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Graft choice and graft fixation in PCL reconstruction

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Abstract Several grafts and several fixation techniques have been introduced for PCL reconstruction over the past years. To date, autograft and allograft tissues are recommended for PCL reconstruction, whilst synthetic grafts should be avoided. Autograft tissues include the bone-patellar tendon-bone graft, the hamstrings and the quadriceps tendon. Allograft tissues are increasingly being used for primary PCL reconstruction. The use of allograft tissues requires a number of formal prerequisites to be fulfilled. Besides the previous mentioned graft types allograft tissues include Achilles and tibialis anterior/posterior tendons. To date no superior graft type has been identified. Several techniques and devices have been used for fixation of a PCL replacement graft. Most of these were originally developed for ACL reconstruction and then adapted to PCL reconstruction. However, biomechanical requirements of the PCL differ substantially from those of the ACL. To date, requirements for PCL graft fixations are not known. From a systematic approach femoral graft fixation can either be achieved within the bone tunnel (nearly anatomic) with an interference screw or outside the bone tunnel on the medial femoral condyle using a staple, an endobutton or a screw. Tibial graft fixation can be achieved either with an interference screw in the bone tunnel or with a staple, screw/washer or sutures tied over a bone bridge outside the bone tunnel (extra-anatomic). An alternative fixation on the tibial side is the inlay technique that reduces the acute angulation of the graft at the posterior aspect of the tibia. Further research is necessary to identify the differences between the various fixation techniques.

Keywords PCL reconstruction · Allografts · Autografts · Graft fixation · Biomechanical properties

Introduction

The interest in reconstructing an insufficient posterior cruciate ligament (PCL) has increased over the past years. Whilst many variables will affect the outcome of surgery, an essential part during the planning of this procedure is the choice of graft material and the appropriate fixation technique. In this article we provide an overview of graft materials that may be used for PCL reconstruction and of the various fixation techniques of such graft options.

Graft choice

Ideal PCL graft

The characteristics for an ideal graft for the replacement of the PCL are summarized in Table 1.

It becomes clear that the ideal PCL graft does not exist. This is mainly due to the fact that the PCL is a complex anatomical structure that has at least two functional bundles, the anterolateral and the posteromedial bundle.

Table 1 Characteristics for the ideal graft for PCL reconstruction

Structural properties identical to intact PCL
Identical geometrical shape
No harvest site morbidity
Easy graft insertion (graft passage)
Secure fixation in an anatomic position
Fast graft incorporation

The femoral insertion site on the medial femoral condyle spans over an area of about 32 mm in length. The tibial insertion is located far back at the posterior aspect of the tibia, which makes it technically demanding to find an attachment for a graft in this location.

Despite these shortcomings, several aspects have to be considered when a graft is selected for reconstruction of the PCL. First, one should choose a graft with similar structural properties as the intact PCL. One should check on the availability of the graft in the individual patient, and be aware of the specific design aspects of the graft and ensure that they match requirements for the chosen operative technique. If associated lesions are present that are planned to be addressed during surgery, the requirements for other graft materials have to be considered. Finally one has to be familiar with various options of graft fixation.

Autografts

To date autograft and allograft tissues are recommended for PCL reconstruction while synthetic tissues should be avoided [12]. Autograft materials include the bone-patellar tendon-bone graft (BPTB), a quadriceps tendon graft and the hamstring tendons. Each of these grafts has specific design properties (Fig. 1). The bone-patellar tendon-bone graft usually consists of a 10–12 mm strip of the patellar tendon with a bone block of 20–25 mm length at each end [10]. With the bone blocks placed in the tunnels the BPTB will incorporate via a bone to bone healing [26]. Bone to bone healing is believed to be complete by 4–6 weeks, leaving the ligament to bone insertion intact.

The quadriceps tendon graft consists of a 10–12 mm strip of the quadriceps tendon with a bone block from the proximal patella [13]. The quadriceps tendon is thicker than the patellar tendon, thus providing a larger cross sectional area than a patellar tendon graft of equal width [32]. However, ultimate load is not increased with the higher cross sectional area [32]. The quadriceps tendon can usually be retrieved with a free tendon end of approximately 8–10 cm. On one side of the graft the bone block can be fixed either in a bony tunnel or using an inlay technique on the tibial side. The free tendon end has to be fixed in a bone tunnel and requires tendon to bone healing on the opposing end of the graft. The quadriceps tendon may also be used as a split graft to allow double bundle reconstruction and two bone tunnels on the femoral side.

