REVIEW OF THE COMPLICATIONS IN PROSTHESIS MAKING & SERVICING

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Article History: Received May 25, 2022; Revised July 12, 2022; Accepted July 14, 2022

ABSTRACT: Prostheses are intended to restore the human body's appearance and return some functions lost due to the loss of limbs. The prosthesis industry exists for this purpose, as well as the servicing of the prostheses. However, there are complications in the design and installation of prostheses, as well as servicing them. Prosthesis usage is subjected to the specific circumstances of the recipient and is dependent on medical coverage for long-term servicing. The relatively low number of cases involving prostheses compared to other medical cases and the circumstantial differences between these cases prevent in-depth and comprehensive studies of the industry, preventing the establishment of standardized best practices. Despite this, research and development of improvements for recipients' problems continue, utilizing the latest technologies to address technical complications. This article consolidates the present-day complications of prosthesis making and servicing.

KEYWORDS: *Prosthesis, Prosthesis design, Affordability, Service complications.*

1.0 INTRODUCTION

The people who need prostheses may not always have the means to afford them. This is especially the case for those whose livelihood depends on their mobility. However, a prosthesis that can restore function in addition to their cosmetic purposes, i.e., masking the absence of limbs, tends to be costly [1]. On the other hand, the relationship between affordability and functionality is not rigidly proportional and is subjected to other factors such as material choices and fulfillment of the intended purpose [2].

Although prostheses can provide aesthetics and function, they are devices that have to be delivered to the recipients in the first place. They also require maintenance and modification for the comfort of the recipients. Incidentally, some issues affect prostheses' quality, availability, and servicing [3].

In terms of scope, this article is primarily about prostheses for limbs. Cosmetic prostheses, e.g., cosmesis, and prostheses that reconstitute cognitive function, e.g., neuroprosthetics, and orthopedic and implant prostheses are not the focus. However, they occasionally mention overlapping factors such as using materials.

2.0 REVIEW OF HISTORICAL DEVELOPMENT OF PROSTHESES

The earliest prostheses were developed to address a relatively simple but sensitive issue: the absence of a body part that defines the silhouette of a human. This absence can lead to a sense of loss, leading to psychological and social issues [4].

As such, most early prostheses were made to resemble human limbs, though they did not have the means to move like them. They were also made using whatever technology that was available at the time, such as metalworking. In terms of functionality, they were mainly intended for acts of gesticulation. There were attempts to create prostheses for more than just this, such as the case of Gottfried von Berlichingen, having commissioned a prosthesis that could hold a sword [5]. There is a lack of technical documentation on whether the prosthesis can perform in combat, e.g., striking a lethal blow or parrying an attack. Yet, this case also involved revisions to the design of the prosthesis to expand functionality [5].

Incidentally, this indicates prosthesis design trends towards more functionality instead of mere appearance. However, present-day clinical studies on the functionality of prostheses show that most prostheses could not completely replicate the function of lost limbs, though there remains room for improvement [4]. Moreover, any advancement in prosthesis designs is still dependent on customizing prostheses for individuals, i.e., on a case-by-case basis [3]. This, in turn, prevents standardized manufacturing. Still, there have been efforts to establish categories of prostheses, e.g., transfemoral and transtibial ones, which are needed to reduce the development time of the prostheses.

At this time of writing, general searches on prostheses on directories such as Scopus would reveal that one of the current prosthesis-making trends is 3D printing. 3D printing is one solution that addresses the complication of the different recipients having variations, such as different shapes of the stumps that would interface with the prostheses and different strengths and endurance in the remainder of their limbs. Other trends include using advanced materials and artificial intelligence in prostheses with electronics. However, these trends are optimistic takes that depend on technological advancements. Realistically, any advancement would pose complications as they address previous ones.

The following sections describe the complications in the prosthetics industry, both direct and indirect, and the solutions that have been pursued to address them.

3.0 MATERIALS

This section is mainly about the materials used in prostheses and their selection and sourcing complications.

