Rate of Tibial Tunnel Malposition Is Not Changed by Drilling Entirely Within the Stump of Preserved Remnants During ACL Reconstruction

A Prospective Comparative 3D-CT Study

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Background: Remnant preservation during anterior cruciate ligament (ACL) reconstruction (ACLR) is controversial, and it is unclear whether the stump aids or obscures tibial tunnel positioning.

Purpose/Hypothesis: The aim of this study was to determine whether the rate of tibial tunnel malposition is influenced by remnant preservation. The hypothesis was that using a remnant-preserving technique to drill entirely within the tibial stump would result in a significant reduction in tibial tunnel malposition as determined by postoperative 3-dimensional computed tomography (3D-CT).

Study Design: Cohort study; Level of evidence, 2.

Methods: Patients undergoing ACLR between October 2018 and December 2019 underwent surgery with a remnant-preserving technique (RP group) if they had a large stump present (>50% of the native ACL length) or if there was no remnant or if it was <50% of the native length of the ACL, they underwent remnant ablation (RA group) and use of standard landmarks for tunnel positioning. The postoperative tunnel location was reported as a percentage of the overall anteroposterior (AP) and mediolateral (ML) dimensions of the tibia on axial 3D-CT. The tunnel was classified as anatomically placed if the center lay between 30% and 55% of the AP length and between 40% and 51% of the ML length.

Results: Overall, 52 patients were included in the study (26 in each group). The mean tunnel positions were 36.8% ± 5.5% AP and 46.7% ± 2.9% ML in the RP group and 35.6% ± 4.8% AP and 47.3% ± 2.3% ML in the RA group. There were no significant differences in the mean AP (P = .134) and ML (P = .098) tunnel positions between the groups. Inter- and intraobserver reliability varied between fair to excellent and good to excellent, respectively. There was no significant difference in the rate of malposition between groups (RP group, 7.7%; RA group, 11.5%; P ≥ .999).

Conclusion: Drilling entirely within the ACL tibial stump using a remnant-preserving reconstruction technique did not significantly change the rate of tunnel malposition when compared with stump ablation and utilization of standard landmarks.

Keywords: ACL reconstruction; computed tomography; ACL tunnel position; remnant preservation; anatomic ACL reconstruction

It is well-recognized that incorrect placement of tunnels during anterior cruciate ligament (ACL) reconstruction (ACLR) adversely influences knee kinematics and clinical outcomes, including graft failure rates.22,25,31 Jaecker et al17 recently reported that 40% of patients undergoing revision ACLR had a malpositioned tibial tunnel. Although there are numerous factors that could influence the rate of tunnel malposition, it is clear that it occurs frequently, and even experienced surgeons can have difficulty with correct placement intraoperatively.1,24,34

It has been suggested that preserving the ACL tibial remnant can aid correct tibial tunnel positioning by providing an important and reliable intraoperative landmark.4 It has also been reported that remnant preservation offers the advantages of reduced postoperative tunnel widening,33 a greater intrinsic potential for healing, better graft vascularization, preservation of proprioceptive nerve fibers,2,13,15,27 better knee stability,3,35 and reduced rates
of graft rupture. In contrast, there are also reports that remnant preservation does not confer an important clinical advantage and that the preservation of a large remnant may furthermore obscure visualization and make accurate tunnel placement more difficult. Besides, in the largest study to date on this specific topic, Delaloye et al demonstrated that the preservation of large remnants was not significantly associated with the development of cyclops lesions or loss of full extension.

We believe that remnant preservation is a reliable way of avoiding nonanatomic tibial tunnel placement because the tunnel is drilled entirely within the stump, therefore requiring the graft to pass through the native footprint. The aim of this study was to determine whether the rate of tibial tunnel malposition is influenced by using a remnant-preserving technique. Additionally, the hypothesis was that using a remnant-preserving technique to drill entirely within the tibial stump would result in a significant reduction in tibial tunnel malposition as determined by postoperative 3-dimensional computed tomography (3D-CT).

