Biophysical Approahes to Tooth Restoration Selection: New Direction Formation in Restorative Dentistry

Nadezda O.Bessudnova, Vladimir S. Senkin, Sergey B. Venig
1)Saratov State University, Saratov , Russia
2)Dental Clinic "Denta", Saratov, Russia

1 Scientific and technological quality. Background and the state of the art

It is a little known fact that dental practitioners spend some 50% of their time replacing failed restorations, be it a filling, crown, bridge or denture. The economic cost of this to the EU runs into many billions of euros. Fractures of fillings, crowns, bridges and dentures and more seriously the remaining tooth structure are frequent problems, as are loosening of posts and crowns, which dental practitioners encounter on a daily basis. For many decades dental researchers have been searching for an ideal approach for the restoration and reconstruction of hard tooth tissues in a way that it would offer maximum protection to the remaining tooth structures, combined with long-term function.

One problem is that the design of dental restorations has evolved over many years of practical experience and thus has been empirical. This empirical approach to design continues to this day but unfortunately the technology and materials are advancing at such a rapid rate that this approach has become unacceptable in the modern age. We should not have to wait 20-30 years before we know how to get the best out of the materials and technologies we have available today. We have a good understanding of the properties of the materials and the biological need, what we don't have is the understanding of engineering design that is so important to determining function. To some degree this is not surprising since, rightly or wrongly, dental practitioners do not see themselves as dental engineers and engineering is subject that appears both alien and inaccessible.

Thus, the solution to improving the performance of dental restorations lies not only with the development of better materials but also with an improved understanding of how to get the best out of these materials and how to avoid failure. The solution to this problem lies with dental engineering, whereby it is possible to engineer designs that are potentially more benign under normal occlusal loading conditions and thus minimize the chances of fracture.

New materials become available with little or no knowledge of their clinical performance and also little or no knowledge of what aspects of our empirical knowledge are relevant and applicable to these new technologies. Therefore, as in engineering, we need to develop and improve our understanding of the factors that govern the selection and use of dental materials. The first step on this road to understanding is to appreciate and recognize the complexity of the many interactions involved in determining the performance of dental materials.

On the one hand we have a lot of knowledge and understanding of the materials available to dentistry and on the other hand we also have a considerable amount of clinical experience to draw on, but little knowledge and understanding of how to connect the two. In the disciplines of mechanical and structural engineering the gap between the empirical approach of say the archway bridge builders of Roman times and the modern engineering approach in producing beautiful suspension bridges has been closed. In dentistry, much of what is done is still at the empirical stage.

The idea of using predictive modeling to assess the performance of engineering structures is something that is now fully embedded in the discipline of engineering, whereas in dentistry it is still in its infancy. Perhaps not surprisingly, where engineering approaches have been adopted, the results are controversial. One of the examples of such a controversy is in the area of restored significantly damaged teeth, when CAD-CAM technology is used. These restorations may or may not have been fixed applying adhesive technology, and in particular adhesive luting cements. Several clinicians promote the use of adhesive material, whereas others report that the placement of resin-based adhesive luting cement could result in durability decrease of adhesive layers between artificial material and hard tooth tissues that finally leads to fractures. The situation is made more complicated by the availability of different luting materials, all of which have very different properties. It is well known that significantly damaged, especially endodontically treated teeth are weaker because of loss of dental structure, cavities, root canal treatment and the like. Consequently, special care is indicated when selecting the best way to restore such teeth in order to improve their survival.

More specifically, this project compares the results of various engineering methods that are applied to the restored teeth, where these teeth have suffered severe coronal damage, incorporating such elements as bridges and dentures. Computational modeling is carried out alongside *in vitro* simulations and related to clinical observations *in vivo* to gain in-depth understanding of mechanical performance of these restorations.

Aims and objectives

The aim of this project is to develop a better understanding of the role of engineering design, biophysical approaches and digital technologies in reconstructive dentistry. The objective is to develop guidelines of improved designs for these restorations in the context of the materials and technologies used, reduce the likelihood of fractures of restored teeth and consequently increase their survival rate.

2 Research Methodology: Approach and Appropriateness

The research project is arranged according to two parallel programs. One program involves the development of 3D computational models of the dental structures to be investigated using finite element analysis (FEA). The second program will consist of real-life simulations of the designs that have been modeled. That way the results from the computational simulations can then be directly compared to the results in the experimental simulations.

Development of 3D computational models

In order to carry out a computational simulation using FEA, first a 3D model needs to be created, where each element can be allocated suitable material properties and meshed to create a solution using an appropriate FEA package such as ANSYS or ABAQUS.

In this *first stage* of the project, micro-CT is investigated for the purposes of 3D model design of tooth hard tissue structures and elements of restorations (posts, crowns, composites, bonding systems, bridges, full denture structures). The extent to which micro-CT is able to differentiate between the various man-made and natural materials is still an area that needs to be examined. Several new ideas for the visualization of the bonding resins are explored by incorporating nano-particulate X-ray markers.

Once the raw data has been obtained from the micro-CT scans in such a way that all components of the structure can be identified, the *second stage* is to manipulate and refine the models using a range of software packages including Mimics, Magics, 3-Matic, SolidWorks, Rhino and Freeform. The strengths and weaknesses of each of these packages in the context of dental engineering still needs to be determined.

In the *third stage* a stress-strain distribution analysis is performed on the designed models to evaluate the biomechanical response of tooth and restorative structures to various loading conditions. Both Ansys an Abaqus are explored for this purpose to determine which combination of material and designs produce the most benign stressing conditions.

Simulations of the designs

The experimental fracture mechanics methods, including fatigue analysis and fracture toughness analysis of the structures of restored significantly damaged teeth, varying elements of CAD/CAM restoration such as types of applied ceramics, types of adhesive luting cement, crown design, with incorporated bridges and dentures (3D- printing), are applied to evaluate survival rate of restorations of various design in vitro. These experiments aid in correlating designs and stress-strain responses of structures of restoration, cracks and fractures of the explored design.

The experiments are performed in two stages. In the first stage, failure mechanisms and crack propagation were studied through the measurement of progressive micro- and macro-changes in the restoration and tooth structures during cyclic loading. Fatigue testing and fracture description in dental restorations identified major factors leading to failure of the restoration. In the second stage, tensile and shear testing are used to observe the fracture response of elements of explored designs during loadings.

It is necessary to notice that whereas surface fractures topography at a macro scale can be evaluated at glance, micro – CT and scanning electron microscopy (SEM), optical computer tomography (OCT) help in visualization and understanding micro-fractures and failure patterns, in case of bonding resin by evaluating the distribution of incorporated nano-particulate X-ray markers at the interfaces of artificial restorative materials and tooth hard tissues (for example, at the interfaces such as “dentine- bonding resin”, “bonding resin cement – crown”).
The suggested experimental approach provides us with proper guidance as to predictive modeling of optimum design for CAD/CAM modeling as well as the optimum combination of materials to decrease possible fractures and increase the longevity of restorations.

3 Originality and innovative aspects of the project

The project drives the development of innovative technologies in dentistry, in particular, it leads to embedding engineering solutions and new digital technologies as a part of routine in dental manufacturing, as a university discipline for undergraduate, graduate and postgraduate students. This project is innovative in the sense that nowadays there is no such a concept as an engineering design at all both in clinical dentistry and dental research. The project gives a chance for developing understanding in what dental practitioners do empirically and what have to be done to improve design of dental restoration at the preclinical stage. Another original aspect of the project is that nobody has been developing the methodology of engineering design in restorative dentistry as conceptual solution so far.