Quadrant Specific Tibial Interference Screw Fixation Allows Constant Displacement of Soft Tissue Grafts Inside Misplaced Tibial Tunnels: A Porcine Anterior Cruciate Ligament Quantitative Assessment Study

La fijación con tornillo de interferencia tibial cuadrante específico permite un constante desplazamiento de los Injertos de tejido dentro de tuneles tibiales mal poscionados: Análisis cuantitativo de ligamento cruzado anterior en porcinos

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Abstract

Background The most common technical error during anterior cruciate ligament (ACL) reconstruction is incorrect tunnel placement. It remains unclear if a misplaced tibial tunnel may be corrected intraoperatively.
Aim To measure the displacement of soft-tissue grafts with tibial interference screws.
Materials and Methods Ex-vivo experimental study in 28 porcine knees. The flexor tendon of the posterior limb was harvested, doubled and sized to fit through a 9-mm misplaced tibial tunnel. The specimens were divided into 4 groups according to the quadrant of entry (anterior [A], posterior [P], medial [M], or lateral [L]) of a 9-mm tibial interference screw in relation to the graft. A millimetric ruler was placed at the tibial plateau, which was photographed with a an EOS T6 (Canon Inc., Ōta, Tokio, Japan) camera, and the image was digitalized and scaled to size. The length and direction of the graft displacements were measured with Adobe Photoshop CC 2019 (San José, CA, US). The mean differences among the groups were analyzed through one-way analysis of variance (ANOVA). The statistical analysis was performed using the Statistical Package for the Social Sciences (IBM SPSS Statistics for Windows, IBM Corp., Armonk, NY, US) software, version 25.0 ($p \leq 0.05$)

Keywords
- anterior cruciate ligament
- soft-tissue graft
- tibial tunnel
- screw displacement

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Results The mean lengths of the graft displacements were similar among the groups: A – 4.4 mm; P –4.6 mm; M – 4.5 mm; and L – 4.3 mm, without statistically significant differences ($p = 0.894$). The mean directions of the graft displacements were also similar among the groups: A – 176° (standard deviation [SD]: ± 15.4°); P – 165° (SD: ± 16.6°); M – 166° (SD: ± 12.1°); and L – 169° (SD: ± 10.6°). No statistically significant differences were found ($p = 0.42$).

Conclusions Regardless of the entry quadrant, constant graft displacement to the opposite side was observed when the tibial screw reached the articular surface. Clinical relevance: a misplaced tibial tunnel may be corrected intraoperatively with a quadrant-specific screw, which must reach the articular surface to produce an effective graft displacement. Nevertheless, we cannot predict the magnitude of this error in every poorly-drilled tibial tunnel; it should be assessed case by case.

Resumen

Introducción El error técnico más común durante la reconstrucción del ligamento cruzado anterior (LCA) es la ubicación incorrecta del túnel. Es incierto si un túnel tibial mal ubicado puede corregirse en el intraoperatorio.

Objetivo Medir el desplazamiento del injerto de tejido blando con tornillos de interferencia tibial.

Materiales y métodos Estudio experimental *ex vivo* en 28 rodillas porcinas. Se cosechó el tendón flexor de la extremidad posterior, que fue duplicado y dimensionado para que pasara a través de un túnel tibial mal posicionado. Las muestras se dividieron en 4 grupos según el cuadrante de entrada (anterior [A], posterior [P], medial [M], o lateral [L]) de un tornillo de interferencia tibial de 9 mm con relación al injerto. Se ubicó una regla milimétrica en la meseta tibial, la cual fue fotografiada con una cámara EOS T6 (Canon Inc., Ōta, Tokio, Japón), y la imagen fue digitalizada, y puesta en escala a tamaño. La distancia y dirección de los desplazamientos del injerto se midieron con Adobe Photoshop CC 2019 (San José, CA, EEUU). Se analizaron las diferencias medias entre los grupos por análisis de la varianza (*analysis of variance*, ANOVA, en inglés) unidireccional. El análisis estadístico se realizó con el programa Statistical Package for the Social Sciences (IBM SPSS Statistics for Windows, IBM Corp., Armonk, NY, EEUU), versión 25.0 ($p \leq 0,05$)).