Hamstring grafts are normally used as multiple stranded grafts [7]. In PCL reconstructions the grafts have to be longer than in ACL reconstruction. Therefore, a double semitendinosus and a double gracilis graft configuration is mostly favoured. The tendons can be either used as a quadruple stranded graft in a single tunnel technique or as double stranded grafts in a two tunnel technique. Osseous integration requires tendon to bone healing, which is influenced by the fixation type. If the tendon tissue is placed in a bone tunnel, usually an indirect tendon-to-bone interface with so called Sharpey-like fibres will develop [29]. If a tight contact between tendon tissue and bone tunnel wall can be achieved (e.g. with an interference screw) a new direct ligament-to-bone insertion (with a calcified and non-calcified cartilage layer) may develop over time [37].

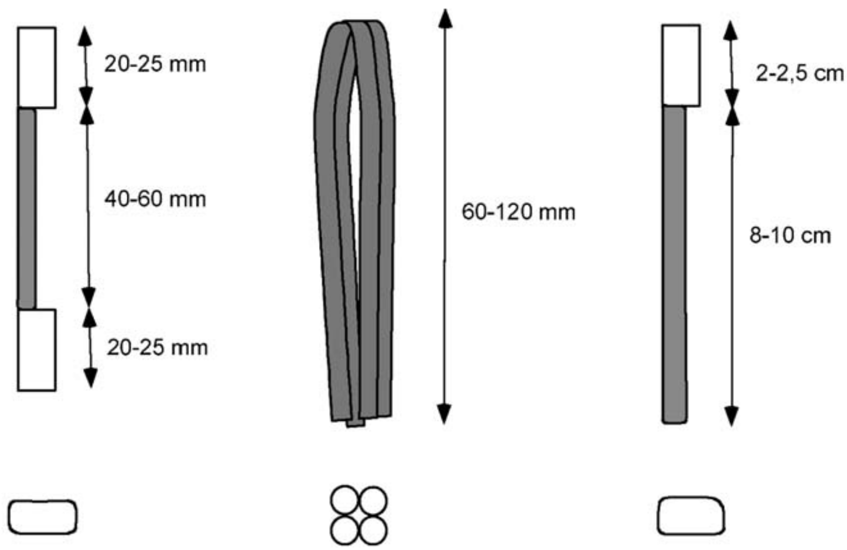

Fig. 1 Schematics of frequently used autograft tissues for PCL reconstruction. Bone patellar tendon bone graft, quadruple hamstring graft, quadriceps tendon graft

Table 2 Comparison of structural properties of the intact ACL, intact PCL and BPTB, quadriceps tendon and hamstring tendons

	Maximum strength (N)	Stiffness (N/mm)	*X*-area (mm^2)	Length (mm)
Intact ACL	2160±157 [39]	242±26 [39]		38 [14]
PCL-AL bundle	1494±390 [19]	306±130 [19]		38–42 [14]
PCL PM bundle	242±66 [19]	75±31 [19]		
BPTB (10 mm)	2977±516[9]	455±56 [9]	36.8±5.7 [9]	52.2±4.8 [9]
Quadriceps tendon (10 mm)	2352±495[32]	325,6±70 [32]	64.6± 8.4 [32]	86.4±9.0 [32]
Quadruple semi-t./gracilis	4090±295 [15]	776±204 [15]	52±5 [15]	100–120 mm

The structural properties of the three common autografts are summarized in Table 2. It should be noted that the ultimate load in the intact PCL was determined to be around 1800 N for the entire ligament [19]. However, these data have been measured in old cadaveric knees. If the relationship between age and structural properties follows the same pattern in the PCL as in the ACL, the ultimate load in a young human may be as high as 3000–5000 N (Table 2). In addition to the structural properties of the graft material, which primarily characterize the mechanical behaviour of the intraarticular graft portion, it is important to note that the biomechanical function of the graft in vivo largely depends on the mechanical characteristics of the entire graft construct including its fixation to bone [20]. Issues of graft fixation, however, will be discussed in the second section of this article.

Graft choice mainly depends on the individual preference of the surgeon and is influenced by technical considerations and harvest site morbidity. However, there is no agreement in the literature on the relevance of potential harvest site morbidity. Concerns with the use of BPTB include anterior knee pain, tenderness over the bony defects and problems with kneeling. Further, there is a risk of patellar fracture and the weakening of the extensor mechanism, which is a synergist to the PCL, and the potential risk that the graft is too short for use as a PCL substitute. Potential weakening of a PCL synergist is also a concern when using a quadriceps tendon graft. Concerns with using hamstring tendons include weakening of the medial aspect of the knee, which may be clinically relevant in certain sports activities such as dancing and skiing and when associated lesions to the medial collateral ligament and/or the posteromedial corner are present.