**METHODS**

Institutional review board approval was granted for this prospective comparative study. All patients aged 17 to 55 years undergoing outpatient ACLR with hamstring tendon autograft between October 2018 and December 2019 were considered for study eligibility. Patients were excluded if they had a history of previous knee surgery or infection, had degenerative changes on preoperative imaging, required concomitant osteotomy or reconstruction of ligaments other than the ACL, required drilling of tibial bone tunnels for meniscal repair, or did not consent to study participation. The flowchart of study patients is reported in Figure 1.

Patients were allocated to the remnant preservation (RP) or control group (remnant ablated [RA]) during diagnostic arthroscopy (immediately before ACLR) on the basis of remnant size, and all procedures were performed by a single surgeon (V.B.C.P.). Remnant size was evaluated with knees placed at 90° of flexion and viewing performed through the anteromedial portal. The free end of the tibial ACL stump was grasped and pulled toward the femoral footprint. Remnants were categorized into ≤50% or >50% of the length of the native ACL depending on whether they extended beyond the central axis of the posterior cruciate ligament (PCL). Only patients with large remnants (>50% of the length of the native ACL), according to the classification of Buscayret et al, were allocated to the RP group. Remnants ≤50% of the native ACL length were not preserved in order to avoid skewing the study results by including small remnants that were unlikely to have the potential to influence tunnel positioning.

The tibial tunnel in both groups was created by positioning the guide so that the tunnel entrance was located approximately 1 cm medial to the tibial tuberosity. In the RP group, the single anteromedial bundle biological augmentation technique was used. The guide wire was positioned within the center of the ACL tibial stump (Figure 2).

The tunnel was drilled with increasingly larger drill-bit diameters (starting at 6 mm and increasing by 1-mm increments). This sequential preparation, in combination with a minimum application of force to advance the drill, with the guide wire held in position intra-articularly with a clamp, minimized the risk of tunnel deviation. To avoid disruption of the remnant, drilling was stopped on each passage as soon as the tibial cortex was breached.

The drill remained entirely within the remnant and was not visualized within the knee. A shaver was then placed within the remnant via the tibial tunnel and used to create a pathway for the graft. The femoral tunnel was created with an outside-in technique, and the graft was shuttled from distal to proximal into the knee with a passing suture. Due to the preserved remnant, grafts could not be seen

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Ethical approval for this study was obtained from the University of Marilia.
exiting the tibial tunnel and could only be observed exiting the preserved remnant more proximally.

Patients with ACL remnants that were ≤50% to the native ACL length were allocated to the control group (RA), and the entire stump was removed.

In this situation, the entire footprint and adjacent osseous (tibial spines) and soft tissue (PCL and the posterior border of the anterior horn of the lateral meniscus) structures could be clearly visualized. The aimer was placed with the intention of positioning it into the middle of the anteromedial bundle of the ACL footprint, in line with the posterior margin of the anterior horn of the lateral meniscus and approximately 5 mm lateral to the peak of the medial tibial spine. Drilling was performed in the same sequential manner as in the RP group.

Femoral tunnels were drilled with an outside-in technique,12 and grafts were fixed with absorbable interference screws on the tibial and femoral sides with the knee positioned at 30° of flexion. Postoperatively, patients were able to mobilize brace-free and fully bear weight as tolerated (unless dictated otherwise by meniscal repair).

Between 30 and 60 days postoperatively, patients underwent a CT scan using a 16-channel Toshiba Activion multislice device, using a slice thickness of 0.5 mm and 3D-CT reconstruction by volume acquisition. No patient had any limitation of knee extension at the time of the CT scan. The most proximal tibial axial section in which it was possible to view the entire tibia was identified and used to determine the location of the center of the tibial tunnel. To record the tunnel location, a rectangle was overlaid at the maximal extents of the tibia in the anteroposterior (AP) and mediolateral (ML) directions, in accordance with the methodology described by Kosy et al,20 and the center of the tibial tunnel was reported as a percentage of the overall AP and ML dimensions of the rectangle (Figure 3). These measurements were made independently by 3 orthopaedic surgeons (L.F.P., L.F.P., P.J.L.G.) who were blinded to all clinical and patient-identifying data at the time of the evaluations. To assess reliability, all measurements were performed twice by each observer, using the measurement tool in the institutional picture archiving and communication system software (Voxar 3D Workstation; Toshiba), with an interval of at least 30 days between the primary evaluation and re-evaluation.

