Alloplastic Reconstruction of the Mandible—Where Are We Now?

R.C.W. Wong, J.S.P. Loh, and I. Islam

Abstract

Mandibular segmental defects happen as a result of trauma, infection or resection. There exist no ideal method to repair such defects. Each method advocated has its advantages and disadvantages. Alloplastic replacement has been advocated but problems exist. This paper reviews the challenges faced for reconstructing mandible defects and the different attempts to improve alloplastic replacement with an emphasis on previous research done on using a modular endoprosthesis for mandibular body replacement. The authors outline previous research in adapting a titanium endoprosthesis to the mandible and future avenues for research.

Keywords

Mandible defects • Alloplastic reconstruction

1 Introduction

The mandible is the only moveable, load bearing bone of the head. It has uncertain seating due to the inter-digitation of the dentition and the position of the temporomandibular joint, which is variable. Mandibular segmental defects occur as a result of trauma, infection and resection due to benign or malignant tumors [1].

The ideal method to reconstruct a mandible would ideally: (1) be cost effective; (2) be simple to perform without the need for special skills that would be hard to train and to gain experience in; (3) does not need to take tissue from another part of the patient's body with its concomitant morbidity; (4) renders the patient back to normal function and appearance almost immediately with no need for long hospitalization and recovery; (5) does not need long operations with its own morbidity and increased cost of operating theatre time; (6) able to withstand the forces of mastication and function without weakening the reconstruction; (7) be able to tolerate exposure into the oral cavity with minimal effect and lastly (8) be able to place teeth replacement. The search for the ideal method to reconstruct mandibles goes on, as currently there is no ideal method.

Methods for mandibular reconstruction include: (1) No reconstruction; (2) bridging plate; (3) free non vascularized bone graft; (4) titanium mesh with particulate bone graft; (5) vascularized free flaps and newer methods like (6) tissue engineered bone scaffold and titanium mandible; each with its own associated problems.

2 The Problems with Existing Methods

Non-replacement of bone with only soft tissue causes the mandible and the face to swing to one side when the soft tissue contracts which is permanent and difficult to correct once it has happened. Use of reconstruction plates to bridge a defect maintains the relationship of the mandible but is prone to either the plate breaking or the screws loosening. The current gold standard is with vascularized free flaps, which takes specialized skills and takes a longer time to

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perform and significant post-operative care and morbidity. Not every patient is fit for such long operations and it takes a very long time before such patients can resume walking or normal eating. Newer methods like the tissue engineered scaffold look promising but are currently still biomechanically weak and still need to be used in conjunction with a staged vascularized free tissue transfer.

3 The Challenges with Alloplastic Mandibular Reconstruction-Emphasis on Previous Research on Modular Endoprosthesis

In the orthopedic field, it is routine now to replace missing bone with a metal implant, usually in the form of an endoprosthesis. How is it that missing bones in the rest of the body can be replaced with an implant with great success and yet in the mandible, it is prone to problems?

The long bone prosthesis or endoprosthesis is connected to the remnant stump with a metal rod that fits into the medullary space of the bone. It is either press-fit or cemented with bone cement. Attempts have been made to replicate the endoprosthesis to the mandible.

The challenges in reconstructing the mandible are: (1) the loading is not in the long axis of the mandible, at almost right angles to it; (2) the thin tissue of the oral cavity makes any temperature transfer almost instantaneous with expansion and contraction of any interphase and any tears easy to expose any hardware in the mandible; (3) the mandible undergoes torsional forces of dorso-ventral shear, corporal rotation and medial convergence as described by Hylander and finally the need to have adequate bone width and height for replacement of missing teeth [2].

Alloplastic mandibular reconstruction is still not widely accepted due to the above problems. Attempts have been made to replace a mandibular segmental defect with a modular endoprosthesis. The first generation endoprosthesis consisted of a three parts, connected by a module. It was designed to be cemented in with a stem [3] (Fig. 1).

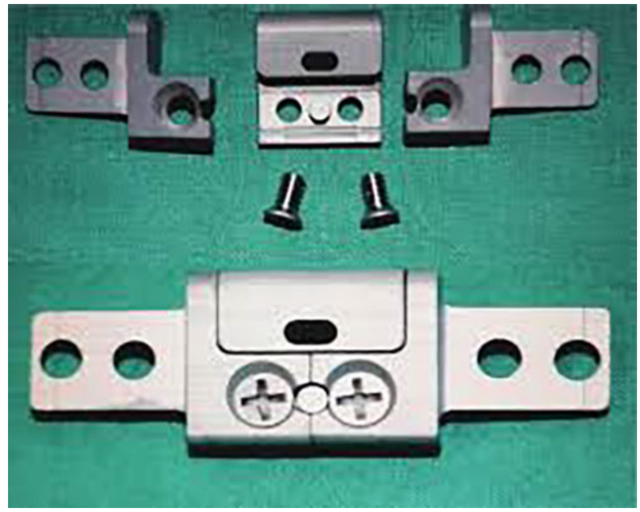


Fig. 1 Design of the first generation modular endoprosthesis for mandible

The prototype was made by a manufacturer (Walter Lorenz, USA) and it was placed into the mandibles of pigs. The animal model was changed from pigs to monkeys (macaca fascicularis) as there was very little cancellous bone in the pig's mandible [4].

