A Review on Design and Fabrication of Biomedical Equipment with Additive Manufacturing

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Abstract — Additive manufacturing, also known as 3D printing, has revolutionized various industries by enabling the creation of complex geometries with unprecedented ease and precision. In the field of medical applications, particularly in reconstructive surgery, additive manufacturing has emerged as a promising tool for fabricating patient-specific implants, including cranial implants such as skulls. This paper explores the advancements, challenges, and applications of additive manufacturing in skull reconstruction. The primary objective of this study is to investigate the feasibility and efficacy of using additive manufacturing techniques for producing customized skull implants. By reviewing recent literature and case studies, this paper discusses the technological developments in materials, printing techniques, and design methodologies that contribute to the successful implementation of 3D-printed skulls in medical.

Keywords: Additive Manufacturing, 3D Printing, Skull Reconstruction, Patient-Specific Implants, Healthcare

I. Introduction

Additive Manufacturing (AM), or 3D printing, builds objects layer by layer from digital designs. Initially used for rapid prototyping, AM has expanded into various industries, including healthcare, for applications like skull reconstructions. Biocompatible materials, such as polymers and metals, are used in AM to meet stringent safety and durability requirements. Researchers aim to enhance AM technologies for better resolution, faster production, and improved materials. Standardization and long-term clinical studies are needed to validate the performance and safety of AM-produced skull implants. Biomaterials must be biomimetic, biocompatible, and structurally stable. Polymers, such as polylactic acid, are commonly used in 3D printing due to their biocompatibility and affordability. Ceramic-based materials also show potential for dental and orthopaedic applications due to their high stiffness.

II. Literature

A review on design and fabrication of biomedical equipment with additive manufacturing .we studied some of the journal papers and mentioned them, below:

Alexandru Dumitras Meius et.al., [1] Reconstructive surgery of the skull base poses significant challenges due to its complex anatomy and uneven edges. Three-dimensional (3D) printing technology offers a promising solution for designing prosthetics to effectively seal defects. Computer-aided design (CAD) software guides the layer-by-layer fabrication of 3D-printed objects. In otolaryngology, 3D printing applications are still in the early stages of development. Preoperative 3D modeling using CT scans can aid in surgical planning. Biocompatibility is crucial for 3D-printed medical products to avoid adverse reactions. 3D printing also enhances understanding of complex physiological relationships in various diseases. Further research is needed to fully explore its potential in head and neck reconstructive surgeries.

Mohd et.al., [2] Additive Manufacturing (AM) enables customization of medical models based on individual patient data. Patient-specific 3D models are created using MRI, CT, or other imaging technologies. AM technology fabricates complex shapes directly from CAD models, aiding surgical planning. Its applications include reverse engineering, rapid tooling, product development, and medical fields. In medicine, AM is used for educational training, device development, customized implants, tissue engineering, and prosthesis design. Additionally, AM solves various dental problems and creates mechanical bone replicas for forensic analysis. Overall, AM revolutionizes medical treatment and education.

M. Vignesh et.al., [3] Advanced 3D printing offers advantages over traditional manufacturing methods, including cost reduction, speed, and design freedom. Additive manufacturing techniques, such as Laser Additive Manufacturing (LAM), Friction Stir Additive Manufacturing (FS-AM), Paste Extruding Deposition (PED), and Selective Laser Melting (SLM), enable layer-by-layer production with minimal material waste. These techniques create complex components in a single step, achieving precise geometric dimensions. However, selecting the optimal technique for a specific material and application can be challenging due to the numerous options available. This review aims to examine the properties of 3D printed biomedical implants produced via these techniques and explore the future scope of Additive Manufacturing processes. The focus is on understanding the benefits and limitations of each technique in biomedical implant manufacturing.