Determination of whether tunnels were placed anatomically was based upon whether the center of the tibial tunnel lay within the range reported in previous studies, as summarized by McConkey et al.26 Specifically, if the center of the tibial tunnel lay between 30% and 55% in the AP direction and between 40% and 51% in the ML direction, it was classified as being anatomically placed.

Statistical Analysis

A sample-size calculation for a binary outcome superiority trial was performed using an online sample-size calculator (sealedenvelope.com). The calculation was based on the primary outcome measure of whether an anatomic tibial tunnel position was achieved on postoperative 3D-CT. It was determined that 38 patients were required in order to have an 80% chance of detecting, as significant at the 5% level, a decrease in the rate of nonanatomic tibial tunnel placement (based on the findings of Pedneault et al,29 who recently reported that 30% of tibial tunnels completely miss the ACL footprint) to 0% in the RP group.

Qualitative variables were described by the distribution of relative frequency (%) and absolute value (n). The relationship between qualitative variables was analyzed using the chi-square and Fisher exact tests. Quantitative variables were described by the mean and standard deviation.
The level of significance was set at .05. SPSS Version 19.0 (SPSS) was used for all analyses. The Kolmogorov-Smirnov test was used to verify normality of distribution. The Student t test was used to compare means. Inter- and intraobserver reliability was evaluated with the intraclass correlation coefficient and was classified according to the criteria of Cicchetti and Sparrow. To analyze the main effect of the measure (time), of the evaluator (observers 1, 2, and 3), and group (RP and RA), a repeated-measures analysis of variance of 2 factors was performed based on the assumptions of homogeneity of the covariance matrices by the Box test, and sphericity by the Mauchly test. SPSS Version 19.0 (SPSS) was used for all analyses. The level of significance was set at .05.

RESULTS

A total of 52 patients were included in the study (26 in each group [RP and RA]). The mean age of the overall study population was 32.5 ± 9.5 years. There were no significant differences between groups with respect to age, sex, or mean tibial tunnel diameter (Table 1).

There were no significant differences in the mean AP and ML tunnel positions between the RP and RA groups (Table 2). In the RP group, the mean values were 36.8 ± 5.5% AP and 46.7 ± 2.9% ML, and in the control group (RA group), they were 35.6% ± 4.8% AP and 47.3% ± 2.3% ML. Intraobserver reliability varied between good and excellent, with interobserver reliability between moderate and excellent (Table 3). Tunnel-positioning data are graphically presented with a scatterplot of the mean locations of the center of the tibial tunnel recorded for each patient in Figure 4. Two patients (7.7%) in the RP group and 3 (11.5%) in the control group met the criteria for a malpositioned tunnel. The precise location of these malpositioned tunnels is also shown in the scatterplot. An analysis of the direction of malposition in each of these patients is summarized in Table 4. There was no significant difference between groups when considering the rate or direction of malposition.

DISCUSSION

The main finding of this study was that there was no significant difference in the rate of nonanatomic tibial tunnel placement, determined by postoperative 3D-CT, regardless of whether a tibial remnant was preserved. Although not directly comparable, the rates of nonanatomic placement

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**TABLE 1**

| Comparison of Age, Sex, and Mean Tunnel Size Between Groups<sup>a</sup>| RP Group (n = 26) | RA Group (n = 26) | P Value |
|---|---|---|---|
| Age, y | 33.8 ± 7.9 | 31.1 ± 10.9 | .300<sup>b</sup> |
| Tunnel size, mm | 8.4 ± 0.6 | 8.3 ± 0.7 | .378<sup>b</sup> |
| Sex | | | |
| Male | 22 (84.6) | 20 (76.9) | |
| Female | 4 (15.4) | 6 (23.1) | |

<sup>a</sup>Data are reported as mean ± SD or n (%). RP, remnant-ablated; RA, remnant-preserved.

<sup>b</sup>Student t test for unpaired samples.

