INTRODUCTION:
Determinants of successful Anterior Cruciate Ligament (ACL) reconstruction are multifactorial. There has been recent evidence emphasizing anatomical reconstruction to achieve better clinical outcomes following surgical intervention. Despite the evidence of two functional ACL bundles, majority of ACL reconstructions are still performed by using a single femoral and tibial tunnel created by transtibial (TT) technique, anteromedial (AM) portal technique and outside-in (OI) technique. Therefore, it is imperative that this single tunnel captures both the functional bundles of the ACL. However, a comprehensive relationship between the ACL, anteromedial bundle (AMB) and posterolateral bundle (PLB) footprints and the single tunnel created for soft tissue grafts remains unclear. Further, the relationship between femoral tunnel exit on the lateral femoral cortex and the lateral epicondyle is critical to elucidate the potential for iatrogenic injury to the lateral soft tissue structures by each of these techniques.

The objectives of this study are to 1) establish a relationship between intra-articular femoral tunnel aperture and anatomical ACL footprint and 2) measure the distance between the extra-articular femoral tunnel exit location and lateral epicondyle for the tunnels created by TT, AM portal and OI techniques for soft-tissue ACL grafts. We hypothesized that tibial tunnel independent techniques can create tunnels more accurately at the anatomical ACL footprint center than the TT technique. We also hypothesized that the femoral tunnel exit location of OI and TT technique on the lateral cortex will be further away from the lateral epicondyle than the femoral tunnel exit location of AM portal technique.

METHODS:
Eight cadaveric knee specimens with a mean age of 56-years were used in this study. A digitizing system (MicroScribe G2LX; Immersion Corporation, San Jose, CA, USA) was used to digitally record circumferential points along the outlines of ACL insertion area and apertures of tunnels created by TT, AM portal and OI techniques in a 3-D solid modeling software (Rhinoceros; Robert McNeil and Associates, Seattle, WA, USA). Following parameters were measured from the digitized points: 1) amount of ACL, AMB and PLB footprints by the tunnels, 2) relationship between the centers of ACL and tunnels, 3) distance between the center of femoral tunnel exit and the lateral epicondyle. All the recorded parameters were analyzed in the 3-D solid modeling software. Statistical analyses were performed by one-way repeated measures analysis of variance (ANOVA). If significant, post-hoc comparisons between the three tunnel creation techniques were made by using the Newman-Keuls tests.

RESULTS:
In this study, no significant difference was observed in the total ACL footprint coverage achieved by these three tunnels (Table 1; n.s.). Coverage of PLB by TT tunnel was significantly lower than the coverage by the tunnels created by OI and AM portal techniques (Table 1; p < .05). In terms of AMB coverage, no significant differences were observed between the three techniques.

<table>
<thead>
<tr>
<th>Surgical Technique</th>
<th>Percentage of ACL footprint not covered by the tunnel</th>
<th>Percentage of ACL footprint covered by the tunnel</th>
<th>Percentage of femoral tunnel outside ACL footprint</th>
<th>Percentage of femoral tunnel within ACL footprint</th>
<th>Percentage of AMB and PLB covered by the tunnel</th>
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</thead>
<tbody>
<tr>
<td>AM</td>
<td>44.96 ± 24.95</td>
<td>55.04 ± 24.95</td>
<td>15.59 ± 15.70</td>
<td>80.41 ± 15.70</td>
<td>86.64 ± 15.76</td>
</tr>
<tr>
<td>OI</td>
<td>43.17 ± 7.66</td>
<td>56.83 ± 7.66</td>
<td>10.81 ± 7.57</td>
<td>89.19 ± 7.05</td>
<td>82.41 ± 29.43</td>
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<tr>
<td>TT</td>
<td>40.97 ± 14.77</td>
<td>59.03 ± 14.77</td>
<td>21.59 ± 17.37</td>
<td>88.41 ± 17.37</td>
<td>76.20 ± 15.94</td>
</tr>
</tbody>
</table>

Table 1: Percentage of femoral ACL footprint covered by the three surgical tunnel techniques (mean ± standard deviation). A, represents statistically significant difference compared to AM portal technique; AMB, anteromedial bundle; O, represents statistically significant difference compared to OI technique; PLB, posterolateral bundle; T, represents statistically significant difference compared to TT technique.

Among the three techniques, tunnel center of the OI technique was the closest to ACL center at 1.5 ± 1.2 mm, followed by AM portal tunnel center at 2.1 ± 0.9 mm and TT technique tunnel center at 3.0 ± 1.5 mm (Figure 1). Center of TT technique tunnel was significantly anterior compared to the centers of both AM portal (p = .004) and OI (p = .001) tunnels (Figure 1). The location of TT technique tunnel center was significantly more proximal than OI technique tunnel center (Figure 1; p = .03).

DISCUSSION:
The percentage of ACL footprint covered by a tunnel is an important parameter, as it is directly related to the amount of collagen within the native footprints of the ACL. Although the maximum coverage was achieved by a tunnel created by OI technique, no significant differences were observed among the three surgical techniques. Tibial tunnel independent techniques were able to cover a larger portion of the femoral PL bundle footprint than the TT technique.

Another important parameter is the location of tunnel center relative to ACL footprint center as this reflects the ability of a technique to position a tunnel at the anatomical center. Centers of femoral tunnels created by AM portal and OI technique were closer toatomic ACL footprint center than the center of TT tunnel.

Iatrogenic injury to the lateral soft tissue structures is cited as a potential concern while preparing the femoral tunnel. In this study the AM portal technique femoral tunnel exit location on the lateral femoral cortex was closer to the lateral epicondyle than the femoral tunnel exit location of OI and TT techniques.

In conclusion, findings of this study indicate that AM and OI techniques can create tunnels more accurately at the anatomical ACL footprint than the TT technique. Attention should be paid to the location of femoral tunnel exit on lateral femoral cortex while using AM portal technique to avoid injury to lateral soft-tissue structures.

SIGNIFICANCE:
Position of tunnels created for graft fixation is critical determinant of good stability and clinical outcomes. The findings of this study provide objective guidelines that can aid the surgeons in choosing a surgical technique that can create accurate anatomical tunnels.