THE POTENTIAL OF USING 3D PRINTED PATIENT SPECIFIC MODELS IN RECONSTRUCTIVE SURGERY OF THE MANDIBLE-REVIEW PAPER

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Abstract

Additive Manufacturing, also known as 3D printing is a manufacturing technique whose process involves laying down of material, one layer on top of the other such that a solid object is formed. Its capability to produce objects of complicated geometrical shapes (otherwise unachievable by traditional manufacturing techniques) within a relatively short time and without extra tooling has made it ideal for prototyping and creation of customized products. In medicine, it finds application in replicating the medical imaging scans to actual tangible solid objects. This births immense potential as the models can be used to extend the pre-surgical preparations to include processes that are otherwise conducted intra-operatively. These include pre-bending the reconstruction plates to fit the patient's anatomy almost perfectly. As such, the intra-operative time is reduced and along with it the peri-operative risks and costs. The outcome is improved as well.

In Kenya, there are very few Oral and Maxillofacial Surgeons and fewer facilities where patients can be attended to. A significant number of the cases presented to them require extensive reconstruction and the process is not only time consuming but also expensive. Therefore, a large number of patients fail to be attended to in due time causing much pain and suffering. Studies have shown that incorporating 3D printed patient specific models in treatment planning has a positive impact in reducing intra-operative time and consequently, costs.

This review is part of a broader study proposal whose objective will be to investigate the impact of using patient specific 3D printed models in reconstructive surgery of the mandible.

Key words: 3D-printing, models, reconstructive surgery, mandible.

Introduction

Reconstructive surgery of the mandible is a challenging procedure especially if it involves a complex bend or if it is a continuity defect. The outcome of the surgery is often inversely proportional to the defect's size. Bending and re-bending the reconstruction plates to form a perfect fit is a tedious and lengthy process. The plate is exposed to forces which may lead to weaknesses and eventually, plate fractures, adding costs to the patient. Additive Manufacturing enables the surgeon to carry out this activity preoperatively such that the reconstruction plate is prepared prior to the surgery. Therefore, the operation would potentially be shorter and the costs and risks minimized while the outcome is improved. that will lead to adaptation of the technology with maximum impact.

Literature Review

The mandible is the bony support of the lower third of the face. It is composed of two hemi-mandibles that fuse at the symphysis. Each hemi-mandible is composed of the body and posteriorly, the ramus. The anterior aspect of the mandible provides attachment for muscles that aid in bolus manipulation, deglutition, positioning of the tongue and in speech .The posterior aspect of the mandible provides attachment for muscles of mastication. Therefore, the consequences of defects of the mandible depend on the region affected. Damage to the anterior mandible will result in posterior displacement of the tongue, poor laryngeal elevation, problems in swallowing and reduced protection from chocking. Damage to the posterior region of the mandible will result in impaired jaw movement. Tension and scarring of the soft tissue will lead to the mandible being pulled towards the side of the defect. In addition to impairing function, this causes asymmetry of the face.

The causes of mandibular defects may be as a result of trauma, disease or treatment of diseases such as refractive osteomyelitis or malignancies .In all age groups, the mandible is the most fractured site of the face that physicians attend to. One of the reasons for this observation is that in many cases, individuals who suffered from fractures of the upper two thirds lose their lives. There is a high predilection of males being victims of the fractures than females

in most age groups. The most common cause of mandibular fractures has been linked to the socioeconomic status of the patient. It was observed that in developed countries, interpersonal violence is the most common cause whilst in developing countries, Road Traffic Accidents (RTA) is the main cause[5,] However, in Tanzania, assault has been shown to be a more prevalent cause[4]. In Jordanian children, the main cause was accidental falls (52%) and the mean age was between 10 and 12 years. Amongst the elderly, the main cause of facial fractures was RTA (58.5%) and the mandible was represented in 91% of the cases[3].In this elderly group of patients, the incidence of mandibular fractures between the males and females were similar (1:1.1). Guthua et al in 1990 found that mandibular fractures were the most frequent fractures of the face. The main cause was interpersonal violence[7]. In 1998, Owino et al found similar results with a key finding that the side that was most frequently fractured was the left. This suggested that the swing of the blow came from the right hand[6]. In Nigeria, the most common cause of mandibular fractures was RTA involving motorbike[8].In UAE, the cause is similar[9].Therefore, and the aetiology of mandibular fractures is related more with the country than its global economic standing.

A second common cause of mandibular defects tumors and odontogenic tumors that are exclusive to the jaws. Tumors are caused by anaplasia of epithelial and mesenchymal cells. The ages that are most afflicted are individuals between 11 and 40 years. Ameloblastoma has been found to be the most prevalent benign jaw tumor in Nigeria, Tanzania and Kenya. In Nigeria, it mostly affected patients in their 4th decade of life whereas in Tanzania, most patients were in their third. Amongst the Kenyan adolescent population, most patients were between 15-19 years. A study by Reichart demonstrated that Ameloblastoma cases affected younger people in developing countries as compared to the more developed countries[11].A common trend in the management of mandibular tumors was late presentation of the cases to the physician. On average, at a teaching hospital in Kenya, patients went to the doctor 45 months after onset of symptoms. Therefore, the defect was already large and required radical surgery to correct. The patients suffer extensively from psychological pain, poor nutrition, poor oral hygiene and interferes with education amongst the school going[14]. Fibrous dysplasia, a fibroosseous lesion affects both genders with similar frequency and is found to be more prevalent in the maxilla than the mandible while ossifying fibroma involved the mandible more than the maxilla.[15,16]

Reconstructive surgery of the mandible aims to restore the form and function of the lower third of the face and aesthesis of the whole. However, the outcome of the surgery is inversely proportional to the size and extent of the defect. Efforts have been made to improve the outcome of reconstructive surgeries of the mandible over the last half century. Initially, they were disfiguring and the quality of life of the patient was adversely affected even after the surgeon's best efforts[1].