Faruk Diblenb et.al., [4] Additive manufacturing (AM) enables the fabrication of complex objects through layer-by-layer deposition. In medicine, AM is used to create tangible models for evaluating complex anatomies and patient-specific constructs like drill guides and implants. These constructs reduce operating times and enhance surgical accuracy. AM is particularly valuable in oral and maxillofacial surgery due to the complex bony geometries in the skull area. A convolutional neural network (CNN) was developed for bone segmentation using labeled CT scans of patients with patient-specific AM skull implants. The CNN demonstrated high overlap with the gold standard segmentation. Further research is needed to investigate the bone segmentation performance of different CNN architectures. AM and CNN technologies show promise in improving surgical outcomes.

Yujing Liu et.al., [5] Additive manufacturing (AM) is increasingly used to fabricate medical models from medical images like DICOM. These models aid preoperative planning, education, and surgical simulation, reducing operating time. AM-fabricated models can also be used for custom implant manufacturing and pre-bending reconstructive plates. A study compared the accuracy of PolyJet, SLS, and 3DP techniques, finding PolyJet to be the most accurate. Repeatability was excellent for 3DP and PolyJet. Clinicians using AM should be aware of potential errors and variations. A standard method for measuring and verifying AM-fabricated medical models is recommended.

Mika Salmi a et.al., [6] This study introduces 3D printer technology, a rapidly developing innovation in the industrial age, and its use in various sectors such as aviation and defense. It discusses the various methods of 3D printing and their application in biomedical applications, including surgery, pharmaceuticals, disease modeling, custom implants, organ printing, vet medicine, and tissue engineering. The study compares 3D printing with traditional methods in the biomedical field and highlights future opportunities that are expected to become widespread and developed in the future.3D printer technology offers the ability to produce complex parts faster and cheaper than traditional methods, making it increasingly popular in various sectors. It is particularly useful in the biomedical field, where it is used for various applications such as surgical modeling, disease understanding, manufacturing medical devices, patient-specific implants and prostheses, vet medicine, tissue engineering, the pharmaceutical industry, and organ bioprinting. The use of 3D models in cancer diagnosis and monitoring has significantly improved the accuracy of operations compared to radiographic and clinical examinations. This technology is also preferred for the production of personalized prostheses and implants, which can be produced in desired sizes and colors based on the patient's anatomy.As it becomes widespread, it will bring revolutionary innovations to the medical field, potentially saving many lives. In all areas of medicine, 3D printing-powered inventions aim to provide patients with a high quality of life and a longer life.

Ali Reza Nouri et.al., [7] Additive manufacturing (AM) builds 3D objects layer-by-layer, formerly known as rapid prototyping (RP) or 3D printing. Chuck Hull coined the term "stereo lithography" and patented the technology in 1986. Despite its 40-year history, AM has only recently gained widespread acceptance in surgical and nonsurgical fields. Recent advances in AM technologies have enabled the production of biomaterials with structural rigidity and high load-bearing capacity. Laser-based powder bed fusion (L-PBF) is a leading AM technology for producing customized implants with complex geometries. L-PBF offers ease of manufacturing, low material wastage, and is suitable for orthopedic, traumatology, craniofacial/maxillofacial, and dental applications. AM technologies have revolutionized the production of structural biomaterials.

Leonardo Rosa Ribeiro da et.al., [8] The global population is aging rapidly, with numbers expected to reach 10 billion by 2050. Life expectancy has increased from 65 years in 1990 to 73 years in 2019, and is projected to reach 77 years by 2050. Advances in medicine have contributed to this trend, but have also led to an increase in age-related diseases and obesity. The musculoskeletal system is particularly affected, with obesity being a major factor. Current additive manufacturing (AM) processes are limited in producing complex chemical structures required for bio-printing. However, future technological developments are expected to overcome these challenges. The growing older population and associated health issues highlight the need for innovative solutions like AM. Further research is needed to address these complex healthcare challenges.

