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Quantifying graft impingement in anterior cruciate ligament reconstruction

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ABSTRACT

Background: Anterior cruciate ligament reconstructions (ACLR) fail at a rate of 10–15%, with graft impingement often a cause. In this study we investigate the prevalence and causes of impingement seen during ACLR surgery.
Methods: We reviewed consecutive primary ACLR from 2012-2018. Graft impingement was estimated intraoperatively by placing the arthroscope through the tibial tunnel and passively extending the knee, observing how much was obscured by the lateral femoral condyle from an anterior and lateral direction. Preoperative MRI scans were used to measure the intercondylar notch; Notch Width Index (NWI) and Notch Depth Index (NDI). Positioning of the tunnels was determined on postoperative radiographs.
Results: There were 283 ACLRs performed with 33 failures diagnosed on MRI (11.7%). 257 patients had complete imaging and follow up (91%). The mean age was 28 (±9) years and mean follow-up 5.3 (±1.8) years. The mean NWI was 0.26(±0.03), and NDI was 0.49(±0.06). The tibial tunnel aperture was located 42(±6) % of the way from anterior-posterior and 39 (±6) % from medial-lateral. Impingement requiring a notchplasty was observed in 80% of cases, with lateral impingement more prominent.
Conclusions: The amount of impingement did not correlate with tunnel position, which was located within the recommended area. There was a weak negative correlation between NWI and lateral impingement ($r_s = -0.16$, $p = 0.01$), and NDI and anterior impingement ($r_s = -0.12$, $p = 0.04$), therefore a smaller notch is associated with greater impingement. Despite optimal tunnel positioning, impingement still occurs in a significant number of cases therefore notchplasty should always be considered to keep revision rates low.

1. Introduction

Reconstruction of the anterior cruciate ligament (ACL) aims to restore knee stability and permit return to pivoting activities with predictable function. When performed successfully, it has a high patient satisfaction rate provided the graft remains functional and does not re-rupture [1–3].

Primary ACL grafts have a failure rate of up to 15% [3,4], leading to a need for revision surgery and ultimately a less favourable outcome [5]. Various factors are associated with re-rupture including younger, more active, and female patients,

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technical errors, episodes of secondary instability and graft impingement. A study by the Multicentre ACL Revision Study (MARS) Group showed in a prospective longitudinal study of revision ACL reconstructions that mode of failure, as deemed by the revising surgeon, was traumatic (32%), technical error (24%), biologic (7%), combination (37%), and infection (<1%) [6].

Graft impingement occurs when the graft prematurely contacts the bone of the femoral intercondylar notch before the knee reaches full extension [7]. This chronic micro trauma to the graft results in symptomatic anterior knee pain, effusions or even instability as the prolonged trauma can disrupt the mechanical integrity of the reconstruction leading to graft attrition and rupture [8,9].

The main causes of impingement are malpositioning of the reconstruction tunnels or stenosis of the notch itself. Tibial tunnel malpositioning is the most common technical error which results in graft impingement [10,11]. Impingement can occur from encroachment on the graft by the lateral femoral condyle when the notch is stenosed or when the tibial tunnel is positioned too laterally [12,13]. This type of impingement occurs in the coronal plane and results when the dimensions of the graft extend beyond the width of the notch [12,13]. A notchplasty can be performed, whereby bone is removed using an arthroscopic burr from the medial wall of the lateral femoral condyle to correct this form of impingement [13].

Impingement in the sagittal plane occurs when the intercondylar roof impacts on the ACL graft before the knee reaches full extension [14]. The normal ACL does come into contact with the intercondylar roof when the knee is in full extension, however the morphology of the native ligament accommodates for this [15].

A uniform tubular graft however can impact against the intercondylar roof before the knee reaches full extension, causing roof impingement [13]. If the tibial tunnel is placed too anteriorly, roof impingement will occur even more prematurely [11]. When it occurs, a notchplasty of the roof can be performed to prevent this premature, unwanted contact.

Roof impingement is often missed intraoperatively because it can be difficult to visualise and quantify [11,14,16]. In this study we employed a technique used to assess the degree of impingement intraoperatively and determine when to perform a notchplasty.

The aim of the study was to investigate the prevalence and causes of impingement seen in a cohort undergoing ACL reconstruction surgery and assess the relationship with graft failure. We hypothesised that smaller notches in coronal and sagittal planes on preoperative MRI scans would be more likely to have graft impingement requiring notchplasty.

2. Methods

2.1. Study design and participants

Ethical approval for the study was obtained from the NHS Regional Ethics Committee (HSC REC B, 19/NI/0133).

We reviewed a consecutive series of primary ACL reconstructions using ipsilateral hamstring autograft, by a single surgeon from June 2012 to September 2018, excluding multiligament injuries. Demographics were recorded including age, gender, pre-injury Tegner activity score and mechanism of injury.

