

# Design optimisation of porcelain-fused-to-metal dental bridges

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## Introduction

All-ceramic dental restorations have been used extensively over the last two centuries because of their superior aesthetics, chemical durability, and biocompatibility. However, a problematic aspect is their strongly limited loading capability, which is caused by the limited tensile strength and low fracture toughness ( $K_{IC}$ ) of ceramic materials [1]. The mechanical long-term behaviour of ceramic restoration is even more critical, since ceramics exhibit a time-dependent strength decrease [2]. This phenomenon is mainly induced by subcritical crack growth even occurring at a low stress level. In general, the more the growth of micro-cracks, the lower the strength of ceramic materials, thereby, the lower the loading capacity of ceramic restoration. Previously, improving the fracture resistance of dental restorations provided the impetus for fusing it to a metal framework. Porcelain-fused-to-metal (PFM) fixed partial dentures (FPD) have been a widely adopted means to the replacement of missing teeth over years. Significant process has been made in the improvement of physical properties and composition of materials for FPD constructions. Along with rapid development of ceramics, the challenge has consisted in producing high-strength ceramic dental bridges without sacrificing translucency for dental bridges.

The aim of this study is to develop some biomechanical-sound design for PFM dental bridges based on existing dental ceramic and metal materials available. The project used clinically computer topography images to create finite element model to improve the stiffness of all-ceramic dental restorations, and design for high stiffness PFM fixed partial denture. The method of topology optimisation is applied to distribute the metal and ceramic materials with the focuses on developing novel PFM dental bridge configuration.

## Materials and Methods

Computed tomography was used to capture the geometry of a dental bridge apparatus including abutments, pontic and dental bone between first molar and first premolar in mandible. Data points derived from the scanning are superimposed and imported into a computer program called Rhinoceros, in order to construct the model of dental bridge. In this paper, a two-dimensional (2D) dental bridge model was taken from a mesial-distal

section of 3D model. The six-node triangular elements were applied for 2D topology optimisation.

In this study, three different load cases are considered. In load case 1, the occlusal pressure was applied on top of all three crown surfaces. In load case 2, a pressure load was only applied on the pontic crown surface. Load case 3 was formed by a combination of load case 1 and 2, indicating a multiply load case. The boundary conditions were applied in terms of a zero displacement on the bottom and both vertical sides of alveolar bone area, as illustrated in Fig.1(a).

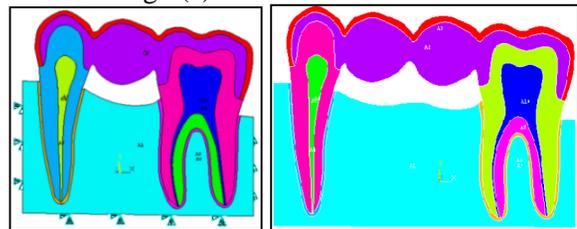


Fig.1: 2D FPD models: (a)three-unit FPD model; (b) four-unit FPD model

To construct the model of four-unit dental bridges, the model is divided in two components at the connector between one premolar and pontic. Furthermore, key points of pontic were copied to create a new pontic and joined them together, as shown in Fig.1(b). The thickness of porcelain layer was approximately 1mm for all the crowns in the fixed partial dentures.

The optimised models will compare the overall stiffness with metal-ceramic models as controlled models. As illustrated in Fig.2, the controlled models have different volume fractions of ceramic and alloy in configurational design.

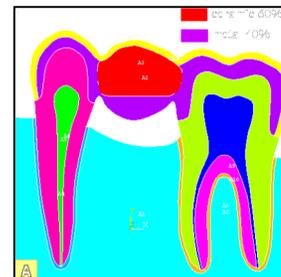


Fig.2: Three-unit FPD optimisation: initial controlled model with 60% ceramic and 40% alloy.

In this study, materials were assumed to be homogenous, linear elastic and isotropic. The material properties

which used in finite element analysis are summarised in Table 1.

Table 1 Material properties are used in this study.