Resultados La distancias medias de los desplazamientos del injerto fueron similares en todos los grupos: A – 4,4 mm; P – 4,6 mm; M – 4,5 mm; y L – 4,3 mm, sin diferencias estadísticamente significativas ($p = 0,894$). Las direcciones medias de los desplazamientos del injerto también fueron similares entre los 4 grupos: A – 176° (desviación estándar [DE]: ± 15,4°); P – 165° (DE: ± 16,6°); M – 166° (DE: ± 12,1°); y L – 169° (DE: ± 10,6°). No se encontraron diferencias estadísticamente significativas ($p = 0.42$).

Conclusiones Independientemente del cuadrante de entrada, se observó un desplazamiento constante del injerto hacia el lado opuesto cuando el tornillo tibial alcanzaba la superficie articular. Relevancia clínica: el tornillo tibial mal posicionado puede corregirse en el intraoperatorio con fijación proximal en cuadrante específico, y debe alcanzar la superficie articular para generar un desplazamiento efectivo del injerto. Sin embargo, no podemos predecir la magnitud de error en todos los túneles mal brocados, que debe ser evaluada caso a caso.

Palabras clave
- ligamento cruzado anterior
- injerto de tejido blando
- túnel tibial
- desplazamiento de tornillo

Introduction

Anatomy studies have led to a better understanding of the anatomical footprints of the anterior cruciate ligament (ACL),[1] which contributed to the advance from non-anatomical to anatomical reconstructions. The aim is to create a ligament that has the same bony attachments and course as those of the native ligament, and to restore the stability and function of the injured knee.[2–4] Failure of an ACL graft may result from any combination of technical errors, biologic causes, and trauma.[5] Suboptimal tunnel placement is a frequent problem among residents and even experienced surgeons, despite the fact that the insertion points and intraoperative landmarks for anatomical ACL reconstruction are well known.[6,7] This may predispose to early graft impingement and subsequent lack of mobility, persistent instability, and failure.[8] Misplaced tibial tunnels may be addressed intraoperatively with interference screws to shift the graft to a better position to avoid impingement against the lateral femoral condyle.[9]

The purpose of the present study is to quantify the graft displacement of porcine flexor tendons inside the tibial tunnel in terms of length and direction according to four quadrant-specific screw locations.

Hypothesis

In a porcine ACL model, tibial interference screws constantly displace soft-tissue grafts to the opposite side, regardless of the location of the screw.

Materials and Methods

An ex-vivo experimental study was performed on 28 porcine knees. The superficial digital flexor muscle tendon was harvested from the lower portion up to its proximal insertion in all specimens. The ACL ToolBox Instrument Set (Arthrex, Naples, FL, US) was used to prepare the grafts and to perform the bone tunneling. Once harvested, all grafts were cleaned from the remnant tissue and folded to create a double-band construct with both ends stitched using #2 FiberWire (Arthrex) suture. All grafts were sized to fit through the 9-mm block. The knees were mounted on a metal frame, and the tibial plateaus were carefully dissected to preserve the anatomical tibial footprint of the ACL. A tibial ACL marking hook was placed intentionally next the tibial ACL footprint with the compass hand guide set to a 55° angle. A drill-tip guide pin was placed from the anteromedial tibia to the articular surface, which was then drilled with a 9-mm cannulated drill bit to create a misplaced tibial tunnel. The doubled grafts were passed inside the tunnel, and a nitinol guide wire was positioned in a specific quadrant to guide the 9-mm tibial interference polyether ether ketone (PEEK) screw. The grafts were fixed with the tip of the screw at the level of the tibial articular surface (►**Fig. 1**). One specimen suffered a tibial plateau fracture after the placement of the screw of the anterior tunnel, and was excluded from the study. The remaining specimens were divided into four groups according to the location of the tibial interference screw in relation to the graft. In group A ($N = 7$), the interference screw was positioned anteriorly; in group P ($N = 7$), posteriorly; in group M ($N = 7$), medially; and in group L ($N = 7$), laterally to the graft. A millimetric ruler was placed at the tibial plateau, which was photographed with an EOS T6 camera (Canon Inc., Ōta, Tokyo, Japan). All images were digitalized, scaled to size, and taken from the same angle and length at 3 specific moments: the bone tunnel without the graft, with the graft positioned in the tunnel, and with the tip of the tibial screw reaching the tibial plateau (►**Figs. 1** and **2**). The length and direction of the graft displacements were measured with Adobe Photoshop CC 2019 (San Jose, CA, US) (►**Fig. 2**). To assess the correct measurement values, the same procedure was repeated with a digital caliper with a precision of 0.05 mm.