2.2. Surgical technique

All patients underwent isolated ACL reconstruction using ipsilateral four-strand semitendinosus-gracilis autograft. The femoral tunnel was drilled using the anteromedial portal technique and fixation achieved using a femoral Endobutton device (Smith & Nephew, Andover, USA) and an Intrafix tibial interference screw and sheath (Depuy Mitek, Raynam, USA).

Graft impingement was quantified intra-operatively by placing the 30-degree arthroscope through the tibial tunnel and passively extending the knee, observing how much of the aperture was obscured by the lateral femoral condyle from an anterior and lateral direction, as a percentage of the overall tunnel. This allowed us to quantify roof impingement and wall impingement independently. Figure 1 shows the tibial tunnel view, with 50% wall impingement evident.

A notchplasty of the lateral femoral condyle was performed using an arthroscopic burr whenever potential impingement was observed on the tibial tunnel view. The articular cartilage edge was marked with the radiofrequency ablation wand before starting the notchplasty, as a guide to prevent excessive resection. Resolution of an impinging lateral femoral condyle was confirmed with a further tibial tunnel view, and we aimed for less than 10% obscured as the target.

2.3. Clinical Follow-up

Patients were followed up directly for 6 months postoperatively at which point objective laxity was quantified using assessment of Lachman test with Rolimeter (Aircast Europa, Neubeuern, Germany) instrumentation. At the time of the study, clinical records were reviewed for incidence of re-rupture. Re-rupture was defined as having undergone revision surgery or magnetic resonance imaging (MRI) scan demonstrating graft re-rupture.

2.4. Radiographic measurements

Preoperative MRI scans of the knee were performed using standard sequences in a 1.5 T scanner and were reviewed retrospectively. T2-weighted axial slices at the level of the popliteal groove were used to measure the intercondylar notch.

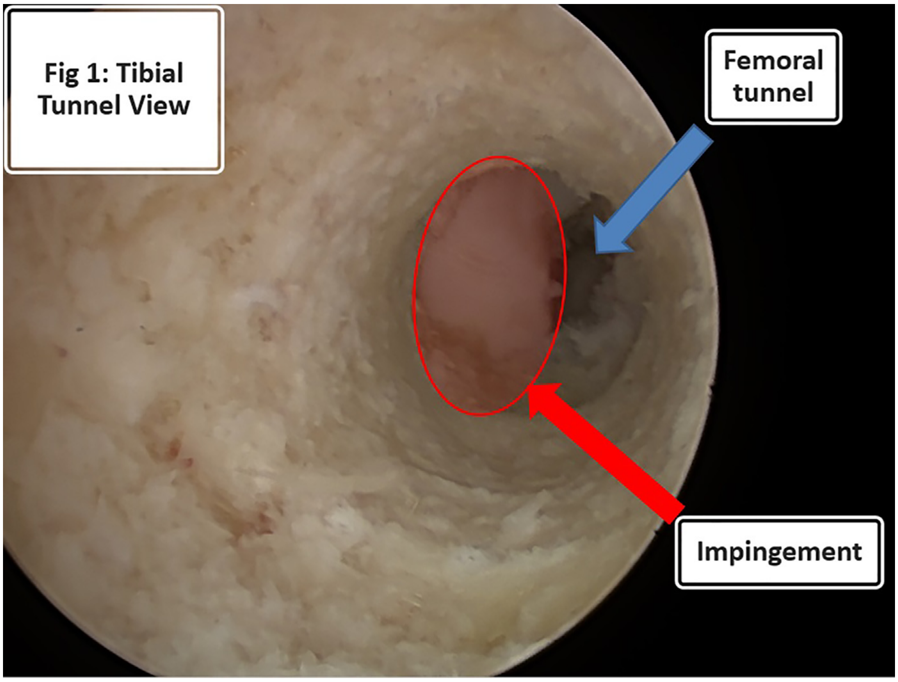

Figure 1. Arthroscopic photograph showing tibial tunnel view to assess impingement. The blue arrow shows the femoral tunnel aperture while the red area shows area of potential impingement by the lateral femoral condyle.

Measures of notch size (depth and width) were calculated according to the methods outlined by Geng, et al. [17] (Figure 2). A reference line was drawn along the posterior borders of the femoral condyle. The femoral condylar width (W) was measured on a line through the popliteal groove parallel to the reference line. The notch width (N) was the distance between the most interior margins of the femoral condyles at two-thirds intercondylar notch depth. The notch depth (D) was identified as the maximum perpendicular height of notch from the reference line. Likewise, the femoral condyle depth (CD) was measured as the perpendicular maximal height of the lateral femoral condyle from the reference line. The intercondylar Notch Width Index (NWI) is the ratio of the intercondylar notch width to the femoral condylar width. Similarly the Notch Depth Index (NDI) is calculated by dividing the intercondylar notch width by the intercondylar notch depth.

