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Additive Manufacturing for Ulna/Radius Fracture Treatment

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Interim Report (1496 words)

Introduction

Although age has a positive correlation with bone fracture frequency, the phenomenon can occur at any age (Demontiero *et al.,* 2012). In addition, due to increases in average life expectancy (OCED, 2019), fracture-related costs are set to rise from 4.52 billion GBP to 5.89 billion GBP in the United Kingdom alone (International Osteoporosis Foundation, 2018). This literature review will focus on potential additive manufacturing (AM) solutions for treating radius/ulna fractures, which are the second most common fracture type, followed by hip/femur fractures (Curtis *et al.,* 2016).

Background Information on Fractures

The conventional treatment for forearm fractures is the implantation locking compression plates or low-contact dynamic compression plates (Snow *et al.*, 2008). The usual procedure for this treatment is known as ORIF: open reduction (aligning bones to their proper position) and internal fixation (reconnecting bones physically) (Johns Hopkins, 2020). The advantages of ORIF are evident. Müller *et al.* (1992, p.13) state that internal fixation offers the stability that fractured bones cannot provide. Moreover, internal plates provide protection and reduce physiological forces in the early stages of healing (Müller *et al*., 1992). Some limitations and disadvantages of ORIF include the necessity of creating holes for the plate and the need to straighten a curved bone that could potentially lead to deformities and stress localisation (Müller *et al*., 1992, p.172). The need for a second operation to remove the plate is another major drawback of internal fixation (Müller *et al*. 1992, p.694). In addition, Akeson *et al*. (1976) states that higher rigidity ORIF plates lead to the thinning of bones in the long term. This phenomenon was further observed in the biological research conducted by Nomura and Takano-Yamamoto (2000). The study confirmed that mechanical stress promotes a series of biochemical reactions and activates osteoblasts and osteoclasts to form new bone tissue. The ORIF method could be improved to provide optimal long-term healing and a more convenient surgical process.

Background Information on Additive Manufacturing (AM)

AM, or 3D printing, is drawing tremendous attention for its potential application in diverse fields, including the aerospace, automotive, energy and medical industries (Campbell *et al*., 2012). Gibson *et al*. (2015, p.5) define AM as the process of adding materials layer upon layer to form 3-dimensional objects. Some advantages of AM include design freedom, the control of object properties and the reduction of assembly counts. Some disadvantages of AM are poor surface finish, the need for post-processing and the high cost of the process. The advantages of AM are highly sought-after in the biomedical industry, and rapid development is continuously taking place to overcome the process's limitations.

Advantages of AM in the Biomedical Industry

AM offers numerous advantages in the biomedical industry. Murr *et al*. (2010) state that the design freedom and complexity of AM can efficiently create desired tissues, bones, and joints.

They suggest that AM's design freedom is not only useful for full customisation by users but is also convenient for using complex mesh controls. Using the mesh variation and AM's ability to create complex parts, Murr *et al*. (2010). They created different types of biomedical parts, from cellular tissues to bone implants. Singh & Ramakrishna (2017) conducted a thorough review of present and future biomedical applications of AM. They suggest that, currently, AM technology can produce simple screws, implants, and joints using biocompatible materials (Singh & Ramakrishna 2017). They also indicate that, with more development, AM could be used in molecular-level applications, such as the creation of ex-vivo tissues and scaffolds and the delivery of drugs (Singh & Ramakrishna 2017).

Disadvantages of AM in the Biomedical Industry

Despite the above-mentioned benefits, however, there are concerns about AM. The core problem hindering the use of AM in biomedical applications is a lack of advances in technology. According to Gibson *et al*. (2015, p.2), due to the manufacturing nature of AM, which adds layers of material, the mechanical properties of the final product are often changed. Although there are many tentative solutions to this issue, including trial and error or finite-element analysis, Campoli *et al*. (2013) note that even computational methods are often inaccurate. This is a major consideration for applications that require accurate and consistent mechanical properties. Moreover, Singh & Ramakrishna. (2017) acknowledge the most critical challenge of AM: the need for post-processing. At this point, post-processing is a necessity that can consume time and money. Finally, only a limited number of materials can be used for AM. Studies have examined materials that could broaden the options for AM printing, which have allowed not only polymers but also metals and hydrogels to be 3D-printable (Singh & Ramakrishna 2017). Some of these materials are corrosive and cannot maintain their shapes for long periods. According to a *Science* article by Ian Randall (2019), many studies are examining the performance of liquid printing because the traditional method of AM is not suitable for creating organs. Randall (2019) notes that although liquid printing is adequate for printing organs and tissues, a lack of structural support and surface tension makes it extremely difficult to perform such a process efficiently. The ideal material for biomedical applications of AM has yet to be developed.