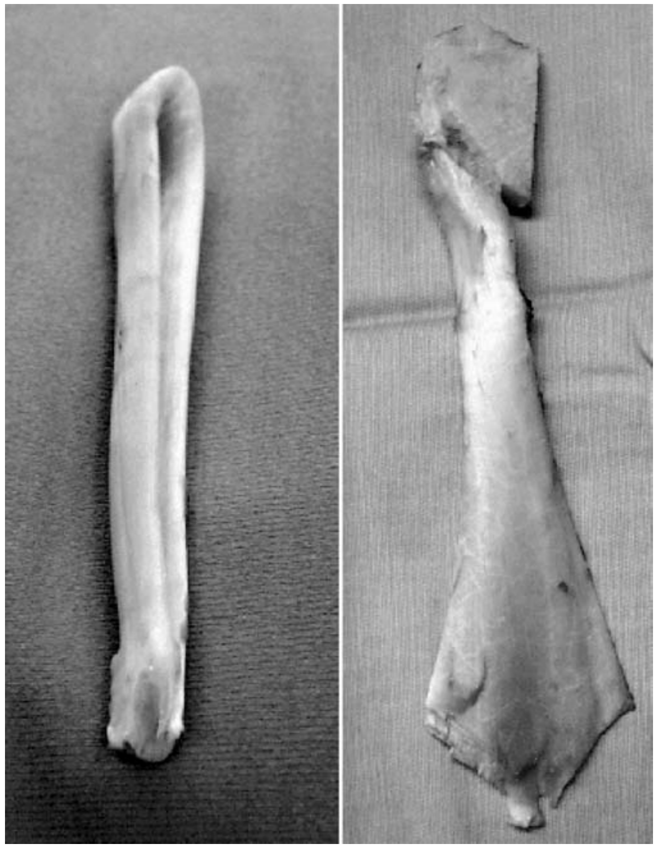

Fig. 2 Examples of allograft tissues. Tibialis anterior tendon providing a homogenous graft with a diameter of 8 or 9 mm and a graft length of 9 to 10 cm as a double stranded graft. Achilles tendon graft with a bone block from the calcaneus on one side and a free tendon end on the other side. Both tissues represent strong grafts with a high cross sectional area and dense collagen tissue

Allografts

Recently allograft materials have become increasingly popular for PCL reconstruction. Specifically in cases with double bundle reconstruction, or in combined injuries such as PCL and posterolateral corner instability, allograft material can substantially reduce harvest site morbidity and operating time [16]. In clinical practice, reconstruction of the posterolateral corner has become a frequent procedure in addition to the isolated PCL reconstruction. Experimental studies have shown for the combined injury of the PCL and the posterolateral structures that isolated PCL reconstruction alone will not be sufficient to restore normal knee kinematics [17].

For PCL reconstruction, several allograft options exist in addition to the aforementioned autograft tissues, such as Achilles, tibialis anterior and tibialis posterior tendons. The latter three tissues all provide strong and dense collagen tissue and have sufficient length for almost all PCL reconstruction techniques (Fig. 2).

Advantages of allograft tissue are the lack of graft site morbidity, reduction of operating time and the increased graft diameter with more collagen tissue of some of the grafts (i.e. Achilles, tibialis anterior tendons).

However, using allograft tissue requires consideration of certain issues. First of all, legal issues have to be cleared. In certain countries such as France allograft tendons are not obtainable. Further issues include availability, price, risk of disease transmission (HIV, hepatitis), tissue quality and graft incorporation. Despite these concerns, at the present time many centres all over Europe use allograft materials routinely for PCL reconstruction. Prerequisites for the use of allografts include information on the origin of the tissues, donor age, tissue retrieval under sterile conditions, fulfilment of legal requirements for storage (only deep frozen or cryopreserved materials) and screening of the donors for possible disease transmission.

Design considerations

According to the graft design, materials can be divided into three groups:

1. Grafts with two bone blocks on each side
   – BPTB
2. Grafts with one bone block and one free tendon end
   – Quadriceps tendon
   – Achilles tendon
3. Free tendon grafts
   – hamstring tendons
   – tibialis anterior or posterior tendon

The intraarticular distance for a PCL substitute approximates 4 cm. Thus, the minimum graft length should be about 8–10 cm, dependent on the technique to be used. In cases of cortical bone fixation grafts may have to be as long as 20 cm.