Positioning of the tibial tunnel was measured on postoperative antero-posterior (AP) and lateral radiographs performed at 6 weeks postoperatively. The position was expressed as a percentage of the centre of the tibial tunnel aperture along a line drawn from anterior to posterior on the lateral radiograph (Figure 3) and from medial to lateral on the AP radiograph

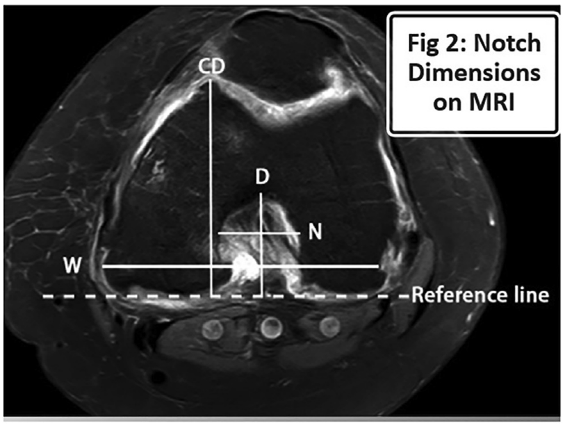

Figure 2. Method of determining parameters of the intercondylar notch on axial MRI scan. N: notch width; W: femoral condyle width; D: notch depth; CD: lateral femoral condylar depth; White dotted line: reference line. Notch width index (NWI) = N/W; Notch depth index (NDI) = D/CD [17].

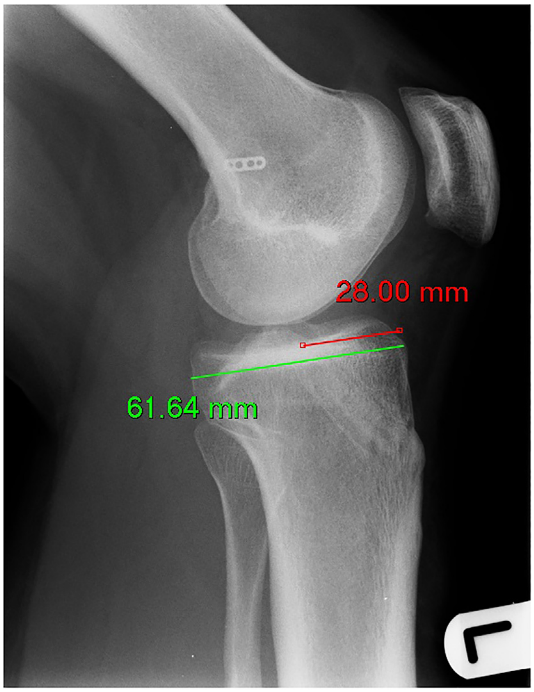

Figure 3. Lateral radiograph of the knee showing method of measuring tunnel position. Red line: distance of tibial tunnel from anterior aspect of tibia, Green line: depth of tibial plateau. Anterior to posterior tunnel position = 45.4%.

(Figure 4) [18,19]. All measurements were carried out by two clinicians independently. Interobserver reliability of radiographic measurements was tested using the Cohen Kappa interobserver coefficient.

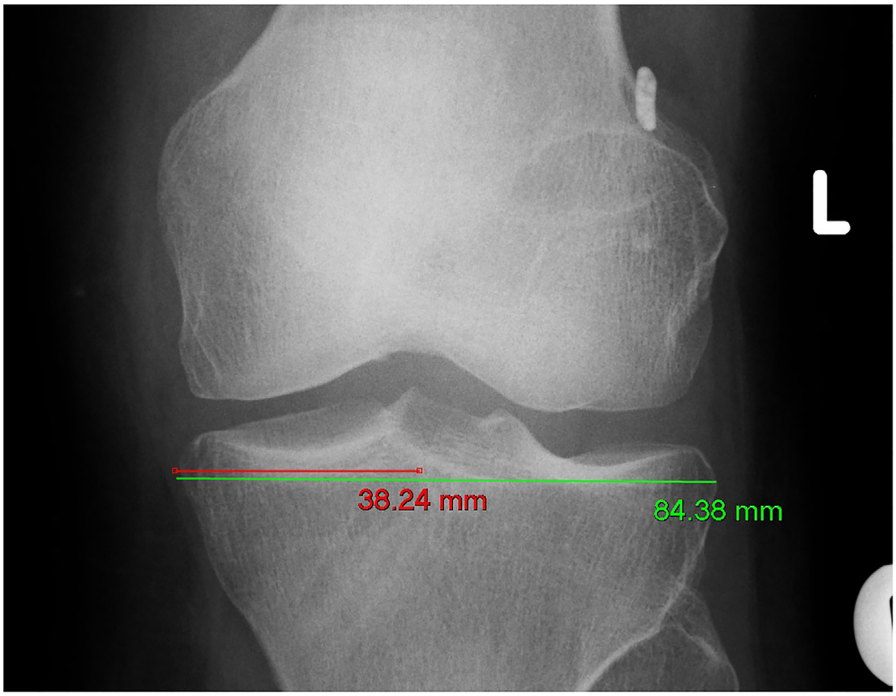

Figure 4. Anteroposterior radiograph of the knee showing method of measuring tunnel position. Red line: distance of tibial tunnel from medial aspect of tibia, Green line: width of tibial plateau. Medial to lateral tunnel position = 45.3%.