Laura Maciel de Vasconcellos Ferreira et.al., [9] Additive manufacturing (AM) is gaining attention due to its low costs, high reliability, customization, and shorter production times. In healthcare, AM is particularly promising for producing prostheses, such as craniofacial prostheses, offering compatibility with diagnostic tests like CT scans and efficient biomaterials for bone regeneration. The advantages of AM are numerous, including precision, cost reduction, and decreased processing time. As AM technology advances, it is expected to become increasingly common in various industries. In production engineering, AM can help companies achieve their profit margin and productivity goals by reducing costs and manufacturing times. Logistics also benefits from AM, allowing for reallocation of resources and improved competitiveness. Overall, AM is a key factor in improving production efficiency and competitiveness.

Ashish Kumar Gupta et.al., [10] Additive manufacturing (AM) is transforming biomedical engineering, enabling personalized medicine through custom implants and complex structures. AM has revolutionized the field, offering unprecedented customization and personalization. Custom implants represent a significant advancement in patient-specific healthcare. Evolving technology and materials will further improve medical outcomes and quality of life. Regulatory frameworks and quality standards are crucial for ensuring safety and effectiveness. AM has immense potential to impact biomedical applications. Continued development and research are necessary to fully realize its benefits. AM is a game-changer in biomedical engineering, offering new possibilities for patient-specific care.

Alexandru Dumitras Meius et.al., [11] Additive manufacturing (AM) enables the fabrication of complex geometries with high customization directly from CAD models. AM has become an attractive alternative to subtractive manufacturing, particularly in the orthopaedic industry. Powder bed fusion techniques, such as L-PBF and EBM, have garnered significant interest. AM has facilitated topology optimization and enabled rapid production of patient-specific implants. A systematic workflow was developed to evaluate AM fabrication of fracture fixation implants, reducing postoperative complications. Patient-specific metal implant designs can be produced in under 24 hours, improving surgical outcomes. This study investigates the use of metal AM for complex 3-part fractures, a first in the field. AM offers significant potential for improving fracture fixation plate design and quality.

Elena Manuela Samaila1 et.al., [12] Three-dimensional (3D) printing is a low-cost technology that can create solid objects from computerized 3D-imaging files, with potential applications in orthopaedic and trauma surgery. 3D-printed models of bones can help surgeons understand complex fractures and improve surgical planning. A study of 52 patients with articular fractures used 3D-printed replicas to enhance surgical preparation and patient understanding. The models took 4-12 hours to print and cost €50-€100. The use of 3D printing reduced the need for multiple fixation devices and saved operating theatre time. This technology has the potential to improve surgical outcomes, reduce costs, and enhance patient consent. Further investigation is needed to fully explore the benefits of 3D printing in orthopaedics and traumatology.

Yanjun Chen et.al., [13] The use of 3D printing technology in orthopedics is rapidly growing due to its ability to personalize and rapidly manufacture customized devices. Personalized casts with ventilated structures can be created using 3D printing for nonsurgical fracture treatment. Technicians use 3D scanner or medical imaging data to design and print casts with a precise fit. 3D-printed casts offer improved pressure distribution, comfort, and are more fashionable and portable. Lightweight materials and personalized design enhance patient comfort. Research has shown that 3D-printed casts can effectively manage fracture displacement. Global displacements were reduced, with maximum sliding displacement of the fracture surface at 1.325 mm. 3D printing technology offers a promising solution for personalized orthopedic treatment.

Feng Qiao a et.al., [14] Lower limb long bone fractures are common in traumatic orthopedic patients, requiring precise treatment to avoid complications. Anatomical reduction is crucial for bone healing, with studies showing faster healing times for anatomically reduced fractures. However, open reduction can damage soft tissues and blood supply, making closed minimally invasive surgery preferred. Closed reduction can be challenging, with repeated attempts increasing surgery time. Customized solutions, such as 3D printing, are necessary due to varying fracture conditions and patient needs. 3D printing technology offers speed and accuracy for complex geometries and structures. A study using 3D printing achieved rotation accuracy of 1.218°, angulation of 1.848°, and lateral displacement of 2.22 mm. Customized 3D printing solutions can improve treatment outcomes for long bone shaft fractures.

