**INTRODUCTION**

Long-term success of load-bearing implants require solid fixation of the implant to the host bone by the process of osseointegration. Osseointegration is achieved by the growth and mineralization of bone tissue onto and into the textured surface of implants. According to current theories on tissue differentiation, peri-implant tissue formation and subsequent mineralization are dependent on several factors, including the local mechanical environment in the interface zone [1]. Experimentally it has been shown that bone ingrowth can occur in the presence of some relative movement between the implant and host bone, while excessive movement (150 µm or more) can result in the formation of a fibrous membrane around the implant. Micromotion in the interface is determined by the local mechanical environment around the implant, which is dependent on the applied forces, implant geometry, and bone quality. Therefore the manner in which load is transferred from the implant to the host bone is a critical factor in determining its long-term fixation.

Accurate assessment of primary mechanical stability is even more critical in areas such as dentistry where early loading has become increasingly accepted clinically. At present there exists no method of planning for surgery which provides an assessment of an implant’s mechanical stability. The aims of this study were: (1) to develop a method of incorporating fast structural analysis into surgical planning, and (2) to assess the accuracy of such an approach using an experimental approach.

**METHODS**

Computer-aided tools are in wide use to enable accurate preoperative assessment and planning prior to surgery. By using such systems, surgeons can place virtual implant within patient’s 3D CT scan and visualize the position of the planned implants. Even with the improved visual access to the CT data it is often very hard to make a qualitative assessment of the bone quality in an area. It is even harder to assess the effects loading an implant will have on the surrounding bone. However, since the intended position of the implant relative to the CT data is known, it is possible, through structural analysis to perform assessment an implant’s stability prior to surgery.

We have developed a finite element analysis methodology and program which performs patient-specific structural analysis in real-time. By integrating this tool into an application for computer aided planning it is possible to build accurate models of the planned implant(s) and the surrounding bone in a fully automatic manner. Upon completing a surgical plan for implantology the surgeon can choose to run an analysis which builds a model of the implant(s) and the surrounding bone, assigns patient-specific material properties based on per-pixel Hounsfield units [2], and applies worst-case physical loading. The surgeon is immediately provided with the predicted implant micro-motion and notified of there are areas of high load-concentration. This analysis tool has been integrated with our system for planning implant dentistry where the information provided by the FEM analysis can help to determine the optimal position for the implants and design of the superstructure.

A set of experiments were conducted to test the accuracy of the predicted implant micromotion. Five fresh porcine mandibles were obtained from the local abattoir and frozen at -20°C. To provide image data for the planning and analysis each of the specimens were equipped with four fiducial markers and CT-scanned. The CT datasets were loaded into the dental planning software and a total of 9 implants (Straumann, ITI solid screw) were placed virtually. Then finite element analysis was conducted where each implant was subjected to and axial load of 100 N was applied gradually using a mechanical testing machine (MTS, Minneapolis, U.S.A.) and the displacement was monitored. In this manner the implant micromotion predicted from the analysis could be directly compared to that of the experiments.

**RESULTS**

Axial micromotion could be compared directly between the experiment and structural analysis. In figure 1 the results from the structural analysis as compared with the experiments for all 9 implants are shown. The CT images did give some indication of the density of the bone, although a 3D assessment is very hard. However, the mechanical stiffness of the bone only became clear when drilling the pilot hole. This subjective feedback was reflected in the experiments and also predicted by the numerical analysis. Note that two of the implants moved more than 150µm even with only 10kg of applied load. Using Wilcoxon matched-pair statistical analysis it was found that there is no significant difference (p=0.65) between the numerical and experimental results.

![Figure 1 – Micromotion of implants embedded in porcine mandible when subjected to 100N bone. Pre-operative structural analysis as compared to post-operative experiments.](image)

**DISCUSSION**

Comparing predicted axial micromotion using numerical analysis to that of experimental tests showed that the structural model gives a good indication of initial axial implant stability. The analysis tool therefore provides clinically relevant information during incipient stages of the surgical pipeline. Since the feedback is provided in real-time the surgeon can use it iteratively to optimize the planned intervention.

Our results further strengthen the validity of using Q-CT Hounsfield units as a measure of structural bone stiffness [2]. Although dental implants a mainly loaded axially, there can also be significant radial and moment components. The analysis methodology does take this into consideration, and further experiment will be conducted to assess its accuracy. These results show the effect just prior to an implant being placed and the analysis does not include bone remodeling or any biological effects. Thus the surgeon must be aware of these limitations and the information obtained using this method can only act as a guideline and will be one of several sources of information on which the surgeon can make his decision. Nevertheless, it is believed that the result obtained gives a strong indication of the likelihood of an implant forming a strong osseointegration with the host bone.

Structural analysis in clinical planning can be a useful tool when it allows for fully automatic, accurate and fast assessment of the stability of an implant. The current imaging and computer technologies makes this a reality today and this methodology of pre-operative structural could therefore also find useful application in other clinical areas.

**REFERENCES**