Procedures such as vascularized free flap have contributed towards success of the reconstruction. In addition to this, introduction and incorporation of non-medical sciences in surgery have been of benefit. Computer Aided Design and Computer Aided Manufacturing have been used to assist in accurately determining the points of resection both of the bone graft and the affected mandible[16].However, these facilities, though beneficial, are out of reach to most Kenyans because of cost and unavailability. Therefore some of the challenges that advances in technology serve to mitigate are still present. These include prolonged surgical times, cost and the risks of the operation.

A possible solution to this in a low income setting is incorporating patient-specific, anatomically accurate 3D printed models in treatment planning. (Figures 1&2)

Additive manufacturing, also called 3D printing, is a manufacturing technique that involves laying down successive two dimensional planes, one on top of the other forming a solid object. The data is sourced from Computer Aided Designs or medically from Computer Tomography (CT) or Magnetic Resonance Imaging (MRI) Scans. The capability of the machines to produce complex geometrical shapes in different materials without the need for extra tooling has made this technology useful for manufacturing custom made products and in this case, models that are replicas of the patient's CT scans. This can be extended into fabricating actual functional implants made of biocompatible material.

The process of creating the models begins with acquisition of the patients DICOM (Digital Imaging and Communications in Medicine) data. These are presented in soft-copy to a software operator who will extract the region of interest and convert it to an STL (Standard Tessellation Language) format. This data is then fed into the 3D printer which does the model creation. There are several types of 3D printing techniques, 3D printers and materials used. The choice of machine, technique and material depends on the use of the product. (Benjamin). The most common technique used is the Fused Deposition Modeling due to the ease of transport of the machine, its affordability and low cost of materials used.

In medicine, 3D printing is not a new phenomenon. However, its use has greatly increased over

the last decade due to democratization of the technology and competition within the industry. This has made it more affordable and as more people have access to it, the need for different materials has led to greater diversification. When it was patented in the 1980s it cost more than 10,000 USD to acquire a single machine. The quality of the product, though superior at the time, left a lot to be desired. The machines' output speed was also slow. However, currently, the print quality has improved, range of material diversified and the printers are more affordable.

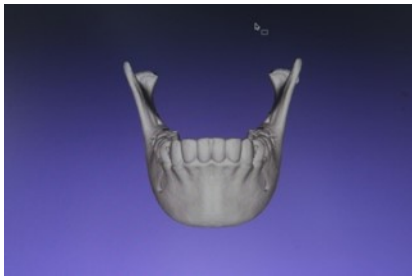

Figure 1*:* Processed CT scan of mandible ready for printing.

Figure 2: Replica of mandible: 3D Printed.

In the field of Oral and Maxillofacial Surgery, several studies on 3D printing in surgery have been done and the results are similar. Surgeons have found it to have a positive impact in their practice, pre-operatively, intra-operatively and also post-operatively.

Preoperatively, it was found that the models were most useful by providing the surgeon with the opportunity to pre-bend the titanium reconstruction plates. The models were useful in visualization of the extent of tumors and fractures. They found them to be remarkable in educating their patients, thus getting their consents with more ease. They also found it beneficial in measuring the exact size of bone grafts that will be used[18].Intraoperatively, surgeons resounded by exclaiming how beneficial the models were in orientation, Interdisciplinary communication, measurement of bone grafts, confirmation of sites of osteotomies and educating trainees[18]. Post operatively, the models were shown to be useful in record keeping and in judicial settings[15].Patients that underwent the surgeries aided by the models were reported to have better outcomes with fewer complications. The time spent in operation room was significantly shorter and the volume of blood lost was lower. Therefore, the models contributed towards low surgical costs directly. It can also be stated that the models had an indirect cost reduction since the surgeries were more successful and thus had reduced incidences of plate-fracture and shorter times spent admitted in the hospital. However, one of the most striking disadvantages of 3D printing was that it was not fast enough to be used in emergency cases[18,19,20,21,22,23,24].

The Kenyan medical scene is characterized by high volume of patients that require extensive reconstructive surgeries. Coupled to this, there are very few facilities and specialists to attend to them. Therefore, measures to improve outcome of the surgeries, reduce surgeon's fatigue and increase the efficiency of operating rooms are desirable. These solutions should

be within the financial capability of the patient to make them viable. Advances in technology have ensured that 3D Printing as an adjunct in maxillofacial surgery is feasible. Studies have reinforced its desirability amongst surgeons and patients alike. However, regional viability studies are yet to be conducted. This study aims to investigate the impact of 3D printing on time, cost and outcome of reconstructive surgery in a resource limited setting, Kenya.

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