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**TABLE 2**

Mean Tunnel Positions Reported for Each Group, by Each Observer<sup>a</sup>

| RP Group (n = 26) | RA Group (n = 26) | | P Value |
|---|---|---|---|
| %AP | | | |
| O<sub>1</sub> | 36.3 ± 5.1 | 37.1 ± 4.7 | | | |
| O<sub>2</sub> | 36.5 ± 5.9 | 36.3 ± 5.5 | | | |
| O<sub>3</sub> | 37.3 ± 6 | 37.2 ± 6.1 | | | |
| Overall | 36.8 ± 5.5 | 35.6 ± 4.8 | | .134 |
| %ML | | | |
| O<sub>1</sub> | 47.3 ± 2.3 | 46.8 ± 3.3 | 47.7 ± 1.9 | 47.4 ± 2 | |
| O<sub>2</sub> | 46.5 ± 2.8 | 46.0 ± 4.3 | 47.7 ± 2.9 | 47.2 ± 2.7 | |
| O<sub>3</sub> | 46.7 ± 2 | 46.6 ± 2.1 | 46.9 ± 1.8 | 46.8 ± 1.7 | |
| Overall | 46.7 ± 2.9 | 47.3 ± 2.3 | | .098 |

<sup>a</sup>Data are reported as mean ± SD. %AP, position of the center of the tibial tunnel as defined as the anteroposterior distance as a percentage of the overall anteroposterior length of the tibial plateau; %ML, position of the center of the tibial tunnel as defined as the mediolateral distance as a percentage of the overall mediolateral width of the tibial plateau; O1, observer 1; O2, observer 2; O3, observer 3. Analysis of variance.

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**TABLE 3**

Intra- and Interobserver ICCs for %AP and %ML<sup>a</sup>

| ICC | 95% CI Interpretation<sup>b</sup> |
|---|---|---|
| Intraobserver reliability | | |
| %AP | O<sub>1</sub> vs O<sub>2</sub> | 0.846 | 0.737-0.913 | Excellent |
| O<sub>2</sub> vs O<sub>3</sub> | 0.888 | 0.805-0.936 | Excellent |
| O<sub>1</sub> vs O<sub>3</sub> | 0.995 | 0.991-0.997 | Excellent |
| %ML | O<sub>1</sub> vs O<sub>2</sub> | 0.698 | 0.321-0.775 | Good |
| O<sub>2</sub> vs O<sub>3</sub> | 0.554 | 0.225-0.744 | Good |
| O<sub>1</sub> vs O<sub>3</sub> | 0.978 | 0.961-0.987 | Excellent |
| Interobserver reliability | | |
| %AP | O<sub>1</sub> vs O<sub>2</sub> | 0.971 | 0.950-0.983 | Excellent |
| O<sub>1</sub> vs O<sub>3</sub> | 0.951 | 0.914-0.972 | Excellent |
| %ML | O<sub>1</sub> vs O<sub>2</sub> | 0.857 | 0.753-0.918 | Excellent |
| O<sub>1</sub> vs O<sub>3</sub> | 0.497 | 0.130-0.711 | Fair |
| O<sub>2</sub> vs O<sub>3</sub> | 0.803 | 0.658-0.887 | Excellent |

<sup>a</sup>%AP, position of the center of the tibial tunnel as defined as the anteroposterior distance as a percentage of the overall anteroposterior length of the tibial plateau; %ML, position of the center of the tibial tunnel as defined as the mediolateral distance as a percentage of the overall mediolateral width of the tibial plateau; E1, primary evaluation; E2, re-evaluation; ICC, intraclass correlation coefficient; O1, observer 1; O2, observer 2; O3, observer 3.