Julie Edwards et.al., [15] Three-dimensional (3D) imaging technology and software can produce scaled digital models of bones for forensic anthropology analysis. Digital models can be easily archived, shared, and updated, and the process is noninvasive and nondestructive. When combined with 3D printing, physical models can be created to scale or enlarged to emphasize features. A study compared three capture methods (laser scanner, SLS, and photogrammetry) for producing 3D digital models of fractures. Results showed that all methods successfully demonstrated relevant details, but SLS performed better at high quality (HQ) levels. Laser scanning performed well at standard quality (SQ) levels. 3D printing was used to create physical models from selected digital models.

Huixiang Wanga et.al., [16] Acetabular fractures are complex and challenging to treat in trauma surgery. The goal is to achieve anatomic reconstruction of the articular surface, but this is difficult due to pelvic anatomy complexity and limited exposure. Preoperative planning is crucial for success. Recent advances in image processing and computer technology have enabled virtual surgical planning. A study successfully performed virtual planning in six patients, with planned approaches followed in all cases. The mean planning time was 38.7 minutes, ranging from 21-57 minutes. Virtual planning times varied by fracture type, with B-type fractures taking 25 minutes and C-type fractures taking 52.3 minutes.

D. Lacroix et.al., [17] Rapid bone regeneration is crucial for successful orthopaedic treatments, such as fracture healing and prosthesis osseointegration. Fracture healing involves a complex sequence of events that restore bone function. Appropriate forces on the bone are essential for successful healing. A simulation study used an iterative procedure to model bone regeneration during fracture healing. The results accurately predicted tissue differentiation sequences, including intramembranous and endochondral ossification. The simulation replicated experimental observations, demonstrating the potential for computational models to enhance understanding of bone regeneration. This research can inform strategies to improve fracture healing outcomes.

Simone Tassani a et.al., [18] Trabecular mechanical behavior is crucial for assessing bone fracture risk. Numerous studies have analyzed the mechanical behavior of trabecular bone structure. Parameters related to fracture zone identification and prediction have been used in clinical and in-vitro studies. In-vitro studies have compared local and global trabecular structure analysis to identify the weakest point and fracture zone. A registration scheme was applied to test datasets, achieving accurate matching and identifying no fracture zones. The mean registration error was 0.002%. The scheme was used to analyze pre- and post-failure datasets, visually identifying the fracture zone and broken region. The results demonstrate the potential for accurate fracture risk assessment using trabecular mechanical behavior analysis.

Laura Maciel de Vasconcellos Ferreira et.al., [19] Additive manufacturing (AM) is gaining attention due to its low costs, high reliability, customization, and shorter production times. In healthcare, AM is particularly promising for producing prostheses, such as craniofacial prostheses, offering compatibility with diagnostic tests and efficient biomaterials for bone regeneration. The advantages of AM are numerous, including precision, cost reduction, and decreased processing time. AM technology is becoming increasingly common in various industries, enabling companies to achieve their profit margin and productivity goals. Logistics benefits from AM, allowing for reallocation of resources and improved competitiveness. Decreased manufacturing time is a key competitive factor for companies. AM is transforming production engineering, enabling rapid production of customized parts with reduced costs and time.

Ashish Kumar Gupta et.al., [20] Additive manufacturing (AM) is revolutionizing biomedical engineering, enabling personalized medicine through custom implants and complex structures. AM offers unprecedented customization and personalization, transforming the field. Custom implants represent a significant advancement in patient-specific healthcare. Evolving technology and materials will further improve medical outcomes and quality of life. Regulatory frameworks and quality standards are crucial for ensuring safety and effectiveness. AM has immense potential to improve biomedical applications. Continued development will unlock new possibilities for custom implants and devices. AM is transforming patient care with personalized solutions.

