Examination of alveolar and trabecular bone morphology and how it relates to masticatory forces

Overview

Detailed characterization of the geometry of the alveolar and trabecular bone in the mandibles of the cat, rabbit, sheep, pig, cercocebus and human was undertaken. In addition, dynamic musculoskeletal models of the rabbit, sheep and pig were developed to provide the most accurate simulations and predictions of tooth loading in these species. The effects of including fibrous periodontal ligaments on the load transfer from teeth to the alveolar bone were also examined thoroughly by finite element (FE) analysis. Overall, a large volume of data has been produced – a small sample of which is presented below.

Variation in cortical and trabecular bone morphology.

High resolution microCT of several mandibles and sections of mandibles have been performed. New techniques to reliably segment out the trabecular bone and new methods to characterise the trabecular network and cortical bone morphologies have been developed. These methods and the data produced will be presented in forthcoming publications.

Figure 1 shows typical plots of cortical bone thickness over all the surface of the mandibles. Areas of blue reflect thin bone, while red represents the thickest bone. For the rabbit, the length and orientation of the (single root) molars and pre-molars are clearly reflected in these plots, with the variation in bone distribution providing an indication of load transfer paths. This method provides an easy visual way to compare mandibles of the same species, and those of different species.

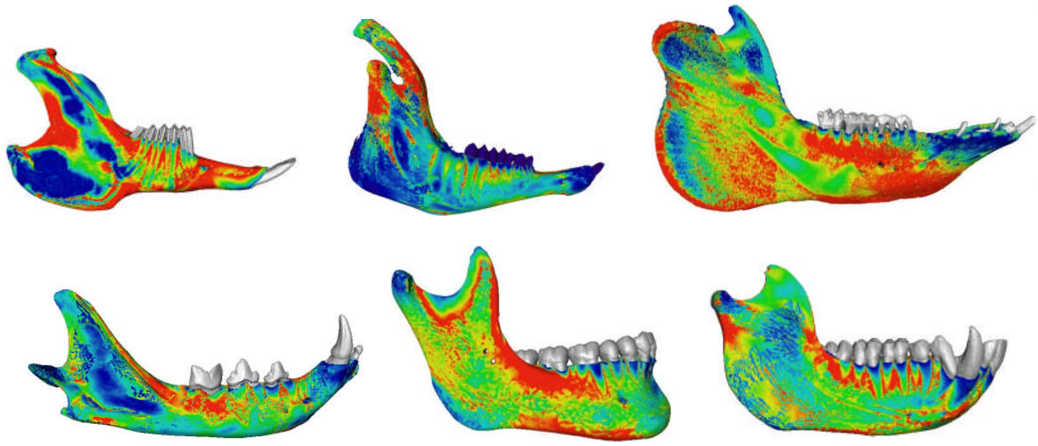

Figure 1. Variation of cortical bone thickness in rabbit, sheep, pig, cat, human and cercocebus mandibles; (blue = minimum; red = maximum); not to scale.

Sample variations in trabecular bone properties along the length of the human mandible are shown in Figure 2. Similar data were determined for the other animals, with typically 12 samples of each examined.

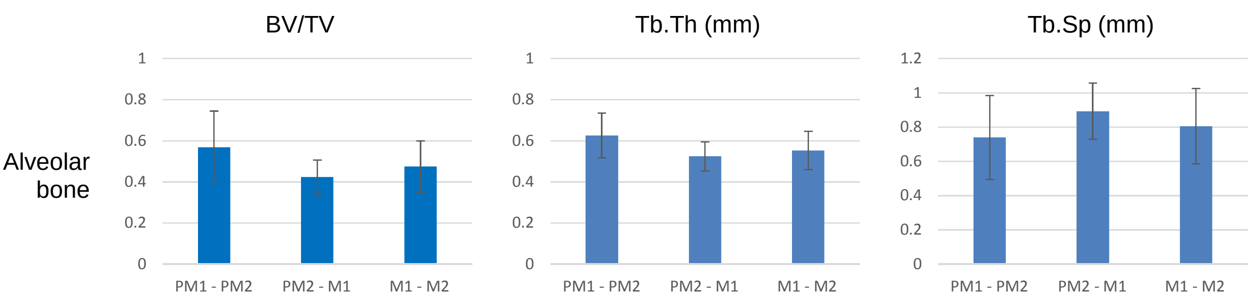

Figure 2. Variation of alveolar trabecular bone (with S.D.) between the teeth along the human mandible. (BV/TV = ratio of bone to total volume; Tb.Th = trabecular thickness, mm; Tb.Sp = spacing of trabeculae, mm; and, for example, PM2 - M1 = bone between pre-molar 2 and molar 1 etc).

A comparison of the average data for the different species is provided in Figure 3, showing the overall differences in the basal bone (within the tooth roots) and alveolar bone (between the teeth).