The mandible segmental body endoprosthesis had a persistent problem with loosening at the connection of the modules. This led to infection and eventual exposure of the endoprosthesis [5].

The effect of placing the endoprosthesis into the mandible on the surrounding bone, specifically the bone mineral density (BMD) was studied. The hypothesis was that placement of the endoprosthesis would cause an initial decrease in BMD in the region of the stems which would eventually lead to an increase in BMD as the forces of mastication get transmitted to the surrounding bone [6].

Two groups of eight monkeys were operated on (defect created) and modular endoprosthesis placed and cemented. The first group of eight had the condyle prosthesis placed and the second group having the mandibular body replaced. Each group of eight was then divided into two with the first half sacrificed after 3 months and the second half sacrificed at 6 months. The mandibles were harvested and sectioned in the regions of the stem. It was then scanned with a micro-computed tomographic machine (micro-CT). Regions of interest on the buccal, lingual and inferior of the stems were outlined. As control, the contralateral side of monkeys that had undergone surgery for a different study was used. The digitized signal was transferred to a PC where the micro-CT images were recorded and reconstructed. The bone mineral density was calculated from a scan of a blank with a known amount of calcium density. In this study, the problems with the connection screw were realized. The BMD for the condyle replacement group showed no difference whereas the BMD for the body replacement showed a decrease at 3 months with a tendency for increase although the BMD were significantly lower than controls. The BMD for the body replacement group was lower because of the loosening of the modules. Evidently there was some factor in the mechanical forces distribution that led to loosening (Figs. 2 and 3).

A systematic review was made looking into the biomodels that were used to study the biomechanics of the reconstructed mandibles. The biomodels could be divided into computer biomodels or physical biomodels. Using any one biomodel alone could lead to errors or inaccuracies.

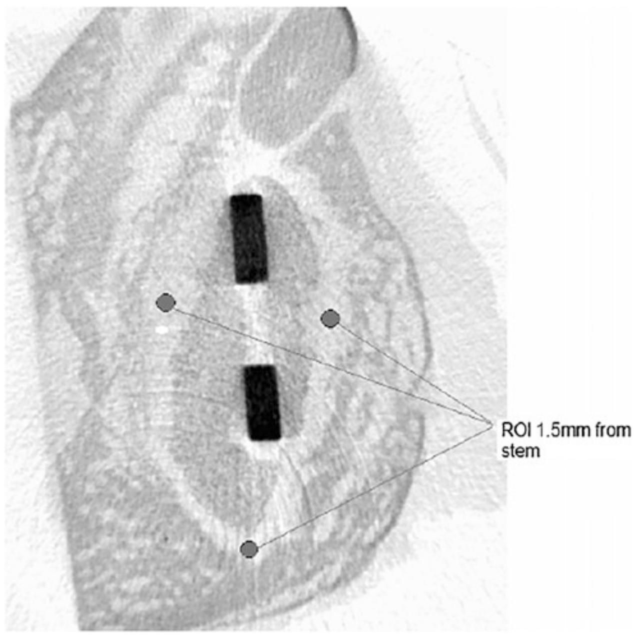


Fig. 2 Regions of interest at the buccal, lingual and inferior areas around the endoprosthesis stems

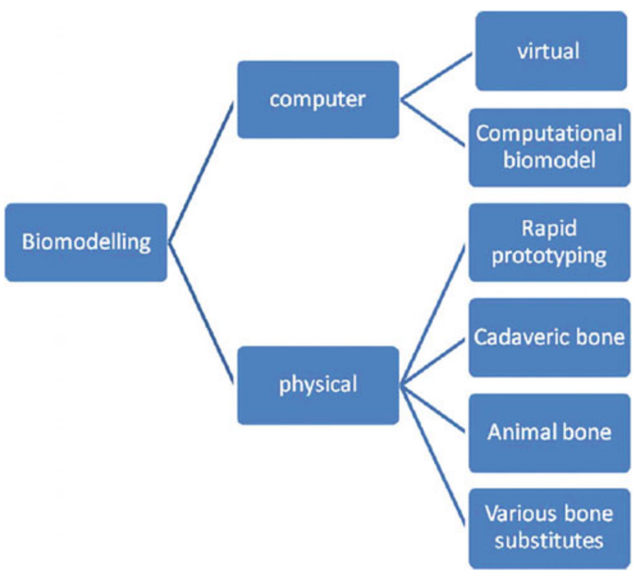


Fig. 3 Biomodels used in studying reconstructed mandibles

It was evident that the best approach would be to use a combination of physical biomodel to conduct mechanical testing with finite element analysis to study the force distribution in detail [7].

