Poly(methyl methacrylate) (PMMA) in Biomedical Applications

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Abstract

Over the last 50 years, the incorporation of biomedical grade polymers in medical implants and devices has grown. Poly(methyl methacrylate) or PMMA has seen wide use in this area. This polymer provides many uses and benefits, from its primary use in intraocular lenses and hard contacts for vision correction, to implants used in rhinoplasty and cranioplasty surgical procedures, to bone cement for joint replacements. PMMA has several desirable properties that warrant its use in these applications. Benefits of this polymer include biocompatibility, strength to weight ratio, and poor conductivity. Viewed on a structural level, PMMA is formed through the polymerization of methacrylic acid. Originally thought to be an atactic polymer in the early years of its discovery, it was later found to be syndiotactic in its chain structure. PMMA is an amorphous polymer due to the pendent groups that are formed off of the backbone of its polymer chain, blocking crystallization because molecules are unable to get close enough to form crystalline bonds. This interesting structure causes PMMA to have many of its favorable properties, such as good mechanical strength and acceptable chemical resistance. Polymers that are used in medical applications are scrutinized heavily for their health effects. MMA is allergenic and poses adverse health effects, however biomedical grade PMMA lacks this residual monomer which makes it have minimal health effects. Although there are certain disadvantages to its use, PMMA is still widely used today in medical implants and devices. There are potential future alternatives that are currently being studied to replace PMMA in certain applications such as in bone cement such as calcium phosphate (CaP) and calcium sulfate (CaS). The implementation of polymeric materials in medical applications, specifically PMMA, has provided healthcare professionals with tools to increase patient treatment options for years and many more to come.

1. Introduction

Advancements in the field of medicine have seen the lifespan of the average person increase. These strides in medicine have made systems of the body that are essential to life able to be revitalized or in some cases completely replaced by artificial implants and devices made from medical grade polymers. Poly(methyl methacrylate) or PMMA is one such example of a polymer that is used in artificial medical implants and devices that help prolong the life of those that require them. PMMA has been used in a wide range of reconstructive implants, particularly those needed for replacing irreparably damaged or lost craniofacial tissues and bones. [1] PMMA saw early use in the field of dentistry in the fabrication of complete denture bases. Its qualities of biocompatibility, reliability, relative ease of manipulation, and low toxicity made it an obvious candidate for incorporation into medical specialties. [2] Its transparent physical properties make it useful when used in intraocular lenses and hard contact lenses. PMMA has a high Young's modulus (approximately 3 GPa) and a compressive strength of approximately 120 MPa. Possessing these mechanical properties allow this polymer to be used in a variety of applications small or large and provide a decent foundation relative to the size of the application. Despite these advantages, it is equally important to note that there are also disadvantages. One noted failure mode involving PMMA is fatigue. Attempts have been made to remedy the issue by reinforcing it with steels and titanium alloys as well as other high-strength materials. [1] With improvements in manufacturing and production, specifically 3D printing, PMMA shows to be a useful medium in the creation of unique structures for medical devices. With its multitude of applications, PMMA is a useful material that demands further examination from the biomedical community in optimism towards providing more avenues of treatment for specific patient cases.

2. Structure and Material Properties

PMMA is formed through block, emulsion or suspension polymerization of methacrylic acid. PMMA was thought to be an atactic polymer through the first half of the 20th century. Indicating that the substituents of the molecular chain alternate randomly along the chain, which is illustrated in below. Since the development of modern equipment and techniques, it has been determined that the molecular chains are mostly syndiotactic, meaning the molecular chain's substituents alternate uniformly. Final processing of PMMA is accomplished through injection molding or extrusion at melt temperatures ranging from 200-230 ºC. [3] [4] [5] [6]

Pendent groups form when a cluster of atoms bonds off of the backbone of the polymer chain. The bulky pendent groups on the polymer repeating unit of PMMA induce several interesting properties. Crystallization is blocked by the pendent groups because the molecules cannot get close to form crystalline bonds. This causes PMMA to be amorphous. Pendent groups snag on adjacent groups nearly eliminating slip between polymer chains. This causes PMMA to be rigid, brittle, have a high glass transition temperature and little mold shrinkage. [3] [4] [5] [6]

PMMA has good mechanical strength and acceptable chemical resistance. Because of the superior optical properties, weather resistance, light weight, impact resistance, dimensional stability, heat resistance, and processability, PMMA has many profound and diverse uses that affect our lives every day. The ability to mold PMMA allows for the easy and inexpensive manufacture of complex optics.