Sunpreet Singh et.al., [21] Polyetheretherketone (PEEK) and its copolymers are promising alternative materials for biomedical applications due to their near-to-bone mechanical properties, chemical resistance, and radiolucency. PEEK is a semi-crystalline polymer developed in 1978, gaining industrial importance in the late 1990s. Various PEEK types (PEEK-LT1, PEEK-LT2, PEEK-LT3) have been used in spine treatment, orthopedic tools, and maxillofacial surgery. 3D printing and PEEK have been integrated in medical devices for years, with researchers highlighting their potential in the biomedical industry. However, manufacturing complex geometries is challenging with conventional technologies, making 3D printing a promising solution. PEEK's mechanical properties make it an ideal material for biomedical applications. 3D printing enables the creation of complex PEEK structures, overcoming existing manufacturing limitations.

Mantrana1Xiaojian Wang et.al., [22] Bone is a dynamic tissue that continually undergoes remodeling, with osteoclasts resorbing mature bone and osteoblasts generating new bone to maintain homeostasis. However, when a bone defect exceeds a critical size, external intervention is necessary to supplement self-healing. Despite advances in biomaterials and tissue engineering, repairing critical-sized bone defects remains a challenge. Autografts (patient's own tissue) are the optimal choice, but alternative solutions are needed. This paper reviews the current status of topological design and additive manufacturing of porous metallic implants. It discusses human bone mechanical properties and demonstrates how topology optimization can create optimal internal architectures for porous implants that satisfy multifunctional requirements.

Ramiro Mantecn et.al., [23] Head impacts in contact sports and high-speed mobility sports pose a significant risk of head trauma. Laboratory testing requires surrogates of human heads to explore impact-mitigating mechanisms safely. This study proposes using polymer additive manufacturing to create a human skull substitute filled with a silicone-based brain surrogate. Head surrogates with varying fidelities and complexities have been designed to replace human or animal models. A 3D-printed head surrogate was verified using an impact with similar attributes, reporting a peak acceleration of 272.70 g. The surrogate's response was comparable to human tissue in terms of elasticity and fracture energy. Filtering was applied using CFC-1000 phase-less filters according to SAE standards. The 3D-printed skull surrogate offers a promising solution for impact testing.

Francesco Buonamici et.al., [24] Reverse Engineering (RE) and Additive Manufacturing (AM) are transforming medical applications with cost-efficient, convenient, and customized solutions. Generating 3D models from patient data enables preoperative creation of custom prosthetics and implants, revolutionizing surgical planning and simulation. However, technical and ethical challenges must be overcome for these techniques to become standard in medicine. A significant limitation is the time-consuming postprocessing required for segmenting and reconstructing regions of interest (ROI). This research surveys state-of-the-art methods for reconstructing defective skulls from diagnostic imaging, categorizing strategies into mirroring, surface interpolation, deformed template, and slice-based reconstruction. These methods aim to improve the efficiency and effectiveness of RE and AM in medical applications.

Uwe spetzger et.al., [25] Skull defects require reconstruction to ensure biomechanical stability, cerebral protection, and optimal cosmetic results. Various techniques have been used, including autologous, allogenic, and alloplastic materials. Autologous bone is typically harvested from the patient's own body. The ideal artificial material for reconstruction should mimic bone properties, being biocompatible, strong, inert, malleable, lightweight, and inexpensive. Additionally, it should allow for unhindered radiological evaluation post-implantation. Artificial materials aim to replicate the characteristics of bone for optimal reconstruction outcomes. Effective skull reconstruction materials are crucial for patient recovery and quality of life.

Major et.al., [26] Additive Manufacturing (AM), also known as 3D printing, builds parts layer by layer from raw materials. Unlike subtractive manufacturing, AM starts from scratch, adding material to create the desired form. Originating in automotive, architectural, and packaging industries, AM is increasingly applied in medicine due to its ability to create customized, complex devices. Medical scans like CT, MRI, and PET scans enable accurate patient-specific models, which can be combined with computer-aided design algorithms for AM device design. 3D printed patient-specific surgical guides and templates facilitate complex surgeries by improving visualization and ensuring accurate section planes. AM offers unprecedented customization and complexity in medical device manufacturing.