From the literature search, many previous studies used synthetic bone, which had similar elastic properties to human bone for mechanical testing. There were biohazard concerns in using cadaveric or animal bone and when the bone dried out, the elastic properties changed, causing inaccuracies.

A third generation endoprosthesis was designed with a male and female part; with the connection in the shape of a dovetail; this was secured with a connection screw. Due to previous experiences with cemented endoprosthesis, a decision was made to directly screw the stem into the medullary space. From previous animal studies, the condyle prosthesis didn't have any problems associated with loosening whereas the body prosthesis frequently had problems with loosening. A decision was made to concentrate on the body prosthesis design [8] (Fig. 4).

A series of mechanical tests were conducted prior to using for animal surgery. The endoprosthesis modules were mounted onto synthetic bone, which had similar elastic properties to human bone and subjected to fatigue testing as follows; three specimens were subjected to continuous increasing loads (static testing) at 1 mm/min to 500 N to get the average load to failure for the endoprosthesis (Fig. 5).

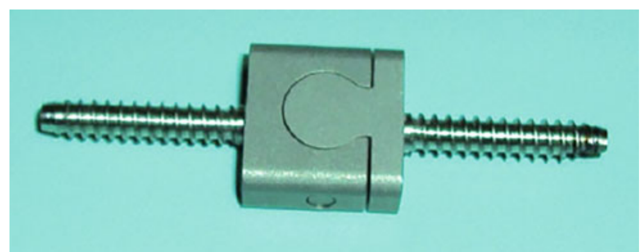


Fig. 4 The third generation endoprosthesis design

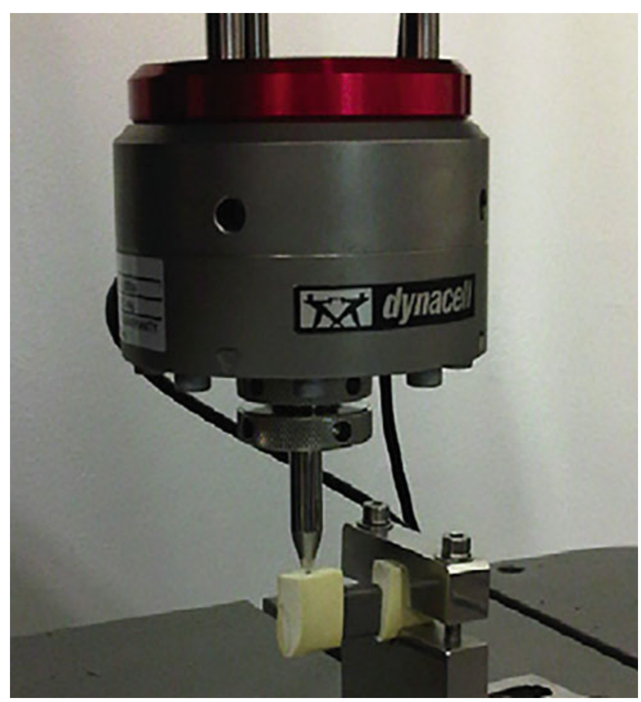


Fig. 5 The test setup mounted to an Instron machine

Five specimens were then loaded at loads of 8–80% of the average load to failure according to the American Society of Testing Materials (ASTM) guidelines and subjected to cyclic loading at 2 Hz up to failure or 500,000 cycles, whichever came first. This speed was sufficiently fast to imitate bite speeds but not fast enough to adversely affect the entire system due to heat generation. The average load to failure was 185 N and the failure occurred consistently at the stem/bone interphase of the clamped male part with fracture of the synthetic bone. The cyclic testing was then set at 10–150 N (8–80% of load to failure) (Fig. 6).

The result of the fatigue testing showed that there was no loosening of the module connection although the stem showed bending or crack lines on the superior surface. One specimen survived the testing intact.

Inspection of the specimen that survived testing showed very good contact at the abutment between the bone and prosthesis at the lower border. This could have contributed to cross bracing of the forces and good stress dissipation. The other specimens had minor gaps, which could have contributed to more micro-motion and hence more shear stress.