With the BPTB, graft fixation distance is defined by the intratendinous length of the graft. In rare cases of a short patellar tendon, the BPTB graft may be too short for PCL reconstruction. As the bone blocks cannot be split without the risk of graft destruction, the BPTB is not suitable for a double bundle reconstruction alone. When using a tibial bone tunnel, passing of the graft around the posterior edge may be difficult because of the rigidity of the bone block and may be a technical challenge at surgery.

When using a graft with one bone block and one free tendon end, graft passage is easier when the free tendon end is pulled in first. It allows the fixation of the bone block in a position close to the tunnel entrance. The geometrical shape of the ligament insertion of the Achilles and the quadriceps tendon helps to reduce shear forces when using the bone block on the tibial side close to the original PCL insertion. The free tendon end allows variable fixation close to the joint in an anatomical position. Further advantages with an Achilles and a quadriceps tendon are the possibility to split the free tendon end and the ability to use them for a double socket reconstruction on the femoral side.

When using hamstring tendons it is important to realize the requirement of a longer graft in comparison with the reconstruction of an ACL. Therefore, both the semitendinosus and gracilis tendon will have to be used to prepare a quadrupled hamstring graft. Graft passage of soft tissue grafts should usually not be problematic as long as the dimensions of the bone tunnel are matched with the diameter of the graft. Care must be taken in suturing the graft ends when the free end is the leading end in graft passage, so that tissue bulking can be prevented. A double socket reconstruction can be performed when two double strands are prepared from both tendons. If reconstruction of the posterolateral corner is planned to be simultaneously performed with autograft hamstring tendons, another graft must be retrieved from the contralateral knee.

In the current literature there are no comparative studies on graft selection in PCL reconstruction. Therefore to date no superior graft has been identified.

Graft fixation

The purpose of graft fixation is to provide a mechanical link between the graft and the bone during the early postoperative period, until biological incorporation of the graft is complete. In the past a wide variety of techniques for graft fixation in PCL reconstruction have been used. However, most of these fixation techniques were originally developed for ACL reconstruction and were adapted for use in PCL reconstruction. Since several biomechanical differences exist between the ACL and the PCL, requirements for graft fixation in PCL reconstruction may differ substantially from those known from the ACL.

Knowledge of the in vitro and in vivo forces in the intact PCL is valuable in characterizing requirements for PCL reconstruction. Basic research studies have indicated that the PCL is the primary restraint to posterior translation of the tibia [8]. Thus, forces in the PCL or a PCL replacement graft will increase in response to a posterior load against the anterior aspect of the tibia. However, it has been shown that PCL forces strongly depend on the flexion angle of the knee being highest at 90° of flexion [11, 24]. As an example, forces of the PCL range around 100 N at 90° of knee flexion when a posterior load of 100 N is applied to the proximal part of the tibia [11]. Also, each fibre bundle may react differently. The anterolateral bundle has its highest forces at 90° of knee flexion, and forces near extension and full flexion are small. In contrast, forces in the posteromedial bundle are larger in extension and full flexion, and are reduced through the mid range of motion [11, 28].

Furthermore, it has been shown that associated insufficiency of the posterolateral structures of the knee will increase forces in the PCL and a PCL replacement graft by up to 30%. This effect is quantitatively largest at low flexion angles [18, 35]. Additionally, hamstring activity will cause high PCL forces, again this effect being greatest at 90° of knee flexion [21]. Lastly, it is believed that the influence of gravity during the supine position may cause a posterior sag force on the proximal tibia, thus loading the PCL.

Whilst data on forces in the PCL under experimental conditions (in vitro, i.e. cadaveric testing) have been fairly consistent among research groups, there is a high level of controversy in the literature about forces in the PCL under in vivo conditions. To date one can only speculate on the forces in the PCL under activities of daily living and activities of early rehabilitation exercises, as most authors have used calculations to estimate these forces. Morrison calculated the mean peak force in the PCL during walking to be 330 N [25]. Zheng et al. estimated the peak force in the PCL during knee extension (open chain) to be about 950 N, whilst forces were as high as 1860 N during full squat and a leg press (closed chain exercise) [40]. Others estimated forces during a squat exercise to be as high as 2500 N [34].