You Chen et.al., [27] Bone defects often have irregular geometries, requiring personalized implant solutions. Additive Manufacturing (AM) techniques excel in fabricating customized implants using patient-specific anatomical data. AM enables precise control over porosity, size, and geometry, tailoring implants to individual defects. This approach accommodates variations in size, anatomy, pathology, and bone quality, offering improved early stability and osseointegration. 3D printed interbody cages exemplify these benefits, providing enhanced stability and integration. AM's personalized approach is gaining recognition for its potential in addressing complex bone defects. Customized implants fabricated via AM techniques show promise in improving patient outcomes.

Weilin Elena Manuela Samaila,et.al., [28] Three-dimensional (3D) models of bone fractures were evaluated by surgeons and residents for educational purposes and preoperative planning. 3D prints facilitated patient understanding of their injury and proposed surgery, enhancing informed consent. The technology improved surgical preparation, reduced costs, and shortened surgical times by 15%. 3D-printed replicas enabled effective surgical planning, simulation, and training. They also strengthened the informed consent process and improved surgeon-patient relationships. 3D-printed models represent a significant step towards personalized medicine, enhancing education and patient care. This technology has the potential to revolutionize orthopedic surgery and patient outcomes.

`Cesar Colasante et.al., [29] Three-dimensional printing (3DP) technology has revolutionized implantable delivery systems, enabling the creation of thermos-sensitive, pH-responsive, and redox reactive devices using various thermoplastic materials. Bioactive materials have been incorporated into macro and micro drug delivery systems, maintaining product integrity and homogeneity. 3DP technology has the potential to transform the pharmacy setting, enabling on-demand printing of medications and reducing costs. Electronic medication formulation databases could replace traditional drug manufacture and distribution methods. This approach could lead to a decrease in pill burden through the provision of polypills, improving patient adherence and outcomes. 3DP technology offers a promising solution for personalized medicine and drug delivery.

Phani Kumari Paritala et.al., [30] Three-dimensional (3D) printing technology creates products by adding materials in successive layers. Since Charles Hull's development of Stereolithography in 1984, 3D printing has evolved significantly. Major technologies include SLA, FDM, SLS, IJP, LOM, and EBM. 3D printing has exciting healthcare applications, but further research is needed for efficient, low-cost, and high-speed use. Organ printing, regenerative medicine, and tissue engineering show promise but require progress before mainstream adoption. Digital innovation with advanced 3D printing technology can reduce healthcare costs without compromising quality.

Ihab El-Katatny et.al., [31] This study investigates errors in fabricating complex anatomical replicas using Fused Deposition Modeling (FDM) rapid prototyping technology. Three-dimensional (3D) printing is a rapidly advancing technology being adopted by the medical field. The study analyzed skull models with 12 landmarks, finding error values ranging from 0.02mm to 0.25mm, with an average deviation of 0.108mm. The replicas were under-dimensioned compared to virtual models, with most errors concentrated between 0.07mm and 0.15mm. The results highlight the need for accurate fabrication techniques in reconstructive surgery applications. FDM technology shows promise, but further refinement is necessary to minimize errors.

Trevor D. Crafts et.al., [32] Rapid prototyping technology is gaining importance in medical device manufacturing. Studies have compared its accuracy to traditional methods. Santler et al. (1998) found that stereolithography (SLA) and milling produce sufficiently accurate models for clinical use, but SLA is preferable for complex geometries. Recent software advances have overcome challenges by generating spatial models from CT, MRI, and US images using post-processing algorithms. These models can be stored in the DICOM format, enabling accurate reproduction of complex structures. Rapid prototyping technology has improved significantly, offering new opportunities for medical device manufacturing. Its accuracy and versatility make it a valuable tool for clinical applications.