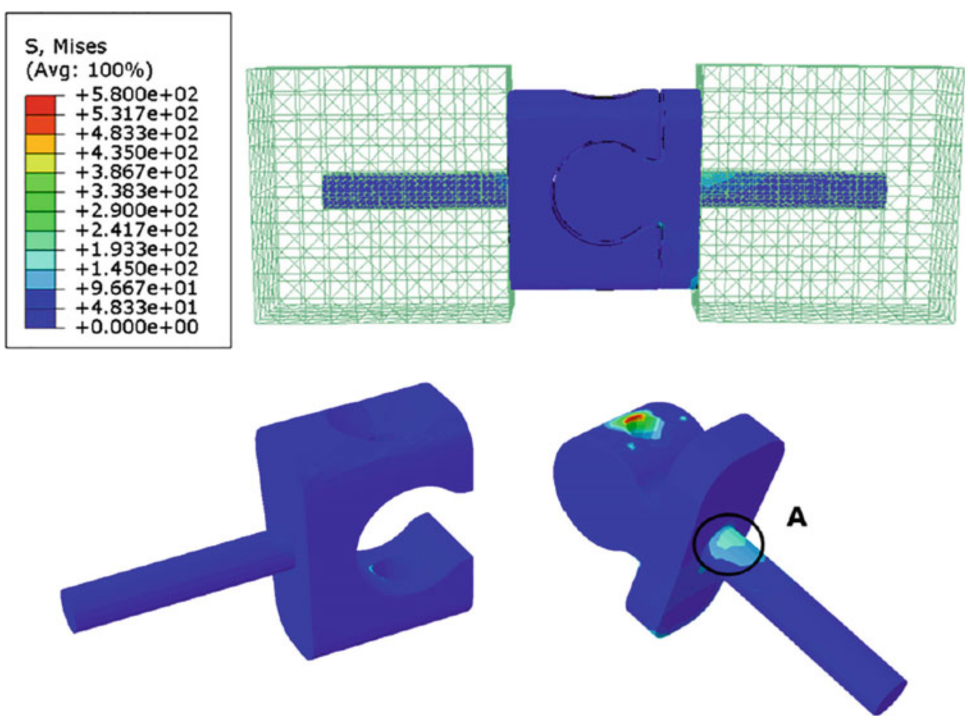
A finite element model of testing setup was created to better analyze the forces within prosthesis and bone. The line drawings of the endoprosthesis were imported into Abaqus v6.10 (Simulia, Dassault Systemes, France). The stems were modeled as smooth cylinders to simplify calculations.

A downward load of 150 N was applied to the top surface of the left block 10 mm away from the endoprosthesis body, while the opposite block was prescribed fixed boundary conditions. Unlike the mechanical test where the load applied was cyclic, the load in this analysis was kept constant and equilibrium achieved. The purpose of doing this was to identify and examine the peak stresses in the specimen, which can eventually cause fatigue failure.

The conclusion from this study was that the finite element analysis confirmed the area of maximum stress was on the superior surface of the stem, which did not exceed the material strength of titanium. Cyclic fatigue tests did not cause loosening of the module connection but caused failure at the superior part of the stem, consistent with the finite element analysis.

A finite element analysis was also performed using a human sized mandible dimension [9]. A synthetic mandible, which was modeled from an average sized mandible, was scanned and the images were imported into Surgicase (Materialise, Belgium) and converted into Standard Tessellation Language (stl) format. 3-Matic (Materialise, Belgium) was used to re-mesh the mandible into more regular triangles. A defect was created. The size of the defect and prosthesis dimensions were changed and varied digitally. Loading and boundary conditions were obtained from the literature. An intact mandible was used as control. The results showed that the reconstructed mandible tended to flex on the side with the prosthesis. The highest stresses were within the endoprosthesis at two areas of stress concentration: (1) shear stress at the superior surface of the stems close to the junction of the stem and the module body; (2) compressive stresses at the bottom bevel of the dovetailed connection.

Fig. 6 Finite element model of the endoprosthesis mounted on synthetic bone for testing



There was a tendency for outward buckling at the module connection when the size of the defect increased. This could potentially cause loosening of the connection.

The outcomes of these studies showed that probably the module connection problem had been solved but only for the small defect sized used for the experiments. Longer defects or defects over the anterior mandible with a curved would lead to problems with fit of the stem or loosening if the design remained in modular form.

4 Future Directions

There have been several subsequent case reports and studies using the term endoprosthesis for mandible reconstruction. These papers report using a flange on the outer mandibular surface which is secured to the bone with screws. The advent of direct metal laser sintering opens up the possibility of creating a patient specific printed prosthesis or implant. The first case of a whole printed titanium mandible was reported in 2013. Further improvements are needed before purely alloplastic mandible replacement can be routine and safely done.

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