extension fibers と呼称した。

anterior および posterior fan like extension fibers, mid-substance の 3 つのエリアを顆間の天蓋部と平行に 4 分割し、右図のように ACL を 12 個の領域に分けて実験を行った。前後方向に負荷をかけて、A から順番に ACL 付着部を切除していき、それぞれの領域がどの程度安定性に寄与するかを計測した。ABCD に当たる領域が posterior fan like extension fibers の領域で、寄与する割合は約 15%という結果だった。一番安定性に寄与していたのは GH のエリアでこれは AM の mid-substance にあたる領域であった。

以上の結果から骨孔作成は mid-substance の位置に作成すべきと考え、Kawaguchi らの論文を引用した。⑥



Kawaguchi Y et al, Arthroscopy, 2015