Review of the Medical and Environmental Implications of Additive Manufacturing (3D Printing) Filaments

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Introduction: Since the advent of additive manufacturing (AM) in the mid-1980's, the use of 3D printing has expanded and diversified at an exponential rate.[1-4] Largely driven by innovation in science and technology and bolstered by the increasing availability and affordability of printers, materials, and design software, AM continues to create new opportunities for novel and unique printed products. Early medical applications focused predominantly on individualized surgical and dental implants, but over the last two decades, this has expanded to include perioperative planning, pharmaceutical drug delivery, bioprinting, prosthetics, simulation models, and more.[2-6] Fused deposition modeling (FDM), a type of material extrusion, is the most common 3D printing method and is used for many of these applications. It utilizes filaments of varying size, color, and chemical composition to produce objects of differing strength, durability, flexibility, and function.[6] As this variety increases, however, so must the medical and environmental considerations used in choosing a particular filament. In our review, we sought to evaluate the medical and environmental implications of three of the most common filaments used in FDM: PLA (polylactic acid), ABS (acrylonitrile butadiene styrene), and PETG (polyethylene terephthalate glycol-modified).

Methods: A literature review was performed using PubMed, Web of Science, and IEEE Xplore Digital Library. Where available, material safety data sheets (MSDS) were also reviewed from various manufacturers. Particular attention was paid to the following stages of filament use: production, heating/deposition, degradation, and disposal.

Results: Despite an increasing rate of publications related to 3D printing, there remains a paucity of evidence regarding the health, safety, and environmental implications of various filaments used in FDM.[2-4,7-10] For example, while PLA is generally regarded as the most eco-friendly and sustainable option of the three due to its natural composition, limited research suggests that the resources necessary to produce its source crops may actually offset this advantage.[11] By contrast, the health and environmental effects of the heating and deposition process have been far better studied. All three filaments produce volatile organic compounds (VOC) and ultrafine particles (UFP) that may lead to skin, pulmonary, and mucosal irritation.[12-15] ABS off gases the most VOCs, including styrene (a possible carcinogen), while PLA off gases the least.[13,15] This can change if additives are incorporated into the base material to change its properties, but because this information is frequently proprietary, it is difficult to evaluate.[4] In addition, the MSDS for each filament varies by manufacturer and often does not include information on said additives or melting/decomposition temperatures, product stability, cleaning/sterilization instructions/limitations, specific health effects, or disposal options.[4] There

is also scarce evidence regarding the stability of these products once the final product is handled, cleaned, or otherwise used for its intended purpose.[5]

Conclusion: The limitations of such specific health and safety data make it difficult to gauge whether one material is superior to another. Given the rapid expanse of this technology for medical use, this creates the potential for both short- and long-term harm to patients, practitioners, and the environment. For this reason, we recommend that further research be conducted that focuses on how the precise chemical composition of these materials affects the health and safety of those in contact with the materials during heating/deposition and use, as well as the environmental implications of its production, degradation, and disposal. Furthermore, we advocate for regulatory clarification and increased transparency regarding these materials to help guide the choosing of safe and appropriate materials based on the intended use of the final product.

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