2.5. Statistical analysis

Descriptive statistics were calculated to summarise the demographics and clinical characteristics and were described with means and standard deviations for normally distributed data or median with ranges for non-normally distributed data. Normality was assessed using the Shapiro–Wilk test. Unpaired students t-tests or Mann-Whitney U tests were performed to compare variables between groups. Correlations were assessed using Pearson's correlation coefficient or Spearman rank-order correlation coefficient and the significance level set at $p < 0.05$. All statistical analyses were performed using SPSS version 26.0 (IBM, Chicago, IL, USA).

3. Results

There were 283 ACL reconstructions performed with a mean age of 28 (±9) years and 229 (81%) patients were male. The median interval from injury to surgery was 1 year and the mean follow up time was 5.3 (±1.8) years. The median pre-injury Tegner activity score was 7 (range 1–10) and the most common mode of injury was soccer (60%). There were 257 patients with complete imaging and follow up (91%).

Failure of ACL reconstruction as defined by graft re-rupture on MRI scan occurred in 33 patients (11.7%) (95% CI 8.2–16.0%). Of these, 27 patients underwent revision surgery. The mean time between primary ACL reconstruction and re-rupture was 1.8 (±1.2) years. The mean age for the group sustaining an ipsilateral failure was 26.2 years versus 27.7 years in the remainder, however this difference was not statistically significant ($p = 0.37$).

Notchplasty was performed when impingement exceeded 15% of the total tunnel aperture on the tibial tunnel view. Significant impingement requiring a notchplasty was observed in 80% of cases, with wall impingement more common than roof impingement (mean percentage of tunnel impingement observed was 33%). In one third of cases, a wall impingement of more than 50% was observed (Figure 5).

Roof impingement was less common and was present in 36% of cases. Notchplasty was performed using an arthroscopic burr with further visualisation confirming no further impingement on the tibial tunnel view (Figure 6).

The mean NWI was 0.26 (±0.03) and NDI was 0.49 (±0.06). The tibial tunnel was located 42 (±6) % of the way from anterior to posterior on the lateral radiograph and 39 (±6) % of the way from medial to lateral on the AP radiograph (Figure 7). The ideal tibial tunnel position should be centred 43% of the way from anterior to posterior and 40% of the way from medial to lateral [18,20]. The tunnel was situated within 10% of the ideal value in 87% of cases on the lateral radiograph and 94% of cases on the anteroposterior radiograph (Figure 7). The mean kappa value for interobserver reliability was 0.89 for the four measured values, indicating very good agreement.

The mean ipsilateral AP knee laxity at 3 months postoperatively was 4.7 mm (range 2–10 mm) while the mean contralateral AP laxity was 4.3 mm (range 2–8 mm) ($p = 0.04$). The mean side to side difference in knee laxity was 0.43 mm (±2.1). 12% of patients had a side-to-side difference of 3 mm or greater, while 2% had 5 mm or greater, indicating clinical failure. The mean side-to-side difference in knee laxity was greater at 3 months in those who went on to suffer re-rupture (2 mm), compared to those who did not (0.2 mm) ($p = 0.007$). Also, the mean ipsilateral laxity in those patients who went on to suffer a re-rupture was 5.0 mm, compared to 4.5 mm in those who did not ($p = 0.04$).

There was no significant difference for any measured parameter comparing gender, age or requirement of notchplasty. There were no differences between failures and non-failures, which may reflect the fact that impingement that was evident was treated adequately by notchplasty.

When the tibial tunnel was located within 10% of the ideal position from anterior to posterior, the rate of graft failure was 12%, compared to 19% when the tunnel was centred outwith that range. Similarly, for medial to lateral tunnel position, the rate of failure was 12% when the tunnel was within 10% of ideal and 20% when positioned outwith that. Neither of these differences reached statistical significance.

There was a negative correlation between NWI and lateral impingement ($r_s = -0.16$, $p < 0.01$), suggesting that lateral wall impingement was more likely to be seen with a narrower notch. There was also a negative correlation between NDI and anterior impingement ($r_s = -0.12$, $p = 0.04$) suggesting that anterior impingement was more likely with a shallower notch.

4. Discussion

The main finding of this study was that the tibial tunnel view can be used to assess for potential graft impingement during ACL reconstruction, and that it occurs frequently. This allows the issue to be addressed proactively to reduce the impact of one of the leading causes of graft failure [6,8,9]. Potential impingement was observed in 80% of cases using this technique, suggesting that impingement may be under recognised. The degree of impingement did not correlate with tunnel position, which was consistently located within the recommended area. Amis, Jakob [18] suggested the ideal tibial tunnel position should be 43% from anterior to posterior, a position which was replicated in this study with a mean value of 42%. Furthermore, Hwang, Piefer, Lubowitz [20] suggested that the tibial footprint of the ACL is centred 40% of the way from medial to lateral and in this study the mean tunnel placement was at 39%. This shows that in this large cohort of patients, tunnel placement was satisfactory and in the ideal position. Indeed, on average, 91% of cases had a tibial tunnel located with 10% of the ideal position. Despite that, graft impingement was still observed and notchplasty performed in the majority of cases.