Health effects are minimal for PMMA. For biomedical grade PMMA, however, there must be no residual monomer. Unlike PMMA, MMA is allergenic, and has health implications. PMMA has many biomedical uses because of its low *in-vivo* immune response. PMMA is not biodegradable and thus is able to stay within a patient's body throughout their lives. [7] [8] [9] [10]

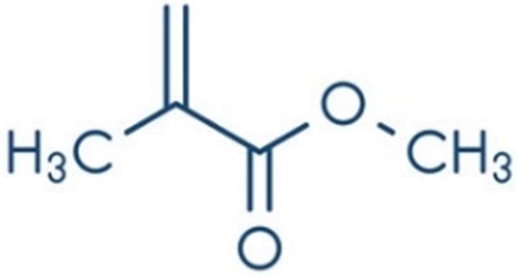

Fig. 1 Structure of PMMA Monomer

3. Uses, Benefits, and Issues

Primary uses for Poly(methyl methacrylate) include intraocular lenses and hard contacts for vision correction, rhinoplasty and cranioplasty implants, vertebrae stabilization, and bone cement for total joint replacements. [2] [11]

The benefits of PMMA for intraocular implants and hard contacts, are its resistance to UV radiation, transparency, abrasion resistance, and rigidity. This, along with the ease of molding and shaping the polymer, makes it ideal for this application. Studies have also shown that lenses produced from this polymer have chromatic focal differences similar to young eye physiological values.

For various other implants, benefits include its biocompatibility, strength to weight ratio, and poor conductivity. When used properly, PMMA can offer a suitable replacement for bone at a relatively low cost. [12] [13] [14]

In rhinoplasties, specifically, there has been a documented benefit to using PMMA, in that it can be safely and non-surgically injected as a means of performing primary rhinoplasty, wherein it is injected as a filler to improve contours. [15]

The compressive and bending strength of PMMA, when compared to other commercially available biomedical polymers, is in the mid-high range at an average of ~137 MPa and ~104 MPa for bending and compressive strength, respectively. This provides the necessary structural integrity for the implant applications listed previously.

Another benefit has become apparent with the implementation of 3D printing, as patient-specific implants can be created using PMMA to form customized structures. This makes reconstructive rhinoplasty and orbital implants more accurately able to reproduce the previous, or ideal, look for each patient. [15]

Useful applications of PMMA typically revolve around areas that require compressive strength or material clarity. Some applications have drawbacks, such as during bone cement applications. It has been observed that the exothermic reaction during the curing process results in temperatures in the range of 90 ºC which can lead to bone necrosis, with tissue proteins coagulating at ~67 ºC causing metaphyseal arterial occlusion. [16] [17] [18] [19] [20] [21] [22]

Another drawback of this polymer is that, while its compressive strength is quite high, the tensile strength is low, with a low-end value of ~48 MPa which could lead to fracture of the implant if stressed beyond this. Therefore, not all implantable applications are ideal. For instance, peripheral limb bone reconstruction, especially in areas of low muscle density but high tensile stress such as the ankle or wrist, would be unsuitable for this polymer.

Fig. 2 Single-piece PMMA intraocular lens during and at the end of surgery.

4. Potential Future Alternatives

Potential alternatives that are being developed as future substitutes for PMMA would include calcium phosphate (CaP) and calcium sulfate cement (CaS). These two injectable materials are being developed as great alternatives in the bone cement area of the biomedical application field. These new injectables have promise as future alternatives to PMMA but they do have some drawbacks. These drawbacks in the purest form of the substances can be overcome. To start the problems come from poor injectability leading to difficulties implanting the material into bones. This is true for both materials. Other issues consist of problems with a lower viscosity than PMMA. This contributes to implant problems. Lastly, the materials in their pure form absorb to fast into the bone. The solutions that have been developed to make this a better alternative to PMMA is changing the biphasic cement to consist of 60% a-CaS hemihydrates and 40% hydroxyapatite (HA). This fixes all of the problems with the material. It increases the viscosity and allows the material to have a more delayed absorbability than in its natural state. The material also increases bone growth by osteo-conductivity. These materials can become great alternatives to PMMA. Using the Cas and CaP in combination with hydroxyapatite the shortcomings of the material can be overcome. This will lead to new development in the field using PMMA for bone cement and other treatments for bones and in optical. CaP shows great promise as an alternative and has been proving in many trials.

5. Conclusions

The life span of the average individual has been able to be extended due to technological advancements in the field of medicine over the last few decades. Polymeric materials have played a role in accomplishing this task. PMMA has proven to be useful in a variety of medical applications for its biocompatibility, availability, and strength to weight ratio, from intraocular lenses to 3D printed patient-specific implants. PMMA provides users with desirable properties such as high mechanical strength, chemical resistance, impact resistance, and rigidity. Although there are concerns with MMA having an effect on a patient’s health, biomedical grade PMMA is free of the residual monomer and has does not cause a high immune response from the body. It is important that uses for PMMA continue to be studied for biomedical applications in order to provide future patients more alternatives in their treatments.

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Author Contribution

Conceptualization, W.C., J.H., N.T., and C.W.; **Abstract**, W.C.; **Introduction**, W.C.; **Opinions and Commentaries**, N.T. (Uses, Benefits, and Issues), C.W. (Structure and Material Properties), J.H. (Potential Future Alternatives); **Conclusion**, W.C.; **Final Review & Editing**, N.T.

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