Whilst absolute values for graft fixation are not known, there is an agreement in the literature that the following measures can help to reduce loading of the PCL and therefore being protective for graft fixation in PCL reconstruction:

1. Restoration of the posterolateral structures of the knee at the time of PCL reconstruction
2. Limitation of knee flexion to 30° during the early postoperative phase
3. Avoidance of active, isolated hamstring activity during early rehabilitation, specifically at high flexion angles
4. Elimination of the negative effects of gravity in the supine position by means of a posterior tibial support brace

Pull-out studies for strength analysis of various graft fixation devices have mostly mimicked conditions relevant for ACL reconstructions, and it is as yet unknown if these conditions apply to PCL reconstructions as well. Essential differences between PCL and ACL reconstructions are the intraarticular length of the graft, the acute angulation of the tissue at the entrance into the bone tunnels, the length of the bone tunnel and the quality of bone at the location of graft fixation. Clinical experience reveals that the posterior aspect of the tibia has fairly soft cancellous bone, so interference screw fixation may not provide the mechanical strength that is achieved in comparable techniques of ACL reconstruction.

When evaluating the literature on experimental studies of graft fixation it is difficult to compare results, as the methods for testing vary widely. These variables include the tested specimen type (cadaveric, porcine, bovine, etc.), the age of the specimens, the experimental set up and the loading conditions. Recently, it has been proposed that in order to characterize the mechanical strength of graft fixation not only maximum pull out force and stiffness should be measured, but also graft elongation and slippage in response to cyclic loading should be included into the testing protocol [20, 24, 30].

The reader of scientific articles has to critically evaluate the literature on the issues mentioned above. However, due to the lack of data on PCL graft fixation in the literature, several data on graft fixation from the ACL literature are reported in this section.

In terms of graft fixation one should consider the following issues:

- Pull-out strength
- Stiffness
- Resistance to elongation and slippage
- Promotion of graft healing and graft incorporation
- Possibility of revision

Besides the mechanical issues of fixation, the biological sequelae on graft healing and graft incorporation have to be considered. Whichever means is used, the surgeon should always keep in mind the possibility of revision. Specifically, titanium fixation devices in the back of the tibia may cause a problem in revision PCL surgery.

The techniques of graft fixation can be divided into nearly anatomic and extra-anatomic fixation [30]. “Anatomic” or better “nearly anatomic” refers to the fact that the fixation site is close to the anatomic insertion of the ligament. “Extra-anatomic” fixation implies that the fixation is away from the anatomic insertion of the ligament. All cortical fixations outside the bone tunnel are extra-anatomic. In the following sections various techniques for femoral and tibial graft fixation are discussed.

Femoral graft fixation

In a one-bundle PCL reconstruction a bone tunnel (outside-in) or a blind ended socket (inside-out) are created into the medial femoral condyle. The following forms of fixation can be used:

1. Anatomic
   - Interference screw within the bone tunnel (metal or bioabsorbable)
2. Extra-anatomic
   - Button or Endobutton fixation on the cortex of the femoral condyle
   - Staples/screws and washer for direct fixation of graft material to bone

The various techniques of femoral graft fixation are illustrated in Fig. 3.

Interference screws can be introduced from outside-in (from the medial cortex of the condyle) or inside-out (i.e. from the joint into the tunnel). Both grafts with bone blocks and soft tissue grafts can be fixed with an interference screw. Fixation strength has been reported in the literature between 200 and 800 N for this kind of fixation [6,