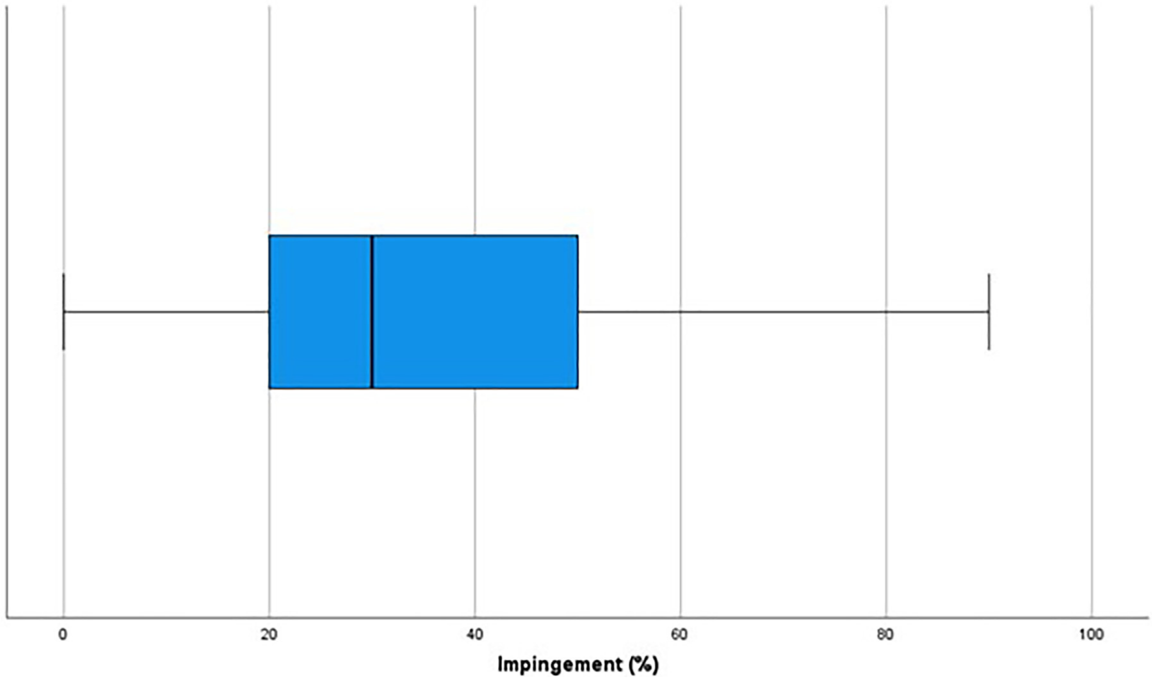

Figure 5. Boxplot showing the distribution of observed lateral wall impingement.

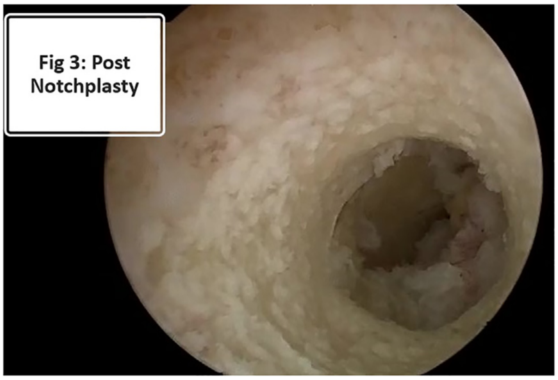

Figure 6. Tibial tunnel view illustrating that the wall impingement seen in Figure 1 is not present following notchplasty.

Notch dimensions were smaller in this cohort than reported in anatomical studies of normal knees [17,21,22], and this may have been a causative factor for sustaining the initial ACL rupture. Stenosis of the intercondylar notch and smaller NWI have been associated with higher risk of ACL injury [22,23]. There was a negative correlation between NWI and wall impingement. This may indicate that a narrower notch measured on a pre-operative MRI scan is associated with greater impingement, and consideration of this may allow impingement to be anticipated and notchplasty planned.

Previously the use of notchplasty had been advocated, but as the orthopaedic community moved away from transtibial drilling to other portal or anatomic placement techniques, it has been used less frequently. The usefulness of notchplasty remains unclear and some concerns have emerged regarding potential harmful effects of notchplasty, relating to the knee biomechanics and postoperative blood loss [24]. It can also have detrimental effects on the nearby articular cartilage if the notchplasty is too aggressive [25] and some have postulated that the bleeding may lead to arthrofibrosis contributing to loss of extension [26]. Furthermore, studies have shown that there may be regrowth of bone following notchplasty [25,27]. There was no evidence of any adverse events directly attributable to notchplasty in this cohort. Our results have demonstrated that despite optimal tunnel position, impingement still occurs in a significant number of cases and notchplasty should be considered if not performed routinely in every case.