AM in Bone Fracture Implants

Considering both the benefits of AM and the limitations of internal fixation for fractures, AM fracture implants have great potential to improve patient healing. AM's design freedom and ability to create complex shapes can provide implants in shapes and sizes that suit everyone and treat fractures in many different areas. More importantly, AM implants could eliminate the deformities and stress localisations that current ORIF procedures create. AM implants can be designed to be used without any screws or plates to hold fractured bones together. In addition, according to Collins *et al*. (2016), AM can produce implants with different mechanical properties using microstructural control. As mentioned above, rigid fracture plates can lead to a thinning of bones and are thus not ideal for long-term healing. In their study, Mavčič & Antolič (2012) found that the optimal mechanical strain during the healing phase of a fracture is between 100 and 2000 microstrains. In summary, AM implants could allow fractured bones to heal better and eliminate the mechanical weaknesses that current ORIF procedures create. With AM implants, patients could heal better and more quickly.

Material Selection for Fracture Implants

However, a thorough examination of the most appropriate material with which to craft AM implants is needed. Singh & Ramakrishna (2017) present a list of biomedical materials detailing the characteristics, advantages, disadvantages and potential applications of the materials. This information is then compiled in Table 1.

Table 1. Advantages, Disadvantages, and Application of Different AM Materials

Material	Advantages	Disadvantages	Applications
Titanium & Ti alloys	Light weight	Potential allergy reactions	Bone fixation
	Resistant to repeated loads	Corrosive	Dental applications
	Low Young's modulus	Repeated replacement	Spinal application
	Withstand strain		Stent
Polymer (PMMA, PEEK)	Easy handling	Risk of infection	Hip joint bearing
	Cheap	Potential toxicity	Soft tissues
	Ready availability		Articular cartilage
Bio-glass	Stimulate bone growth	Relatively fragile	Dental application
	High bioactivity	Lower fracture resistance	Orthopedic implants
	No known side-effect		

Both titanium alloys and polymers have a critical drawback: due to their corrosiveness and toxicity, these materials may not be suitable for semi-permanent implants. Bioactive glass, or hydroxycarbonate apatite (HCA), in contrast, is not only fully biocompatible but also promotes bone growth. Nommeots-Nomm (2015) states that HCA interacts with damaged bones. Although HCA's mechanical properties are inferior to other materials, Srivastava *et al*. (2012) results show that its mechanical properties are highly superior to those of human ulnas (Kim, 2014). Thus, bioactive glass could sufficiently perform as the material for fracture implants. As bioactive glass has no known side-effects so far, it does not need to be removed from patients' bodies. This could remove the need for secondary surgery that the ORIF method requires.

Potential Improvements in the Future

The most attractive aspect of AM implants is the potential to develop them even further. In October 2019, *Advanced Material* published a research paper by Luo *et al*. (2019). Luo *et al*. (2019) successfully created a stable membrane using a hydrophilic bio-ink called aqueous twophase system (ATPS). Using ATPS, Luo *et al*. (2019) created an aqueous structure that lasted more than ten days. After further development, this technology could also be applied to fracture implants. ATPS could be used to print internal tissues and blood vessels, which are often ruptured during a fracture (Canadian Orthopaedic Foundation 2019). Although the results of Luo *et al*. require development before they can be commercialised, this example shows that AM implants have the potential to evolve as the technology develops.

Conclusion

The present findings suggest that AM can be an appealing solution for treating ulna/radius fractures. AM plates can stimulate a quicker cure using bioactive glass and enhance the patient experience by removing the need for secondary surgery. Additional developments are needed to produce a complete solution, and consumers need to consider the expensive price tag for these implants. As technology advances, AM implants are likely to become a more affordable and powerful treatment for fractures.

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