Material	Young's Modulus E (MPa)	Poisson's Ratio
Ni-Cr alloys	202000	0.3
Alveolar Bone	12000	0.15
Pulp	10	0.49
Periodontal Ligament (PDL)	1.18	0.45
Dentine	18000	0.31
Vita VMK 95	91000	0.24

Mathematically, the topology optimisation problem of compliance minimisation can be formulated as

where  $\{u\}$  is the displacement vector,  $[K]$  is stiffness matrix,  $V_0$  is the constraint of volume fraction. In this paper, we gradually change the distribution ceramic and metal materials so that the compliance can be minimised and the stiffness can be maximised.

## Results and Discussion

In this study, the design constraint can be setup in a range of 50 to 80% for ceramic, and 50 to 20% of alloy in terms of volume fraction.

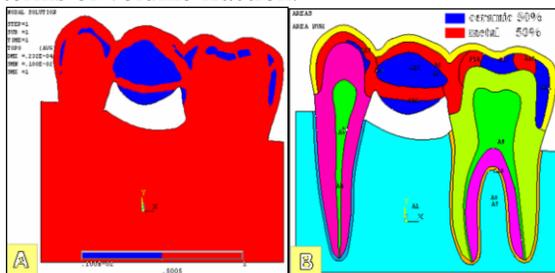


Fig. 3: (a) topology optimisation (b) Final optimised model with 50% ceramic and 50% alloy.

The design constraint as shown in Fig. 3 is 50% ceramic and 50% alloy for load case 1. The final optimal shape is shown in Fig.3(a). It appears that the metal configuration takes a shape of truss-like reinforcement in the core if ceramic pontic, which covered by a porcelain layer. The red colour area represents metal material, and blue colour area is porcelain. Fig.3(b) shows the construction of optimised model based on the topological optimisation result. Since sharp corners and relative small areas should be avoided for manufacturing purpose, it has no point to create the optimised model exactly as same as topology optimisation result (Fig. 3a).

Fig.4 shows the convergence process of topological optimisation of three-unit dental bridge with a 50% volume fraction. The lowest weighted compliance value is  $5.013 \times 10^{-5}$  at iteration number 7, which is of

maximum stiffness as an inverse measure to the compliance value.

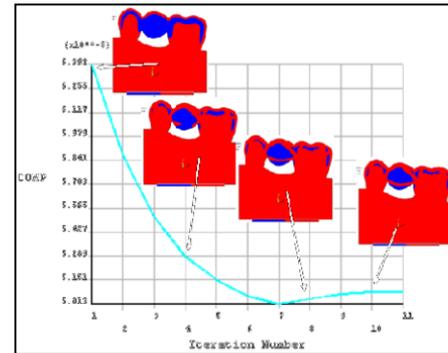


Fig. 4: Convergence history of objective for the three-unit dental bridge with a 50% volume fraction.

Fig. 5 shows the maximum displacements of optimised models are lower than those of control models in different volume fraction. This indicates that the stiffness of optimised models increased in comparing their corresponding control models at load case 1.

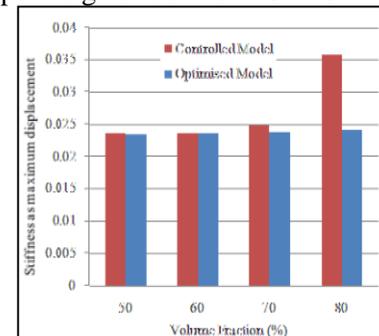


Fig. 5: Stiffness of controlled models and optimised models at load case 1.

## Conclusion

The purpose of topological optimisation is to determine the best allocation of metal and ceramic material for dental bridge. This paper aims to generate a stiffest design subject to different volume fractions of metal-ceramic materials. It is observed that the topology optimisation provide some novel material configuration in FPD application. The design made certain improvement in terms of objective functions when compared with the baseline design models. The results shows considerable implication in extending it to other design criteria like stress and fracture strength etc..

## Reference

- Green D.J., an introduction to the mechanical properties of ceramics. Cambridge: Cambridge University Press, (1998).
- Munz D., Fett T., Ceramics: mechanical properties, failure behaviour, materials selection. 1<sup>st</sup> ed., Springer, Berlin, (1999).