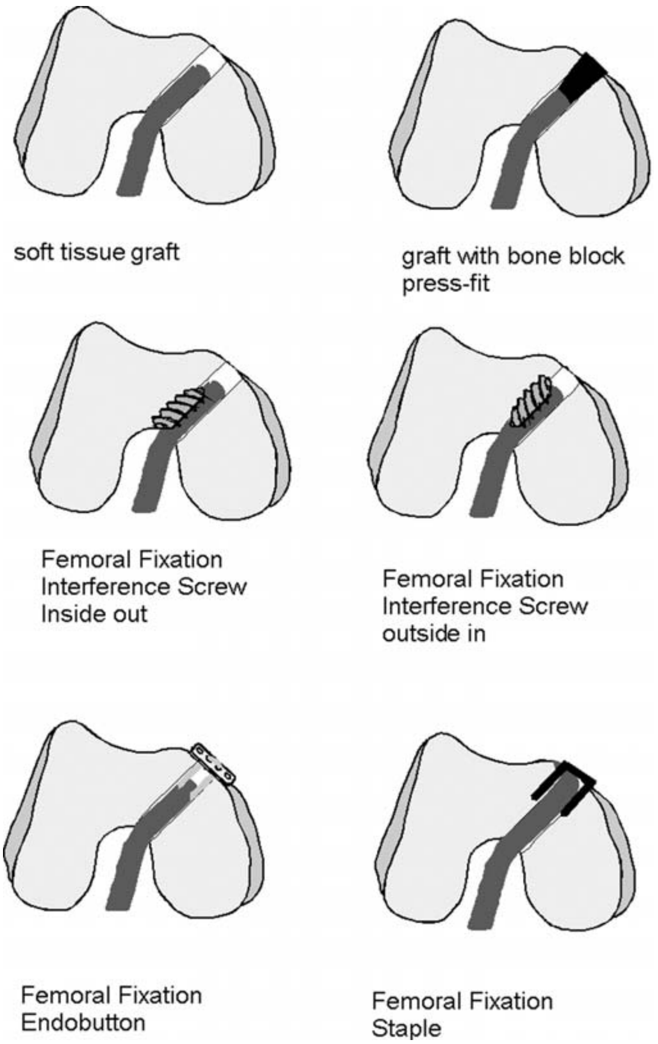

Fig. 3 Principles of femoral graft fixation (single bundle)

31]. Additional pull out strength can be achieved by adding a back up fixation device (so-called hybrid fixation) to the end of the graft [27, 38]. If a bone block is used on the femoral side, a press fit fixation can be achieved when the bone block is prepared in a slightly wedge-shaped form.

Extra-anatomically, grafts can be fixed to the cortex of the medial femoral condyle outside of the bone tunnel. Clinical experience reveals that prominent fixation devices over the medial femoral condyle can cause irritation of the soft-tissue and may cause tenderness and pain with knee motion. Furthermore, if an Endobutton fixation is used in an inside-out fashion, the Endobutton may be located within the joint and may cause synovial irritation.

In case of a double-bundle reconstruction, two diverging sockets or bone tunnels are created in the medial femoral condyle. Fixation can be achieved both by anatomic or extra-anatomic fixation. A mixture of both techniques, rather than introducing one screw in each tunnel, is believed to be advantageous in order to avoid collapse of the bone bridge between the two tunnels.

Table 3 provides an overview on the structural properties of femoral fixation techniques.

Recently, double-bundle reconstruction has been advocated by several authors as it appears to better restore normal knee kinematics than a single bundle reconstruction [18, 28]. There is an increasing number of clinicians who create two tunnels in the femoral condyle for double-bundle reconstruction, to better replicate the broad insertion site area of the PCL. In most cases, two sockets are created arthroscopically in an inside-out fashion. Fixation of the posteromedial bundle can be achieved by insertion of a second interference screw or through an Endobutton. Care should be taken when using two interference screws, as the wall between the two tunnels may collapse with this procedure.

The principles of femoral double tunnel fixation are illustrated in Fig. 4.

Tibial graft fixation

Tibial graft fixation can be achieved in three ways:

1. With a bone tunnel technique
   – Anatomic: metal or bioabsorbable interference screw
   – Extra-anatomic/cortical: (a) sutures /screw post, (b) screw and washer over graft tissue, or (c) staple over graft tissue
2. Without a tibial bone tunnel
   – Tibial onlay/inlay technique
   – direct fixation of a bone block to the posterior aspect of the tibia (onlay) or into a bony trough at the posterior aspect of the tibia (inlay) using a lag screw or staples.

Table 3 Structural properties of femoral graft fixation

Fixation device	BPTB		Hamstrings		Quadriceps	
	Pull-out (N)	Stiffness (N/mm)	Pull-out (N)	Stiffness (N/mm)	Pull-out (N)	Stiffness (N/mm)
Interference screw (bioabsorb.)	621±139 [22]	76±20 [22]	480±133 [1]	126±14 [1]	339±185 [5]	54±15 [5]
Interference screw (metal)	774±154 [22]	80±15 [22]	242±91 [9]			
Endobutton	554±276 [33]	27±13 [33]	520±50 [33]	35±22 [33]	445±93 [5]	24±5 [5]