3.1 The Consequence of Material Choices

The need for functional prostheses to be able to withstand the rigors of motion limits the range of materials that are practical for prostheses. In particular, materials have to be light enough because the rest of the recipient's body would have to support the weight of the prosthesis [6].

There is also the fact that most materials, on their own, do not come close to emulating the bone, sinew, and muscles of human limbs. Designs that make use of composite materials and/or multiple parts with different materials are attempts at such emulation. Still, the variety of materials can pose complications, such as how they react with each other and the location of the body they are installed onto [7].

Choosing materials means deliberation and testing of the materials, which in turn add to the development time and complications of the prostheses. Efforts to address this issue are usually pragmatic, such as making decisions based on the availability of materials; any further complexity is only considered if complications arise from the default choices. In the present-day, knowledge bases about these decisions have been implemented in decision-making and simulation software to reduce time spent on deliberation [8].

3.2 Sourcing of Materials

Research and development (R&D) efforts in materials include finding alternative sources of suitable materials. This is so that the use of materials for prosthesis-making does not compete with the same materials for other practical endeavors. Incidentally, shortage of materials has been cited to be a considerable problem in making prostheses, such as in resource-strapped nations like Tanzania [9].

Contemporary R&D, in this matter, attempts to derive viable materials from cheaper sources, such as fiber from plants [10]. Such advancements do diversify the sources of materials for prostheses; in some cases, short-term tests of their strength suggest that they can perform just as well as prostheses that are wholly made of the usual materials such as fiberglass [11]. However, these also pose the complication of manufacturing methods involving more types of materials, thus increasing the complexity of developing prostheses.

The long-term viability of alternate materials is unclear due to the lack of in-depth studies on the durability of these materials. On the other hand, certain alternative materials may provide certain advantages. For example, biodegradable materials are utilized in prosthetic implants, albeit with risks of toxicity from the decomposition [12]. These may be helpful in the disposal of limb prostheses that are not intended for long-term use, such as those for growing children.

A particular avenue of the solution to sourcing materials is using recycled waste, especially plastic waste. Incidentally, this is being pursued in countries with pervasive issues of plastic waste, such as the Philippines [13]. However, as this is a nascent solution, the long-term complications of using recycled materials have yet to be made clear. For example, residual chemicals remain in recycled plastics [14], which can pose a health risk; there has yet to be an in-depth study on this.

3.3 The Durability of Materials & Associated Complications of Maintenance and Replacement

Most prostheses for adults are intended for long-term use. They have to endure the weight of their users and withstand the rigors of providing function. Thus, the selection of materials has to consider the durability of the materials and how this would affect the frequency of maintenance and replacement.

However, due to the differences in the lifestyles of recipients, there have not been many comprehensive experiments and studies comparing the effect of the usage of different materials on the frequency of maintenance and replacement. Indeed, in this matter and practice, complex factors like availability of materials, comfortable fitting for the recipient, and safety of the recipient take precedence over cost comparisons of materials [2][15].

4.0 DESIGN

This section concerns the complications posed by implementing the technical designs for prostheses.

4.1 Designs of Prostheses & Associated Complications of Maintenance

The design, the installation method, and the expected stresses on the prostheses while they are being used contribute greatly to the rate of wear on the prostheses and thus their needs for repairs and replacement. However, as with the aforementioned matter of choices of materials, there are not many comprehensive studies on the costs associated with prosthesis designs due to the variety of recipients and their circumstances. Attempts at these studies greatly depend on the contribution of data from prosthetic clinics and the workshops that provide service to the former, as well as the consent of the patients [16]. Furthermore, due to the relatively low number of cases involving prosthesis use compared to cases in other fields of medicine and rehabilitation, any source of data that is substantial enough to account for a diversity of factors would be subjected to the issue of significant time spans, i.e., some cases may be so many years apart from each other that the techniques that are used may not be fairly comparable [16].

4.2 Fabrication of Materials for Prostheses

Although the designs of prostheses in their entirety are not comparable due to the many factors involved, there are still efforts to compare options with each other on a lower level. One of these is fabricating the materials that would be shaped into a prosthesis.

