THE DYNAMIC STABILITY OF THE INTACT AND LIGAMENT DEFICIENT Ovine STIFLE JOINT DURING WALKING, INCLINE WALKING, AND RUNNING

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Introduction

Ligament deficiency alters dynamic joint loading and stability, and has been associated with a high incidence of development of secondary osteoarthritis (Marshall JL et al, 1971). Although anterior cruciate ligament deficiency causes passive knee instability, its relationship with dynamic knee instability is not clear. This study uses the in vivo ovine stifle joint model to investigate the impact of ligament deficiency on joint stability during locomotion. It was speculated that joint position variability would increase following ligament transection, and be reflected by an increase in the standard deviation in joint.

Methods

The stifle joint kinematics of one Suffolk sheep were studied during level walking (2.0mph), incline walking (2.0mph), and level running (3.5mph) on a treadmill. Thirty strides were recorded for each activity in the intact joint, and at 15 days after combined transection of the anterior cruciate and medial collateral ligaments (ACL/MCLX). Treadmill training was conducted over an eight week period. One month prior to kinematics testing, stainless steel bone plates were surgically implanted into the anterolateral aspects of the tibia and the femur, adjacent to the stifle joint. On the day of testing, the sheep was anaesthetized with Xylazine (0.14mg/kg), incisions were made over the plates, stainless steel posts were inserted into the bone plates, and the incisions were sutured closed. A tetrad of reflective markers was then firmly attached to the end of each post via a hex interface (Figure 1). Following implantation, the anaesthetic was reversed with Yohimbine (0.2mg/kg). Local analgesic (0.2% Lidocaine) was infused subcutaneously in the area of the incision. All animal surgeries and testing were approved and are in compliance with the Canadian Council of Animal Care guidelines.

Figure 1: Implantable bone markers with global coordinate system and anatomical coordinate systems in the femur and tibia.
The 3D spatial positions of the markers during gait were recorded via a high speed (120Hz) video based motion analysis system (Expert Vision, Motion Analysis Corporation, Santa Rosa, CA) utilizing four Falcon hi-resolution cameras. Following calibration, the demonstrated accuracy of the spatial reconstruction of the marker positions was 0.15mm. The 3D marker coordinates were tracked and smoothed (3rd order spline; cutoff 6Hz for level and incline walking, and 12Hz for running), and then normalized to percentages of the gait cycle between successive hoofstrikes.

Following euthenization, the tibia and femur were dissected and anatomically based coordinate systems were digitized within each bone (Faro Technologies, Florida, USA). The origins of the tibial and femoral coordinate systems were located at the insertions of the anteromedial band of the ACL into the tibia and femur respectively. The z-axes were directed proximally (parallel to the long axis of each bone), the x-axes were directed laterally lying in the plane formed by the z-axis and a line parallel to the segment joining the medial and lateral collateral ligament insertions, and the y-axes were directed anteriorly perpendicular to this plane. The bone markers were reinserted and their positions were digitized within their respective bone-fixed anatomical coordinate systems. The 3D in vivo bone positions were then reconstructed using coordinate transformations in conjunction with the 3D in vivo spatial information obtained from motion analysis. Repeatability studies showed that the markers could be repositioned to within 0.1mm. Given the Faroarm digitizer precision of 0.05mm, the error in the relative bone-marker position is 0.15mm. The total cumulative error in the marker position reconstruction is 0.3mm.

Tibial motion is described relative to the femoral coordinate system. Joint angles and translational positions were calculated using a joint coordinate system (Grood and Suntay, 1986). The neutral position of the joint is defined when the two coordinate systems are coincident. The standard deviations (sd) of the joint position at each point in the gait cycle were used as a measure of dynamic joint stability.

Results & Discussion

Dynamic joint stability is assessed in terms of joint position repeatability throughout the gait cycle during walking, incline walking, and running. In general, there is more variability in the joint flexion angle than in the abduction and rotation angles. This might be expected since the flexion angle is controlled primarily by the musculature whereas the angles of abduction and rotation are more tightly constrained via the joint ligaments and capsule.

![Variability of joint flexion angle and anteroposterior position during walking, incline walking, and running.](image)

The solid lines represent the intact joint and the dashed lines represent the ligament deficient joint.
The standard deviations for flexion angle and anteroposterior position are shown in Figure 2. The averages of these values over the gait cycle are shown in Table 1.

<table>
<thead>
<tr>
<th>Joint Position</th>
<th>Flexion Angle [degrees]</th>
<th>Anteroposterior Position [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>WALKING</td>
<td>4.4</td>
<td>0.4</td>
</tr>
<tr>
<td>INCLINE WALKING</td>
<td>1.8</td>
<td>1.0</td>
</tr>
<tr>
<td>RUNNING</td>
<td>2.5</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Table 1: The average standard deviations in stifle joint position over the gait cycle during walking, incline walking, and running.

In the intact joint, the flexion angle is less variable during incline walking and running than during walking. This may be the result of increased muscle activity during these activities compared with that required during level walking. Following ACL/MCLX the variability in the flexion angle during walking decreases. In contrast there is a small increase in the variability in the flexion angle during incline walking and running. This may suggest that the increased muscle activity required to control the motion of the ligament deficient joint results in a decrease in the variability of the joint flexion angle.

Relative to level walking, incline walking provokes an increase in AP position variability, however running has no analogous effect. This implies that incline walking poses a greater challenge to AP stability and might rely more heavily on ACL integrity. However, following ACL/MCLX, the AP position variability during inclined walking actually decreased by 60%. For running, the AP position variability increased with ACL/MCLX. The increase in variability of both flexion angle and AP position following ACL/MCLX suggests that the increased speed of running poses critical challenges to dynamic control in the ligament deficient joint.

Our speculation that variability in joint position would increase following ligament transection is only partially supported by these results. These results are preliminary and representative of only one subject, nevertheless they clearly demonstrate the disparity between passive and dynamic joint stability, as well as the need for further investigation into the complex nature of dynamic joint control. Further studies are in progress.

References


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