In this study the results demonstrated no differences in the degree of impingement between the patient cohort who suffered graft re-rupture versus those with a successful outcome. It is not possible to say whether this demonstrates that

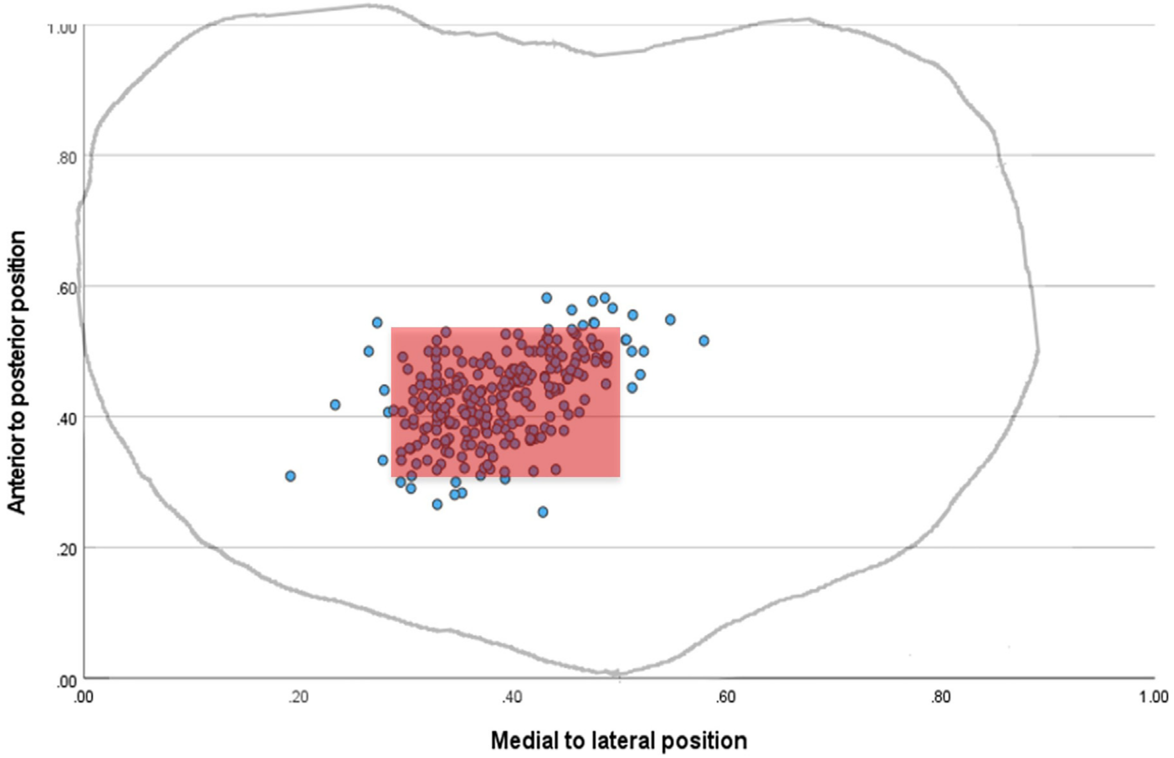

Figure 7. Scatter plot showing position of each tibial tunnel centre from medial to lateral and anterior to posterior on a sketch of the surface of the tibial plateau, with the shaded area (red) representing 10% either side of ideal position.

adequate clearance of the notch was achieved by this technique or whether the impingement observed is irrelevant and treatment with a notchplasty is not required. In this study there was no control group in whom a notchplasty was not carried out. Previous studies have however shown a clear link between impingement and graft failure [11,28,29].

We found that this ACL reconstruction technique satisfactorily restores AP knee laxity to close to normal in most patients. The mean side to side laxity difference of less than 1 mm shows that in most cases laxity is close to symmetry with the contralateral, uninjured side. In a large series, Cristiani, et al. [30] showed a mean side to side difference of 1.8 mm for their hamstring autograft group, which was larger than for their patellar tendon group. Clinical failure, defined as side-to-side laxity difference of greater than 5 mm was found in 4.3% of their series, compared to 2% of the patients measured in our cohort [30].

Although the laxity measurements were satisfactory overall, a small, but statistically significant difference was found between the laxity of those who went on to suffer graft re-rupture compared to those who did not. This finding may be an important indicator of future outcome. Lindanger, et al. [31] investigated the effect of early residual laxity after ACL reconstruction on long-term laxity, graft failure, return to sports, and subjective outcome at 25 years. They found that a slightly loose graft, defined as side-to-side laxity difference of $\geq$3 mm at 6 months postoperative increased the risk of graft failure and revision surgery, reduced the length of the athlete's sporting career, caused permanently increased laxity, and led to an inferior Lysholm score. From our measured cohort, 12% of patients fall into this category, which may have implications for their future outcome.