<sup>b</sup>According to Cicchetti and Sparrow.
based upon mean tunnel positions (7.7% in the RP group and 11.5% in the RA group) appear to be low when considered alongside the 22% rate of nonanatomic tibial tunnels reported by McConkey et al26 when using the same criteria. The low rate of nonanatomic tunnels in the RP group is consistent with Buscayret et al,4 who demonstrated that preserving large remnants does not compromise tunnel positioning. However, in contrast to the study hypothesis, preservation of ACL remnants did not result in a reduced rate of nonanatomic tibial tunnels when compared with stump ablation and utilization of standard surgical landmarks. It was an unexpected finding that 7.7% (2/26) of patients in the remnant-preservation group had tunnels that were classified as nonanatomic because intraoperatively the graft is shuttled within the remnant, and therefore, the tunnel must lie within the footprint. Upon that basis, it should be considered that in 3 patients, the tunnels were identified to be just outside the cutoff boundaries (within <1.5%). It could be argued that such small deviations from the cutoff fall within, or close to, the expected error of 3D-CT measurement tools, which have a reported accuracy of approximately 0.3 mm18 and are therefore unlikely to be clinically relevant. However, it should also be noted that in both patients with a malpositioned tunnel in the RP group, the tunnels were anteriorly placed according to 3D-CT. Another potential explanation for these findings is that the most anterior fibers of the ACL fan out.10,11,14,42 It is therefore possible that an anteriorly malpositioned tunnel could be concealed by these anterior fibers but still allow shuttling of the graft entirely within the remnant. This seems unlikely because these fibers are only observed immediately at the attachment and empirically are very susceptible to disruption by reaming if a tunnel is malpositioned. Furthermore, the rate of anterior malposition was not significantly different in the control group, despite complete ablation of the remnant, therefore suggesting that an alternative explanation, potentially including the variety of tibial footprint shapes and sizes, should be considered.

Perhaps a more robust explanation for the disparity between intraoperative observation and tunnel malposition identified by 3D-CT lies in the lack of both normative data and consensus regarding what exactly constitutes an anatomic position. Although criteria recently published26 were utilized to classify anatomic and nonanatomic positions, the unexpected result prompted a review of the correlation.

Table 4

| Direction of Malposition | RP Group | RA Group | P Value | b |
|--------------------------|----------|----------|---------|---|
| Anterior only            | 2        | 2        | >.999   |   |
| Medial only              | 0        | 0        | >.999   |   |
| Lateral only             | 0        | 1        | >.999   |   |
| Both anterior and lateral| 0        | 0        |         |   |
| Both anterior and medial | 0        | 0        |         |   |
| Total                    | 2        | 3        | >.999   |   |

aRA, remnant-ablated; RP, remnant-preserved.
bFisher exact test.
between the anatomic ACL footprint and imaging criteria. To our knowledge, only 3 previous studies comprising 46 patients have mapped the tibial ACL footprint to 3D-CT (Appendix Table A1). This small number precludes a reliable estimate of the true range that might be encountered in clinical practice, particularly when several different morphologies of tibial footprint have been reported (e.g., triangular, oval, and c-shaped). Furthermore, when all imaging modalities are considered, the range of means varies from 24.6% to 62.1% from anterior to posterior and 40% to 55% from medial to lateral. If the current study had used this broader range, every tunnel would have been classified as anatomic. However, using such a broad range may result in classifying a tunnel as anatomic when individual variation in footprint morphology and location means that a tunnel may completely miss, or only partly overlap, the footprint but still lie within this broad range of values. An alternative strategy is to use magnetic resonance imaging (MRI) of both knees to evaluate tunnel position. Pedneault et al reported that, using this strategy, they identified that in 30% of patients the tibial tunnel missed the footprint completely, and in an additional 25% of patients, there was <50% overlap with the footprint. Pedneault et al concluded that there is room for improvement in tunnel positioning and that this should be individualized to the patient. These findings, along with those of the current study, suggest that despite its widespread clinical use and acceptance as the gold standard for determining postoperative tunnel position, 3D-CT may not be a reliable method to determine whether a tunnel is anatomically placed for an individual patient, and clearly, further study is needed in this regard.

In a recent study by Kosy et al., the authors evaluated the accuracy and precision of the tibial tunnel in the RP and RA groups using the mean AP (38.7%) and ML (49.1%) positions determined by Lertwanich et al as the reference standard. Those authors reported no significant differences between groups regarding these metrics, and their work is therefore broadly consistent with the findings of the current study. However, in light of the reported variation in the center of the anatomic footprint when correlated with 3D-CT, it is unsurprising that Kosy et al reported accuracies between 4.8% and 6.1% and a precision between 2.8% and 3.9% when using a specific point as a reference standard. It could perhaps be argued that these metrics are incorrectly used because none of the intraoperative steps taken or landmarks used actually sought to achieve this specific position that was identified only on postoperative CT. Specifically, ML and AP tibial plateau widths are not measured during surgery, and instead, intraoperative landmarks are utilized. Recently, Cremer et al attempted to address this issue by evaluating postoperative tunnel position using a grid positioned according to the intracondylar bony landmarks seen intraoperatively. Although the technique is of interest, there are currently limited data to support its validity and further study is needed.