Incidentally, R&D efforts in this matter address the notion of substituting one material for another with the idea of having different materials compensating for each other [7]. Furthermore, there can be additional potentially beneficial effects from having mixtures of materials. For example, fabricating composite materials for implants instead of homogeneous materials promotes bone growth [17].

3D printing, otherwise known as additive manufacturing, has been implemented in the manufacture of prosthetics, especially for customized designs and where manufacturing by molding is not convenient [18]. 3D printing is feasible for custom designs of parts away from the connection between the prosthesis and the recipient's body. However, the connection, i.e., the fitting of the prosthesis, requires frequent monitoring and modification to suit the patient's comfort. Computer-aided design (CAD) and finite element analysis (FEA), which goes hand-in-hand with 3D printing, do not reliably accelerate this process [19].

4.3 Inclusion of Advanced Technology

Electrical and electronic components have been implemented in the designs of prostheses to improve response and expand mobility, though the improvements have not been universal for every recipient [20]. R&D for such prostheses continues, including additional types of sensors and associated programming, more sophisticated osseointegration, and utilization of augmented and virtual reality in rehabilitation [21].

However, including such advanced technologies and techniques also increases the costs of prostheses. For example, an arm prosthesis with electromyography (EMG) control for the fingers of its hand can cost up to US$50,000, which is very high compared to a powered prosthesis that only grips and has few other complex motions and which purportedly has material costs of just AU$ 30 [22]. As of now, there have not been any comprehensive studies that yield a clear and consistent relationship between the efficacy of prosthetics and their level of technology.

R&D efforts to implement advanced technology while minimizing costs continue through the means described in sections III. On the other hand, the inclusion of any technology to improve and expand function is expected to increase the complexity of the design, thus introducing additional costs through other avenues like fitting calibration and acclimation efforts [21].

Furthermore, due to the case-by-case nature of prosthetic designs, the correlation between improved function and advanced technology is not certain; the study carried out by Carey et al. shows that the circumstances of recipients and their satisfaction are varied such that there is no conclusive correlation between the two [23].

5.0 DISTRIBUTION

This section concerns the complications in delivering prostheses to recipients and servicing them afterward.

5.1 General Availability of Services and Associated Complications

Prostheses are devices that require installation and maintenance. Consequently, any consideration of complications should consider long-term contributors as well as the hurdles of getting the prostheses to the recipient.

Incidentally, there is not much data on prostheses in low-income countries, which is due to the low number of practitioners of prosthetics in these places as well as the consequently low number of reports on prosthetic use [24]. This scarcity is due to underlying causes such as poor quality of life and lack of a comprehensive healthcare system for reasons such as the prevalence of violent conflict [24].

Thus, the diminished capacity for healthcare services would also affect the distribution of prosthesis usage. There has to be a significant investment to establish a healthcare system that can support the use of prosthetics [25].

5.2 Regional Issues

After fabricating prostheses, they and the recipient must be brought together for fitting and testing. Prosthesis clinics allow this process to be performed safely and reliably, but these clinics are not common. In particular, recipients in developing countries must travel considerable distances and inconvenient terrain to reach the clinics [26]. The solution to this problem of remoteness would seem to be the establishment of more clinics while making prostheses more affordable (as has been described in previous sections), usually through the efforts of non-governmental organizations (NGOs) [26].

However, even if the investment costs can be addressed, other obstacles prevent the proliferation of clinics and distribution of prostheses, such as cultural complications regarding understanding the need for prostheses [27]. The causes for these obstacles can be socio-politically sensitive. For example, there is contention over the issue of prostheses for former Turkish soldiers who are amputees. Their veteran status entitles them to have prostheses, but they have to make payments and risk repossession upon failure to make payments [28].

As has been mentioned in the previous section, the solution has to include the establishment of a healthcare system that can support the use of prostheses. Furthermore, the system must be standardized nationwide instead of relegated to local authorities like in Canada [29]. This is to have uniform service quality and prevent traveling to have satisfactory service elsewhere.