The limitations of our study are that it has been performed in a single centre, by a single surgeon with no control group. Furthermore, the method of calculating notch dimensions from preoperative MRI scan is based upon a 2-dimensional measurement and may not accurately reflect the 3-dimensional morphology. Furthermore, assessment of tunnel positioning, although using recognised methods, was assessed on 2-dimensional radiographs and a more accurate assessment could be obtained with cross-sectional imaging.

The clinical relevance of the results in this study is that this method is an easy way to assess and predict potential cases of graft impingement and allow the surgeon to proactively take steps to avoid it. Suspicion may be raised preoperatively by measuring the notch dimensions on the MRI scan. Intraoperative assessment using the tibial tunnel view, allows the surgeon to make an intraoperative decision regarding notchplasty, although this does require complete resection of the remaining ACL stump on the tibial side to obtain a satisfactory view.

In conclusion, graft impingement is more prevalent than expected, when evaluated intra-operatively, yet notchplasty is not as commonly performed. We advise the use of the tibial tunnel view to assess for graft impingement and that performing notchplasty when it occurs yields good results. In addition, consideration of notch dimensions on preoperative MRI scans may help with surgical planning.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Kahlenberg CA, Nwachukwu BU, Ferraro RA, Schairer WW, Steinhaus ME, Allen AA. How are we measuring patient satisfaction after anterior cruciate ligament reconstruction? Orthop J Sports Med 2016;4(12). doi: https://doi.org/10.1177/2325967116673971. 2325967116673971.
[2] Nwachukwu BU, Voleti PB, Berkanish P, Chang B, Cohn MR, Williams RJ, et al. Return to play and patient satisfaction after ACL reconstruction: study with minimum 2-year follow-up. JBJS 2017;99(9):720–5. doi: https://doi.org/10.2106/jbjs.16.00958.
[3] Samitier G, Marcano AI, Alentorn-Geli E, Cugat R, Farmer KW, Moser MW. Failure of anterior cruciate ligament reconstruction. Arch Bone Jt Surg 2015;3(4):220–40.
[4] George MS, Dunn WR, Spindler KP. Current concepts review: revision anterior cruciate ligament reconstruction. Am J Sports Med 2006;34(12):2026–37. doi: https://doi.org/10.1177/0363546506295026.
[5] Wright RW, Gill CS, Chen L, Brophy RH, Matava MJ, Smith MV, et al. Outcome of revision anterior cruciate ligament reconstruction: a systematic review. J Bone Joint Surg Am 2012;94(6):531–6. doi: https://doi.org/10.2106/jbjs.K.00733.
[6] Wright RW, Huston LJ, Spindler KP, Dunn WR, Haas AK, Allen CR, et al. Descriptive epidemiology of the Multicenter ACL Revision Study (MARS) cohort. Am J Sports Med 2010;38(10):1979–86. doi: https://doi.org/10.1177/0363546510378645.
[7] Iriuchishima T, Shirakura K, Fu FH. Graft impingement in anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc 2013;21(3):664–70. doi: https://doi.org/10.1007/s00167-012-2014-6.
[8] Iriuchishima T, Tajima G, Ingham SJM, Shen W, Smolinski P, Fu FH. Impingement pressure in the anatomical and nonanatomical anterior cruciate ligament reconstruction: A cadaver study. Am J Sports Med 2010;38(8):1611–7. doi: https://doi.org/10.1177/0363546510363461.
[9] Howell SM, Taylor MA. Failure of reconstruction of the anterior cruciate ligament due to impingement by the intercondylar roof. J Bone Joint Surg Am 1993;75(7):1044–55. doi: https://doi.org/10.2106/00004623-199307000-00011.
[10] Goss BC, Hull ML, Howell SM. Contact pressure and tension in anterior cruciate ligament grafts subjected to roof impingement during passive extension. J Orthop Res 1997;15(2):263–8. doi: https://doi.org/10.1002/jor.1100150216.
[11] Howell SM. Principles for placing the tibial tunnel and avoiding roof impingement during reconstruction of a torn anterior cruciate ligament. Knee Surg Sports Traumatol Arthrosc 1998;6(0):S49–55. doi: https://doi.org/10.1007/s001670050223.
[12] Gillquist J, Odensten M. Arthroscopic reconstruction of the anterior cruciate ligament. Arthroscopy 1988;4(1):5–9. doi: https://doi.org/10.1016/s0749-8063(88)80003-3.
[13] Howell SM, Clark JA, Farley TE. A rationale for predicting anterior cruciate graft impingement by the intercondylar roof. Am J Sports Med 1991;19(3):276–82. doi: https://doi.org/10.1177/036354659101900312.
