INTERRELATIONSHIP OF COMpressive, BENDING AND TORSIONAL STIFFNESS AND TORSIONAL LOAD BEARING CAPACITY OF CONSOLIDATING CALLUS TISSUE DURING DISTRACTION OSTEOGENESIS

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INTRODUCTION:
Non-invasive prediction of load bearing capacity is an important issue in the advanced clinical treatment of limbs length discrepancies by distraction osteogenesis. Several methods have been proposed in the past to predict the load bearing capacity non-invasively, e.g. DEXA (1, 2) and quantitative computed tomography (1). Recently, non-invasive stiffness measurements were recommended as a promising tool because of the high correlation between measured bone regenerate stiffness and its strength. However, previous experiments only analyzed the relationship between a single type of stiffness, e.g. bending stiffness (3, 4), torsional stiffness (5), and the maximum load bearing capacity. This approach neglects the multi-dimensional characteristics of bone loading in compression, bending and torsion. In this paper, we investigate how compressive, bending (antero-posterior and medio-lateral) and torsional stiffness are related to the torsional load bearing capacity of healing callus tissue using a common set of bone regenerate samples. The experiments were conducted using a tibial distraction osteogenesis model in sheep.

METHODS:
Mid-diaphyseal osteotomies were performed in 26 right tibiae of mature, female domestic sheep. Tibiae were then stabilized using an external half-ring Ilizarov fixator. After a 4-day latency period the tibiae were lengthened at a rate of 1.25 mm per day in two increments for 20 days. As a result of a parallel study, the callus was treated with different combinations of growth factors and carrier material resulting in four treatment groups plus a contralateral control group. On day 74 the sheep were sacrificed and the tibiae were harvested. Animal experiments were conducted in accordance with German federal animal welfare legislation. The ends of the tibiae were embedded in PMMA (Technovit 4004, Heraeus Kulzer, Wehrheim, Germany) and mounted to a sequence of special custom made jigs for compressive, 4-point-bending and torsional testing in a material testing machine (Model 858, MTS Corp., Minneapolis, USA). The specimens were randomized and stiffness measurements were performed under compressive, four-point-bending (antero-posterior and medio-lateral) and torsional loading. The load was applied by the MTS and the resulting deformation was detected by custom made compression, torsion and deflection sensors (LVTD and precision potentiometer). In a final experiment, the specimens were loaded in torsion until failure to record the maximum torsional moment. Stiffness was calculated by regression of the initial linear part of the load-displacement curves. Linear regression was performed on each stiffness type versus maximum torsional moment with SPSS-Software (SPSS, SPSS Inc., Chicago, USA).

RESULTS:
Correlation of torsional, bending (antero-posterior and medio-lateral) and compressive stiffness with the maximum torsional moment is illustrated in the following scattergrams including linear regression (--), 95%-confidence interval (- - -) and 95%-predicting interval (-----). Each black dot represents the characteristics of a single bone. The small empty circle represents the mean value for characteristics of intact bone determined by the measurements of the 26 contralateral, intact tibiae. Table 1 presents the coefficient of determination (R²) of the analysis of the correlations of each stiffness with the maximal torsional moment. While torsional stiffness exhibits the highest correlation, the correlation of compressive and bending stiffness with the maximum torsional moment are only slightly lower.

DISCUSSION:
This ex-vivo study in sheep shows that torsional, bending (antero-posterior and medio-lateral) and compressive stiffness measurements are all suitable means to predict the load bearing capacity of healing callus tissue. Our results show that torsional stiffness measurements perform slightly better than compressive and bending stiffness measurements. However, further studies are necessary to underline the superior performance of torsional stiffness measurements, since the sheep tibiae were failed by applying torsional stress.

The results of our biomechanical study analyzing bone healing of sheep tibiae confirm previous work, which showed that stiffness measurements are suitable tools to predict the load bearing capacity of bone regenerate in the advance clinical treatment of limb length discrepancies. By analyzing various types of stiffness with a common type of samples, we showed that torsional, compressive and bending stiffness measurements are all adequate means to forecast the maximum load capacity of bone regenerate.

Table 1: Coefficient of determination (R²) of analysis of each stiffness with maximum torsional moment

<table>
<thead>
<tr>
<th>Stiffness</th>
<th>Linear regression (R²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torsional stiffness</td>
<td>0.77 *</td>
</tr>
<tr>
<td>Bending stiffness ap</td>
<td>0.70 *</td>
</tr>
<tr>
<td>Bending stiffness ml</td>
<td>0.66 *</td>
</tr>
<tr>
<td>Compressive stiffness</td>
<td>0.60 *</td>
</tr>
</tbody>
</table>

* P < 0.0001 by ANOVA

REFERENCES:
(3) Hente, R., Cordey, J., Perren, S., BioMedical Engineering OnLine, 2003; 2:8

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