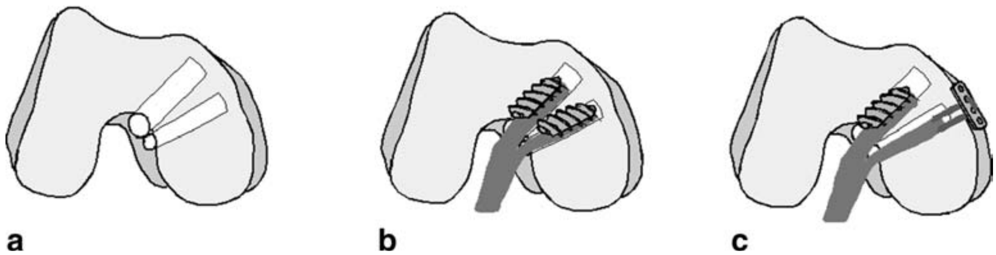

Fig. 4a–c Principles of femoral double tunnel fixation. **a** Creation of two sockets arthroscopically in an inside-out fashion. **b** Femoral fixation with two inside-out interference screws. **c** Femoral fixation with one inside-out interference screw and one Endobutton

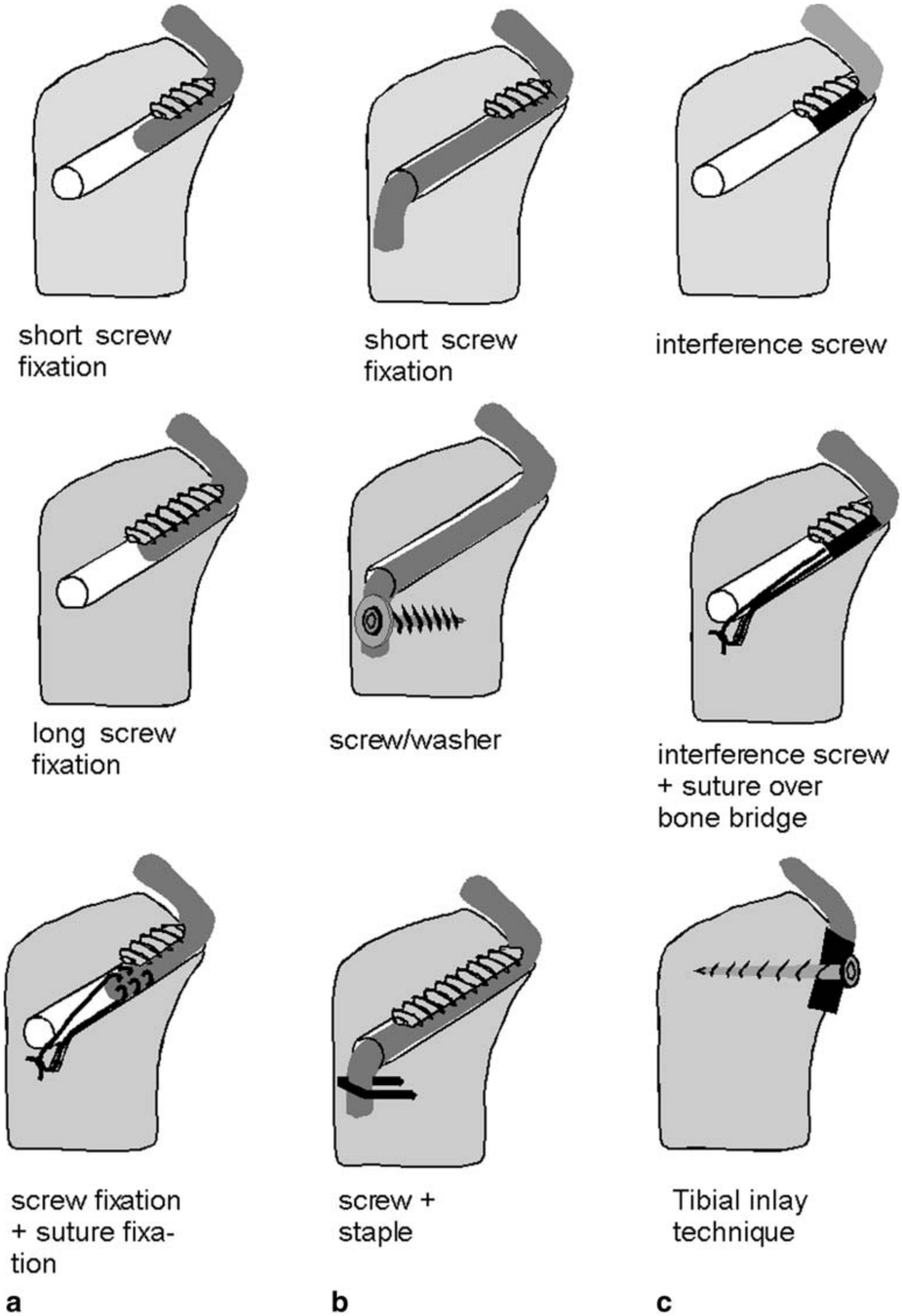

Fig. 5a–c Principles of tibial graft fixation. **a** Short soft tissue graft. **b** Long soft tissue graft (e.g. allograft). **c** Graft with bone block