[14] Howell SM, Berns GS, Farley TE. Unimpinged and impinged anterior cruciate ligament grafts: MR signal intensity measurements. Radiology 1991;179(3):639–43. doi: https://doi.org/10.1148/radiology.179.3.2027966.
[15] Norwood Jr LA, Cross MJ. The intercondylar shelf and the anterior cruciate ligament. Am J Sports Med 1977;5(4):171–6. doi: https://doi.org/10.1177/036354657700500406.
[16] Iriuchishima T, Tajima G, Ingham SJM, Shen W, Horaguchi T, Saito A, et al. Intercondylar roof impingement pressure after anterior cruciate ligament reconstruction in a porcine model. Knee Surg Sports Traumatol Arthrosc 2009;17(6):590–4. doi: https://doi.org/10.1007/s00167-008-0691-y.
[17] Geng B, Wang J, Ma JL, Zhang B, Jiang J, Tan XY, et al. Narrow intercondylar notch and anterior cruciate ligament injury in female nonathletes with knee osteoarthritis aged 41–65 years in plateau region. Chin Med J (Engl) 2016;129(21):2540–5. doi: https://doi.org/10.4103/0366-6999.192771.
[18] Amis AA, Jakob RP. Anterior cruciate ligament graft positioning, tensioning and twisting. Knee Surg Sports Traumatol Arthrosc 1998;6(Suppl 1): S2–S12. doi: https://doi.org/10.1007/s001670050215.
[19] Ducouret E, Loriaut P, Boyer P, Perozziello A, Pesquer L, Mounayer C, et al. Tunnel positioning assessment after anterior cruciate ligament reconstruction at 12 months: Comparison between 3D CT and 3D MRI. A pilot study. Orthopaed Traumatol: Surg Res 2017;103(6):937–42. doi: https://doi.org/10.1016/j.otsr.2017.06.005.
[20] Hwang MD, Piefer JW, Lubowitz JH. Anterior cruciate ligament tibial footprint anatomy: systematic review of the 21st century literature. Arthroscopy 2012;28(5):728–34. doi: https://doi.org/10.1016/j.arthro.2011.11.025.
[21] Li Z, Li C, Li L, Wang P. Correlation between notch width index assessed via magnetic resonance imaging and risk of anterior cruciate ligament injury: an updated meta-analysis. Surg Radiol Anat 2020;42(10):1209–17. doi: https://doi.org/10.1007/s00276-020-02496-6.
[22] Oshima T, Putnis S, Grasso S, Parker DA. The space available for the anterior cruciate ligament in the intercondylar notch is less in patients with ACL injury. Knee Surg Sports Traumatol Arthrosc 2020;28(7):2105–15. doi: https://doi.org/10.1007/s00167-020-05921-w.
[23] Andrade R, Vasta S, Sevivas N, Pereira R, Leal A, Papalia R, et al. Notch morphology is a risk factor for ACL injury: a systematic review and meta-analysis. JISAKOS 2016;1(2):70–81. doi: https://doi.org/10.1136/jisakos-2015-000030.
[24] Ranuccio F, Familiari F, Tedesco G, La Camera F, Gasparini G. Effects of notchplasty on anterior cruciate ligament reconstruction: A systematic review. Joints 2017;05(03):173–9. doi: https://doi.org/10.1055/s-0037-1605551.
[25] LaPrade RF, Terry GC, Montgomery RD, Curd D, Simmons DJ. Winner of the AlbertTrillat Young Investigator Award. The effects of aggressive notchplasty on the normal knee in dogs. Am J Sports Med 1998;26(2):193–200. doi: https://doi.org/10.1177/03635465980260020801.
[26] Pape D, Seil R, Adam F, Gödde S, Georg T, Rupp S, et al. Blood loss in anterior cruciate ligament (ACL) reconstruction with and without intercondylar notchplasty: does it affect the clinical outcome? Arch Orthop Trauma Surg 2001;121(10):574–7. doi: https://doi.org/10.1007/s004020100290.
[27] May DA, Snearly WN, Bents R, Jones R. MR imaging findings in anterior cruciate ligament reconstruction: evaluation of notchplasty. AJR Am J Roentgenol 1997;169(1):217–22. doi: https://doi.org/10.2214/ajr.169.1.9207528.
[28] Bents RT, Jones RC, May DA, Snearly WS. Intercondylar notch encroachment following anterior cruciate ligament reconstruction: a prospective study. Am J Knee Surg 1998;11(2):81–8.
[29] Meyers AB, Haims AH, Menn K, Moukaddam H. Imaging of Anterior Cruciate Ligament Repair and Its Complications. AJR 2010;194(2):476–84. doi: https://doi.org/10.2214/AJR.09.3200.

[30] Cristiani R, Sarakatsianos V, Engström B, Samuelsson K, Forssblad M, Stålman A. Increased knee laxity with hamstring tendon autograft compared to patellar tendon autograft: a cohort study of 5462 patients with primary anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc 2019;27(2):381–8. doi: https://doi.org/10.1007/s00167-018-5029-9.
[31] Lindanger L, Strand T, Mølster AO, Solheim E, Inderhaug E. Effect of Early Residual Laxity After Anterior Cruciate Ligament Reconstruction on Long-term Laxity, Graft Failure, Return to Sports, and Subjective Outcome at 25 Years. Am J Sports Med 2021;49(5):1227–35. doi: https://doi.org/10.1177/0363546521990801.