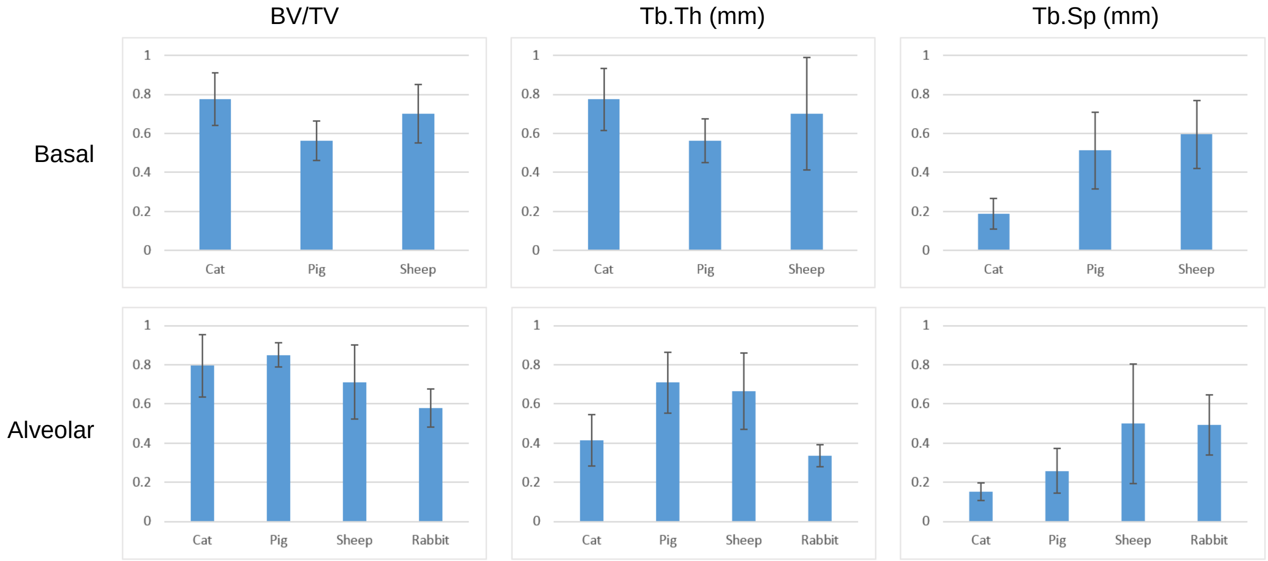

Figure 3. Variation of trabecular bone within the tooth roots (basal) and between the teeth (alveolar) in the mandibles of the cat, pig, sheep and rabbit; (the cat teeth have single roots, so no basal values).
(BV/TV = ratio of bone to total volume; Tb.Th = trabecular thickness, mm; Tb.Sp = spacing of trabeculae, mm).

Investigation of masticatory forces and load transfer in the mandible.
Detailed dissections of a number of pig, sheep and rabbit heads were undertaken, after being scanned by MRI. The MRI data was reconstructed and used to extract muscle details, including points of attachment and the muscles' lines of action for comparison to the dissection work, and to construct detailed musculoskeletal models. Figure 4 shows sample models, which provide accurate predictions of tooth loading during mastication. In the case of the rabbit model, we also collected *in vivo* bite force data that was used to successfully validate the model predictions. A paper describing this work has been published.

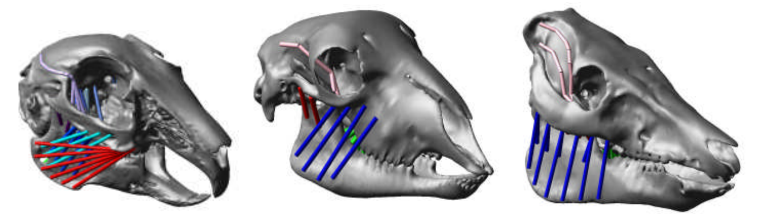

Figure 4. Sample MDA models of rabbit, sheep and pig skulls, including all the main masticatory muscles (not to scale).

Modelling of tooth-bone load transfer
Three-dimensional FE analyses have been carried out to investigate the role of the periodontal ligament (PDL), especially the ligament fibres, in transferring the load from the teeth to the alveolar bone. The model results confirm that inclusion of the PDL fibres is important to reliably predict load transfer to the bone. These results also have direct implications for the current debate about the mechanism underlying orthodontic tooth movement. By modelling the fibrous structure of the PDL, we have shown that the fibres lead to strain distributions in the alveolar bone that are not predicted by current hypotheses about the mechanical stimuli for orthodontic tooth movement. This work has been published recently. FE modelling of mandible segments has also been undertaken, and is being analysed further.

Continuing work and application of the results
Detailed interpretation of the FE results and investigation of the overall role of the trabecular and cortical bone on mandible performance is being completed now, and a number of papers are in preparation. The models developed have significant future potential. In particular: the sheep and pig models will be applied in further research into animal health; the work on characterization of bone details in the human mandible and role of the PDL will be of interest for dental applications; all the models will be used in future research to understand skull development and medical conditions affecting that development.