Table 4 Structural properties of tibial graft fixation

Fixation device	BPTB		Hamstrings		Quadriceps	
	Pull-out (N)	Stiffness (N/mm)	Pull-out (N)	Stiffness (N/mm)	Pull-out (N)	Stiffness (N/mm)
Interference screw (bioabsorb.)	431±37 [4]	66±9 [4]	507±93 [36]	58±14 [36]	293±137 [5]	45±15 [5]
Interference screw (metal)	293 [23]	42 [23]	419±77 [36]	40±11 [36]		
Suture/post	396±124 [33]	27±13 [33]	573±109 [33]	18±5 [33]		
Screw/washer			821±219 [33]	29±7 [33]		
Staple	129±15 [33]	11±2 [33]	137±23	9±1		

Table 5 Comparison of the tibial tunnel and tibial inlay technique

Advantages	Disadvantages
Tibial tunnel technique	
Arthroscopic procedure	Acute graft angulation at tibialtunnel entrance
No hardware necessary at posterior tibia	More graft thinning, fraying and elongation?
Tibial inlay technique	
No acute angulation at posterior tibia	Open approach
Experimental studies:	Prone position
Less AP laxity	Difficult to revise
Less elongation/graft fraying	

Figure 5 illustrates the various techniques for tibial graft fixation. Table 4 provides an overview of the structural properties of the tibial fixation techniques.

Interference screws provide the opportunity to fix the graft in a more anatomical fashion. In soft tissue grafts significant increase in strength can be achieved when using longer screws [9, 31]. However, clinical experience shows that the torque produced during introduction of these screws into the tibial bone tunnel may be small, suggesting weak cancellous bone at the posterior aspect of the tibia. Therefore, many surgeons suggest additional fixation on the anterior aspect of the tibia as a backup for axial loading of the graft. Also, cortical fixation alone can be performed for tibial graft fixation [16].

An alternative fixation technique on the tibial side is the tibial inlay technique. It was originally developed in order to improve graft and fibre orientation near the tibial attachment site [2]. In this technique a bone block is placed into a bony trough about 1 cm distal to the tibial PCL insertion site area. The bone block is usually fixed with one or two cancellous screws from posterior. A theoretical advantage of the tibial inlay technique is that the acute angulation of the graft at the posterior cortex of the tibia may be reduced compared to a tibial tunnel technique [3]. This acute angulation has also been referred to as the “killer turn”. The major disadvantage of the inlay technique is that it requires an open posterior approach to the knee. Frequently the patient is turned into the prone position. Using the lateral decubitus position allows for both an anterior and posterior approach without turning the patient. Another disadvantage is the difficulty with hardware retrieval from the posterior aspect of the tibia in revision cases.

The inlay technique has raised a lot of controversy in the literature. Recent experimental data in cadaveric studies have suggested that the tibial inlay technique may have biomechanical advantages over a tunnel technique with respect to thinning and fraying of the graft at the posterior cortex of the tibia and to reduced AP laxity of the knee [3, 24]. However it remains unknown whether the tested loading conditions reflect the actual clinical situation. There appears to be the possibility of overconstraining the knee joint when reconstructing the PCL with the tibial inlay technique [3]. Other authors could not confirm a functional advantage of the inlay technique from tests with a robotic/universal force moment sensor test system (Harner, personal communication). Table 5 summarizes the advantages and disadvantages of both techniques.

Conclusion

In terms of graft selection the surgeon may select from various auto- or allografts. Specific structural properties and design characteristics of each graft have to be considered, and will have an effect on the operative technique. To date no superior graft has been identified, as there is a significant lack of comparative studies on the mechanical properties of the various existing graft options for PCL reconstruction in the current literature.

In terms of graft fixation, various techniques have been used in PCL reconstruction. Overall we are lacking experimental data of these fixations under the specific testing conditions of PCL reconstruction. We can distinguish between nearly anatomic and extra-anatomic fixation when using a bone tunnel technique. There has been a trend towards a hybrid fixation (with an extracortical back up) in a tibial bone tunnel technique. On the tibial side the tibial inlay technique is an alternative for graft fixation. To date no superior technique of graft fixation has been identified.

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