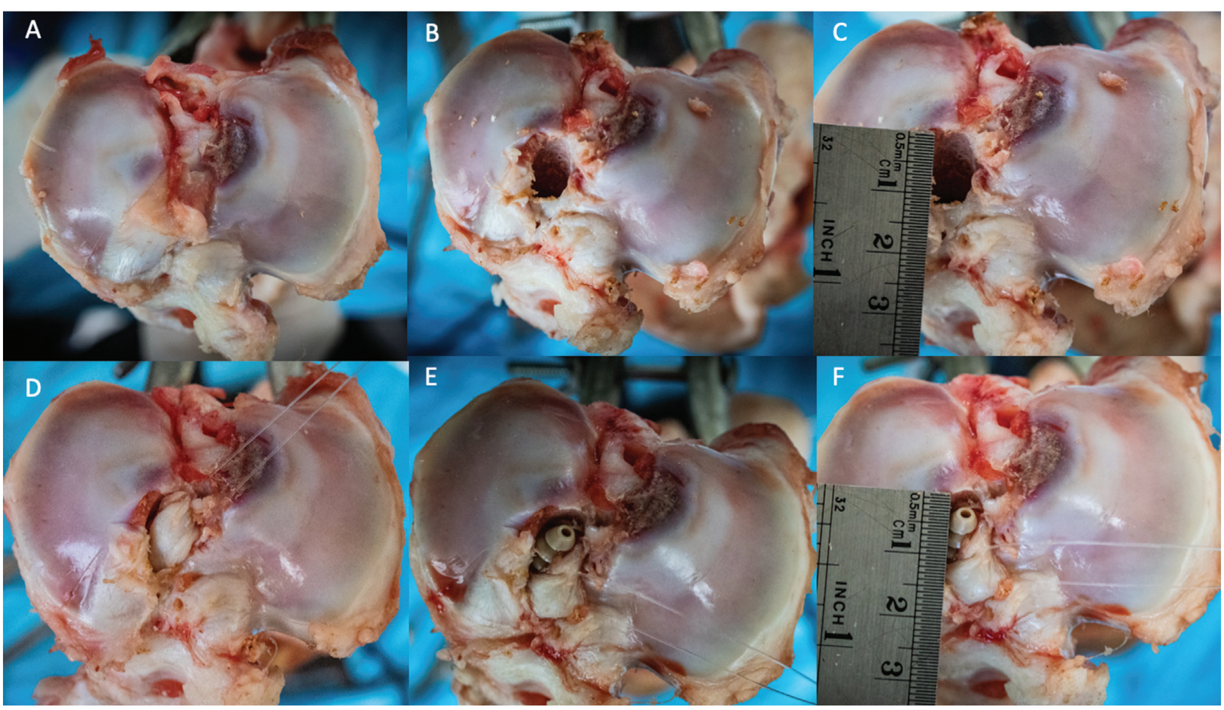

Fig. 1 Surgical technique. (**A**) Identification of the tibial ACL footprint. (**B**,**C**) Misplaced tibial tunnel that was drilled and measured. (**D**) Graft within the tibial tunnel. (**E**) Screw fixated at the articular surface. (**F**) Measurement of the diameter of the tibial tunnel after screw fixation.