It is our opinion that the disparity between the intraoperative observation of a tibial tunnel drilled entirely within the remnant and postoperative CT, suggesting malposition is due to a lack of normative data and highlights one of the limitations of evaluating malposition in this manner. This is of particular importance from a medicolegal perspective due to the ramifications of incorrectly classifying a tunnel as nonanatomic. Surgeons and radiologists should be aware of this limitation of 3D-CT criteria in the assessment of tunnel positioning and also that anatomic variations may exist outside of the normal range.

The main limitation of the current study was that there are limited published data correlating 3D-CT measurements and the actual tibial ACL footprint. This is compounded by the fact that large interindividual variation in footprint morphology and position is reported. This suggests that although 3D-CT is frequently used to determine tunnel position, it may not be reliable in evaluating malposition. A further limitation is that bilateral postoperative MRI according to the methodology of Pedneault et al was not undertaken, and this may have helped to clarify whether tunnels were anatomic. Additionally, other potential risks of bias were that the study was not randomized and that only a single experienced surgeon decided group allocation for patients. However, attempts to minimize bias were made by using the classification system of Buscayret et al to determine group allocation. Further limitations include that clinical outcomes were not compared between groups and that differences in the size of patients were not considered in any evaluations. Finally, the literature demonstrates a lack of agreement on the ideal single-bundle tibial tunnel position. As a result, the findings of this study may not extrapolate well to other techniques for localizing tunnel position.

CONCLUSION

Drilling entirely within the ACL tibial stump using a remnant-preserving reconstruction technique does not significantly change the rate of tunnel malposition determined by postoperative 3D-CT when compared with stump ablation and utilization of standard landmarks.

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### APPENDIX

**TABLE A1**
Anatomic Studies

| Lead Author (year) | Measurement | N  | at/AP | mt/ML |
|--------------------|-------------|----|-------|-------|
| Lorenz (2009)23    | CT          | 12 | 37 ± 3 (31-41) | 52 ± 2 (47-55) |
| Tampere (2017)40   | CT          | 8  | 39.7 ± 2.9 | 49.3 ± 2.1 |
| Parkinson (2017)28 | CT          | 26 | 38 ± 2 | 48 ± 2 |
| Parkinson (2017)28 | MRI         | 76 | 39 ± 3 | 48 ± 2 |
| Colombet (2006)5   | XR          | 7  | 36 ± 3.8 | —     |
| Zantop (2008)42    | XR          | 20 | 30 | —     |
| Pietrini (2011)30  | XR          | 12 | 37.7 ± 6.6 | 48 ± 3 |
| Tsukada (2008)41   | Photograph  | 36 | 37.6 ± 3.6 | 46.5 ± 3.2 |
| Iriuchishima (2010)16 | Photograph | 15 | 31 ± 3 | 49 ± 4 |
| Edwards (2007)7    | Photograph  | 55 | 36 (29-46) | 43 |
| Takahashi (2006)38 | Photograph  | 31 | 28.6 ± 5.3 | 44.2 ± 2.4 |
| Takahashi (2006)38 | MRI         | 23 M | 44.1 (28.3-59.9) | — |
| Takahashi (2006)38 | MRI         | 12 F | 43.7 (27.4-60.0) | — |
| Staubli (1994)36   | MRA         | 5  | 43 (24.6-62.1) | — |

aData are reported as mean ± SD (range where provided). Dashes indicate that in that study those measurements were not performed. ACL, anterior cruciate ligament; CT, computed tomography; F, female; M, male; MRA, magnetic resonance arthography; MRI, magnetic resonance imaging; XR, radiography.

b at is the distance from the anterior tibial border of the superimposed rectangle to the tunnel center; AP is the anteroposterior border length of the rectangle.

c mt is the distance from the medial border of the rectangle to the tunnel center; ML is the mediolateral border length of the rectangle.