BONE RESONANCE ANALYSIS, HISTOMORPHOMETRY AND THE MECHANICS OF FRACTURE HEALING

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CHAPTER FOUR
FRACTURE HEALING STUDY: OVERVIEW AND MECHANICAL PROPERTIES

ABSTRACT

The overall aim of this thesis was to assess the use of bone resonance analysis (BRA) as an indicator of fracture healing. BRA measures the resonant frequency of the fractured bone and may be compared to the contra-lateral bone as a reference of normality. No studies have previously correlated in-vivo resonant frequency changes with the mechanical and histomorphometric properties of healing fractures. Also BRA is theoretically a measure of stiffness and techniques using BRA assume a workable correlation between stiffness and strength. This has not, however, been demonstrated in the literature.

Thus the detailed aims of this study were:

1. to assess the validity of using the contra-lateral limb as a control;
2. to develop a reproducible technique of BRA for use in a sheep fracture healing model;
3. to examine the mechanical changes in a sheep fracture healing model and determine the relationship between stiffness and strength;
4. to assess the use of in-vivo BRA as an indicator of fracture mechanical properties;
5. to describe the histomorphometry of the healing fracture callus and adjacent cortex;
6. and, to relate the histomorphometry to both the mechanical and vibrational properties of the healing fracture.

The first part of this study assessed the symmetry of properties between the left and right tibiae of normal sheep. Very strong correlations were found in the resonant frequency values of normal left and right sheep tibiae, justifying the use of the contra-lateral limb as a control for the resonant frequency. Strong left/right concordance was also found in mechanical tests of strength. Left and right stiffness values, however, correlated poorly in individual cases, even though the mean values were symmetrical. The correlation improved as the load used to measure stiffness was increased.

Following this a highly reproducible technique of in-vivo BRA was developed justifying its use in the subsequent fracture study.

The main study subsequently used a sheep fracture healing model. Forty merino wethers were assigned to five groups of eight sheep and were culled at 2, 4, 6, 8 or 10 weeks. The fracture was created with an osteotomy to the tibial midshaft after application of an

external fixator. Resonant frequencies were determined both prior to fracture and at the time of culling and expressed as a ratio of post- to pre-fracture values (FI). This value was squared to give a 'stiffness index' (SI) that was theoretically expected to better reflect mechanical stiffness changes. The mechanical properties were determined from torsional and four-point bending tests on both 'fractured' and normal tibiae and 'healing ratios' were calculated. Histoquantitation was performed of the healing callus and adjacent cortex.

From the mechanical tests, the study found marked variations in stiffness and strength at each duration of healing examined. Stiffness was shown to be load-dependent: measurements at higher loads reflected ultimate strength more accurately. There was a biphasic relationship between stiffness and strength: at first there was a strong correlation regardless of loading conditions, but in the second phase, which included the period of 'clinical healing', stiffness and strength were not significantly correlated.

The BRA indices, FI and SI, were correlated with the mechanical healing ratios. BRA showed only moderate correlations with bending stiffness in the corresponding plane of vibration. The correlation was better with stiffness measured under low loads which was consistent with the unloaded testing conditions of BRA. There was no significant correlation of BRA with strength. Unexpectedly, FI reflected the mechanical ratios better than SI. Reference errors, due to use of the contra-lateral tibia for mechanical control values, were believed to significantly influence the correlations found with BRA.

This study described changes in the microstructure of the healing callus. Bone volume and trabecular thickness increased whereas the surface area and number of trabeculae decreased. Trabecular separation did not change significantly. Callus histomorphometry correlated poorly with the mechanical properties but very strong correlations were found with BRA: bone volume and trabecular thickness showed strong positive correlations; trabecular surface area and number showed strong negative correlations.

In the cortex adjacent the fracture line, porosity increased with healing. The square root of the cortical porosity correlated moderately with stiffness but strongly with strength. It was hypothesised that this association was a reflection of the regional acceleratory phenomenon.

It was concluded from this study that BRA and techniques that monitor bending stiffness were inherently limited in the assessment of strength at the time of clinical union but would be useful primarily in showing a progression (or failure to progress) towards union. Any assessment of stiffness must take into account the loading conditions. In-vivo BRA was shown to be a valid indicator of fracture healing; at least at the early callus microstructual level. Monitoring cortical porosity changes may have clinical application in the assessment of fracture strength: either independently or in conjunction with other monitoring techniques.