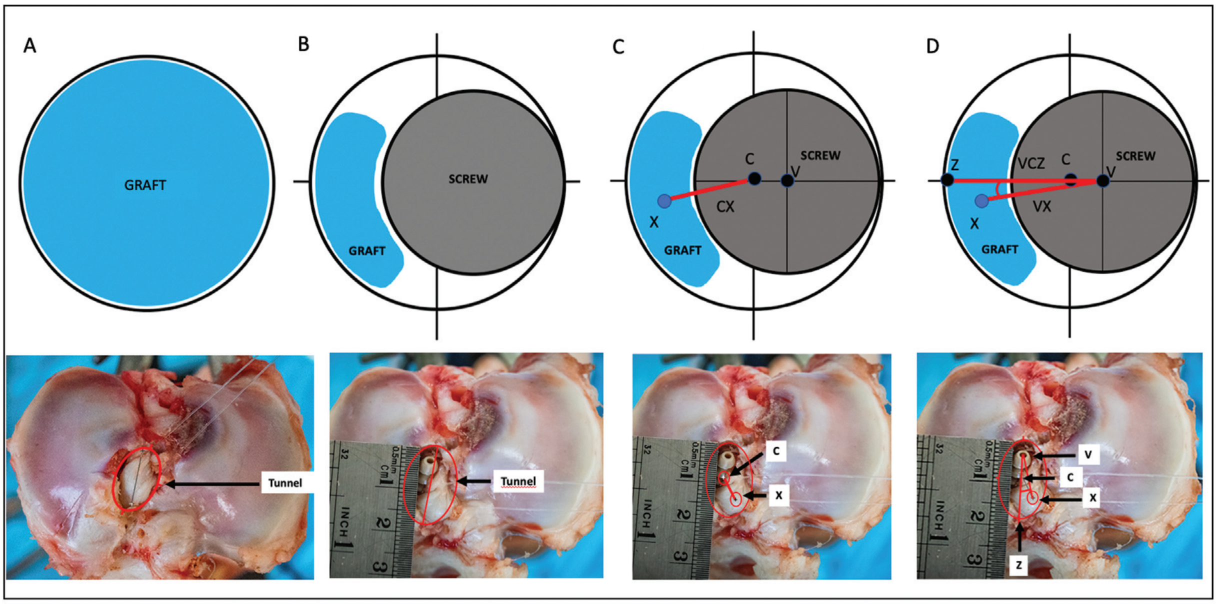

Fig. 2 Schematic representation and measurements performed on digitalized images (Photoshop CC 2019). (**A**) Graft within the tibial tunnel. (**B**) Tibial tunnel with graft and screw fixated at the articular surface. (**C**) Distance of the graft displacement (CX) measured in millimeters from the center of the tibial tunnel (C) to the center of the graft (X). (**D**) The angle of displacement of the graft was measured in degrees as following: angle between two arms, VX and VCZ, with center of the screw as the vertex (V). VX: line from center of the screw (V) to the center of the graft (X). VCZ: line from the center of the screw (V) passing through the center of the tunnel (C) to the tunnel perimeter point (Z), which is 180° opposite to the entry location of the screw. This was repeated for all groups.

Statistical Analysis

The Shapiro-Wilk test was performed, and it showed normal distribution among all specimens ($N = 28$). The mean differences in length and direction of the graft displacements among the four groups were analyzed through one-way analysis of variance (ANOVA). The statistical analysis was performed using the Statistical Package for the Social Sciences (IBM SPSS Statistics for Windows, IBM Corp., Armonk, NY, US) software, version 25.0, and values of $p \leq 0.05$ were considered statistically significant.

Results

Data describing the size of the tunnel before and after the fixation with screws, as well as the length and direction of the graft displacement for each specimen in each group are shown in ►**Table 1**. Graft displacement only occurred when the screw reached the tibial plateau, and its mean length was similar in all four groups (►**Fig. 3**): A – 4.4 mm; P – 4.6 mm; M – 4.5 mm; and L – 4.3 mm, with no statistically significant differences ($p = 0.894$). The mean direction of the graft displacement was also similar among the groups: A – 176° (standard deviation [SD]: 15.4°); P – 165° (SD: 16.6°); M –166° (SD: 12.1°); and L –169° (SD: 10.6°). No statistically significant differences were found ($p = 0.42$).