6.0 RECIPIENT'S NEEDS

Prostheses must be made to fit the recipient while also providing function, so there will be complications in satisfying the recipient.

6.1 Disparity in Service

The extent of medical coverage for recipients of prostheses is not universal. The cause of the recipient's need for a prosthesis can be a factor in the difference in the quality of service between recipients. For example, in the USA, military veteran amputees have access to more options and complete coverage of costs. In contrast, civilians have to obtain coverage through their insurance schemes, the benefits of which can vary significantly. Ethical issues among the practitioners of prosthetics can arise from such disparity [30].

A significant aspect of prosthesis service is refitting; as a recipient acclimates to the prosthesis, the recipient may require readjustment of the fitting. This incurs costs of testing and fabrication of new prosthesis parts. Due to disparities in servicing, the recipient may have limited refits, which can affect satisfaction and rejection of the prosthesis [31].

6.2 Ease of Use and Comfort

Most prostheses, including state-of-the-art ones, are not within the complete control of the recipient like an actual healthy limb would be. Thus, ease of use is important in their acceptance of the prostheses. Yet, this factor is also determined by their lifestyle and culture. For example, Cambodian recipients still observe religious rites, such as kneeling to pray. These activities are complicated by prostheses that are not designed to facilitate any activity other than walking or standing, e.g., lower limb prostheses chafe with the back of the thighs when kneeling [32].

The general solution is to include considerations of comfort in the design of the prostheses. However, this increases the complexity of the designs and necessitates more tests, though using FEA can reduce the need to make more prototypes [33].

Since prostheses involve skin contact with the prosthesis's materials, there is the issue of comfort or loss thereof from this contact. The design of the prostheses has to include consideration of and testing for dermal allergies that the patient may have [15].

The matter of ease of use and comfort also reinforces the notion that prosthesis designs must be done on a case-by-case basis. This, in turn, recalls the aforementioned issue of the recipients needing the necessary medical coverage that allows for modifications of the prostheses.

7.0 CONCLUSION

The advancement of technology has contributed to the design of prostheses that perform better in restoring performance. However, implementing state-of-the-art technologies like robotics and neuro-cybernetics to improve response times and modern manufacturing techniques like 3D printing has also increased the complexity of prostheses. This poses significant long-term concerns such as ease of maintenance and availability of expertise to service the prostheses.

Efforts to solve this problem include the exploration of alternative sources of materials, e.g., molding using recycled plastics. Furthermore, Knowledge on prosthesis designs accumulated, documented, and disseminated over many years has been implemented in software designed to support and accelerate prosthesis development. This angle of addressing the issue of prosthesis complications can be contributed to via further sharing of ideas and case studies, as well as utilization of the latest physics simulations to predict the performance of prosthesis designs.

However, solutions that rely on R&D could only address problems of technical nature in the field of prostheses. There are problems with more complicated causes, such as cultural issues and healthcare systems that could not completely support or protect recipients of prostheses. There are also the subjective matters of the recipient's eagerness to have a prosthesis and satisfaction of having one, which leads to the provision of prostheses being a case-by-case matter and thus posing a difficulty in having comprehensive studies on the use of prostheses.

Lastly, reviews on matters in the field of prostheses and analytical studies of prostheses would indubitably be hampered by a lack of cases [34]. The need for prosthetics is not expected to diminish entirely due to circumstances that prevent medical treatment required to save limbs from amputation. However, the scarcity of data would continue to worsen due to medical advancements in limb salvage and limb-sparing that are focused on preventing amputation and, in turn preventing the use of prostheses.

On the other hand, advancements in the field of prostheses can be applied in the field of reconstructive surgery and rehabilitation, e.g., prosthetic implants. Thus, in the event of diminishing prospects for the field of prostheses due to a reduction of patients needing them, practitioners and researchers of prosthetics can pivot their efforts to the latter, such as in the case of the development of materials for osseointegration [35].

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