Discussion

The most important finding of the present study is that, regardless of the entry quadrant, constant graft displacement to the opposite side was observed when the tibial screw reached the articular surface. We were able to quantify the mean distance and direction of the graft displacement using a quadrant-specific 9-mm PEEK screw inside a 9-mm tibial tunnel; these measured diameters are frequently used in ACL reconstructions. This distance could be use by the surgeon as a guide in case a misplaced tibial tunnel is drilled. Nevertheless, the magnitude of this error cannot be predicted; hence, it should be assessed case by case.

Parate and Chernchujit.[9] developed an arthroscopic technique to adjust the placement of the guidewire for the interference screw in the tibial tunnel in anatomical single-bundle ACL reconstruction. The authors[9] state that posterolateral placement of the tibial screw helps to push the graft medially and anteriorly in the tibial tunnel to avoid impingement with the lateral femoral condyle. As this is an arthroscopic technique, no precise information is given regarding the magnitude and direction of the graft displacement. To date, no articles have described the capability of tibial interference screws to correct misplaced tunnels by shifting a soft-tissue graft toward a more anatomical location.

As aforementioned, suboptimal tunnel placement is a frequent problem among residents and even experienced surgeons,[10] despite the fact that the insertion points and intraoperative landmarks for anatomical ACL reconstruction are well known.[6,7] Most authors suggest[11] inspecting the tibial footprint before ACL reconstruction, as well as marking the center of the planned tunnel with a radiofrequency ablation probe. The center of the tibial tunnel should be located at 40% of the medial-to-lateral width of the interspinous distance, in line with the posterior edge of the anterior horn of the lateral meniscus, ~ 15 mm anteriorly to the posterior cruciate ligament. A tibial guide is set to 50°

Table 1 Results of the digital measurements for each specimen in all four groups

Group "A" (anterior)				
Porcine tibia	**Tunnel diameter without screw (mm)**	**Tunnel diameter with screw (mm)**	**Graft displacement (mm)**	**Graft direction (angle)**
1	9	12.6	4.2	180.4°
2	9.2	13.6	4.7	160.3°
3	9.3	12.3	2.7	180.6°
4	9.3	11.9	4.5	180.4°
5	9.6	13.1	4.7	195°
6	9.5	13.2	5.1	186.6°
7	8.6	11.8	5	150.6°
AVERAGE	**9.214**	**12.643**	**4.41**	**176.27°**
	Group "P" (posterior)			
Porcine tibia	**Tunnel diameter without screw (mm)**	**Tunnel diameter with screw (mm)**	**Graft displacement (mm)**	**Graft direction (angle)**
1	9.1	11.9	3.8	188.4°
2	9.6	11.8	3.9	174.6°
3	9.1	11.3	3.5	169.6°
4	9.6	13.9	4.4	150.2°
5	9.7	13.8	5.8	137.5°
6	9.6	13.4	5.2	166.4°
7	8.9	13.8	5.6	168.4°
AVERAGE	**9.37**	**12.843**	**4.60**	**165.01°**
	Group "L" (lateral)			
Porcine tibia	**Tunnel diameter without screw (mm)**	**Tunnel diameter with screw (mm)**	**Graft displacement (mm)**	**Graft direction (angle)**
1	9.8	13.3	4.3	175.6°
2	8.8	11.5	3.8	155.6°
3	9.4	14.4	4.5	181.9°
4	8.7	12.2	4.7	154.9°
5	9.7	13.7	4.2	158.7°
6	9.7	11.5	4.7	155°
7	8.5	12.9	3.9	177.3°
AVERAGE	**9.22**	**12.78**	**4.3**	**165.57°**
	Group "M" (medial)			
Porcine tibia	**Tunnel diameter without screw (mm)**	**Tunnel diameter with screw (mm)**	**Graft displacement (mm)**	**Graft direction (angle)**
1	9.5	11.8	4.1	152.4°
2	9.6	12.1	4.5	166.6°
3	8.9	13.3	5.4	171.4°
4	10.2	13.6	5.4	167.2°
5	8.9	12.6	4.1	186.2°
6	8.8	12.8	3.7	161.7°
7	9.8	13.5	4.04	174.5°
AVERAGE	**9.38**	**12.81**	**4.5**	**168.57°**

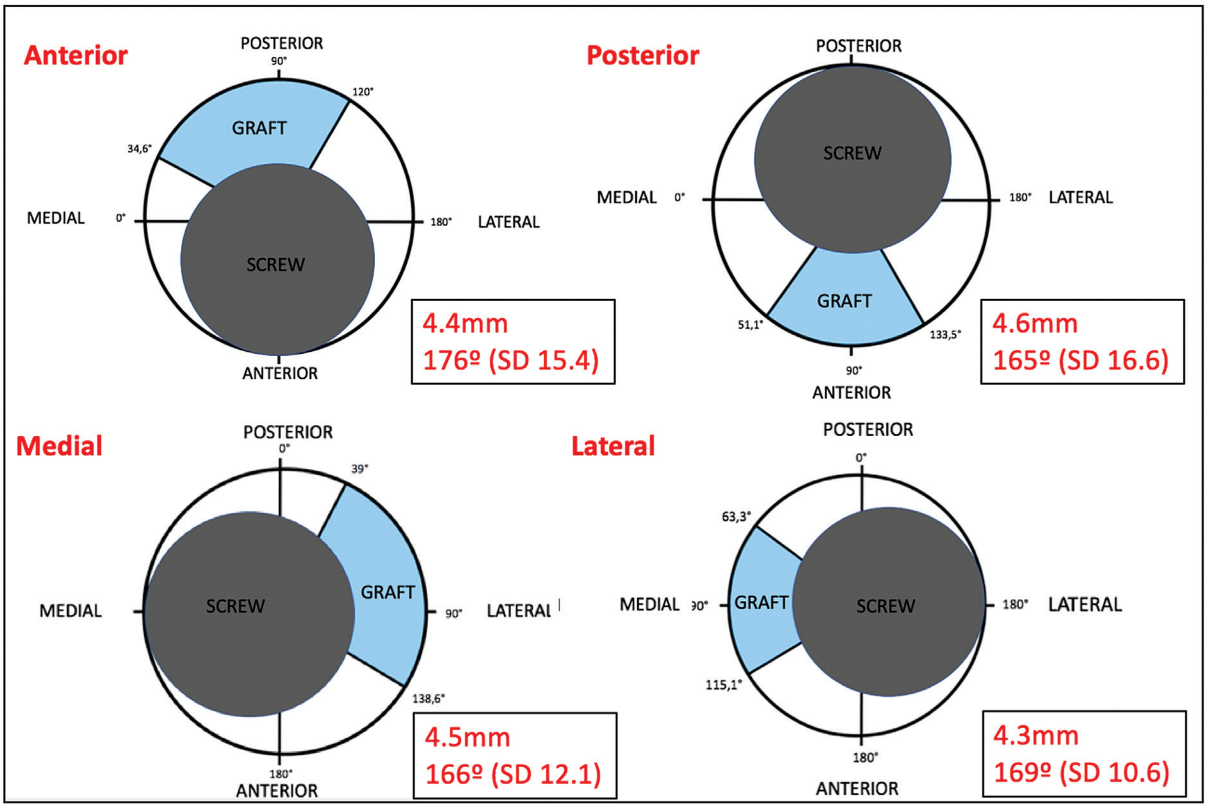

Fig. 3 Mean distance and direction of the graft displacement measured in all four groups.

and positioned with the aiming tip intraarticularly at the centrum of the ACL footprint.[12]

The present study helps the surgeon to predict where to place a screw inside a misplaced 9-mm tibial tunnel: a quadrant specific 9-mm interference screw fixed at the joint line enables a constant displacement of 4.5 mm of the soft-tissue graft toward the opposite side (169°; SD: 13.7°). Interestingly, this was only observed when the interference screw reached the articular surface (►**Fig. 3**). On the contrary, there was no displacement when the screw had not reached the surface. This could be explained because an interference screw is only able to shift a graft where both come into contact; hence, the screw will not have any influence on graft displacement if it is placed bellow the intended level of correction, in this case, the articular surface. This observation is a key factor in the present, study and was observed in all specimens. It is well known that proximal tibial graft fixation leads to more stable knees.[9,13] We also believe this observation is a key factor to achieve a constant graft displacement when one needs to correct a misplaced tibial tunnel. Therefore, we suggest arthroscopic visualization of the nitinol wire that will guide the tibial screw in a specific quadrant. The screw is then inserted until visible and withdrawn until only the tip is at the same level as the articular surface. The surgeon must take care of tensioning the graft with their hand during screw insertion to prevent the graft from wrapping around the screw. This can also be double-checked with an arthroscopic view from inside the tibial tunnel, to confirm the desired position of the nitinol wire in relation to the graft.

Another positive aspect of the present study is its reproducibility: since there were no significant differences among the groups, comparisons could be performed. The present study was performed in porcine knees mainly because of their wide availability, but also because of the similar biomechanical properties and diameter of the porcine superficial digital flexor tendon compared with human flexor tendons.[14–16] Graft fixation was performed with a PEEK interference screw because, compared with titanium screws, they present excellent mechanical characteristics, biological compatibility, and result in absence of metal artifacts on the MRI scan.[17] Regarding the surgical technique, we performed extraction drilling (ED) with a 9-mm drill bit because the mean diameter of the porcine posterior flexor tendon was of 8.7 mm. A screw with a 9-mm diameter was used following the recommendations of the manufacturer (Arthrex), who suggests using an implant with diameter as close as possible to that of the graft. The same screw diameter was used for all the groups so the results could be comparable. We have also decided to use 9-mm screws based on a 2013 study[18] which compared the ultimate failure load and cyclic displacement of different screws for the fixation of soft-tissue grafts in a similar ACL porcine model. The authors[18] used 9-mm screws for 9-mm grafts inside 9-mm tunnels, with equal results for PEEK screws compared with other types of screws. One of the drawbacks of the surgical technique used in the present study is that serial dilation (SD) was not performed, and enlargement of the tibial tunnel was observed in all the specimens after screw fixation (►**Table 1**). Biomechanical studies have demonstrated that ED had a lower mean load to failure for the graft, as well as increased tibial tunnel expansion and postoperative graft migration at the tibial fixation compared with SD, but no functional differences were found in a recent systematic review.[19] Although SD might reduce the expansion of the tibial tunnel, we believe this does not alter the final objective of the present study, which was to quantify graft displacement in terms of distance and direction.

Regarding the measurement techniques, previous studies[20] describe the use of a digital caliper. In the present study, graft size, tunnel size before and after screw fixation, and graft displacement (►**Figs. 2** and **3**) were also measured with a digital caliper with a precision of 0.05 mm. These values were very similar to those observed with digitalized images set to scale using Adobe Photoshop CC 2019, which we decided to use because it offers more accurate tools to measure the angular displacement of the graft.

Screw positioning may also have an effect on the orientation of the graft. Parate and Chernchujit[9] mention that the placement of posterolateral tibial screws may have an effect on graft obliquity, and Mall et al.[21] demonstrated that more vertical grafts on MRI are associated with greater anterior tibial translation on Lachman testing. We agree with the aforementioned authors that ACL graft obliquity is particularly sensitive to tibial tunnel placement and can influence knee stability. Since femoral tunnel drilling was not performed, graft obliquity could not be evaluated in the current study. We believe a future cadaveric study with anatomical femoral and tibial ACL reconstruction should be performed to determine if a quadrant-specific tibial screw has any influence on graft obliquity and knee stability.

Conclusions

Regardless of the entry quadrant, a constant mean graft displacement of 4.5 mm to the opposite side was observed when the tibial screw reached the articular surface.

Clinical relevance: non-anatomically placed ACL soft-tissue grafts can be corrected intraoperatively with the use of quadrant-specific tibial interference screws. Nevertheless, we cannot predict the magnitude of this error in every case of failed tibial tunnel drilling; hence, it should be assessed case by case.

Statement of Authenticity

The present research is original, and all the information was duly cited, ruling out plagiarism.

Conflict of Interests

The authors have no conflict of interests to declare.

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