Elena Manuela Samaila et.al., [33] Three-dimensional (3D) printing creates solid objects from computerized 3D-imaging files at a low cost. In orthopaedic and trauma surgery, 3D-printed models of bones can help study fracture patterns and deformities, potentially improving surgical practice. A study at the University of Verona selected patients with articular fractures of the calcaneus, tibial plateau, and distal radius from 2013 to 2016. 3D-printed replicas of these fractures enabled detailed study due to their complex anatomy. Recent software advances have improved spatial model generation from CT, MRI, and US images. Post-processing algorithms and DICOM format storage enable accurate 3D model creation. This technology has potential to enhance surgical understanding and planning.

LongYang et.al., [34 Three-dimensional (3D) printing creates solid objects from computerized 3D-imaging files at a low cost. 3D-printed models of bones can aid orthopaedic and trauma surgery by revealing detailed fracture patterns. A University of Verona study used 3D-printed replicas to study articular fractures in 140 patients from 2013 to 2016. These replicas provided a better understanding of complex fractures. The study concludes that 3D-printed replicas are an innovative tool for personalized medicine and health technology assessment. This approach may reduce healthcare costs and improve surgical practice. 3D printing technology has potential to enhance surgical understanding and planning.

Yashan Fenga et.al., [35] Large-scale bone defects remain a significant challenge in orthopedics. While bone tissue has self-healing capabilities, external intervention is often necessary. Autologous bone transplantation is the gold standard, but limited sources and surgical complications restrict its use. Biocompatible and bioactive bone replacement materials are being developed to address these limitations. Ideal bone substitutes require high porosity, cytocompatibility, histocompatibility, and biomechanical strength. 3D printing technology offers a promising solution, enabling the creation of customized bone implants with precise control over material properties. This technology has the potential to revolutionize bone injury repair and precision medicine.

D. Lacroix I P.J et.al., [36] Polyetheretherketone (PEEK) and its copolymers are promising alternative materials for biomedical applications due to their bone-like mechanical properties, chemical resistance, and radiolucency. Developed in 1978, PEEK is a semi-crystalline polymer that gained industrial importance in the late 1990s. Various PEEK variants (PEEK-LT1, PEEK-LT2, PEEK-LT3) have been used in spine treatment, orthopedic tools, and maxillofacial surgery. A computational algorithm has been developed to simulate tissue differentiation, successfully replicating fracture healing patterns. This algorithm accounts for non-homogenous precursor cell distribution, enabling simulation of the healing time course. PEEK's properties and the algorithm's capabilities show potential for improved biomedical applications.

Oscar Mario Jacobo1 et.al., [37] Reconstructive surgery aims to restore morphology and function in abnormal body areas affected by congenital or acquired lesions. Achieving this goal can be technically challenging, requiring careful preoperative planning. Three-dimensional (3D) models created with Fused Deposition Modeling (FDM) technology can aid in this planning, offering high-quality, accurate, and low-cost guides for complex surgical treatments. These models can reduce anesthetic and surgical times, optimize outcomes, and improve patient understanding. 3D printing techniques are particularly beneficial in plastic surgery, especially maxillofacial and hand surgery, and contribute to academic education. This study followed ethical standards, with no conflict of interest or funding declared. Informed consent was obtained from all participants.

Anil Murat Ozturk et.al., [38] The tibial plateau is a critical load-bearing area in the human body, and fractures in this region are challenging to treat due to their intra-articular nature and soft tissue involvement. Open reduction and internal fixation are often necessary to restore joint surface alignment and lower limb alignment, particularly for displaced bicondylar tibial plateau fractures. Three-dimensional printing (3DP) technology has been used to aid in preoperative planning for these complex fractures. In a study of 19 patients, 3DP technology was used to create personalized plans, which were accurately replicated during surgery, including operative approach, nail diameter and length, and screw blade length and position. This technology shows promise in improving surgical accuracy and outcomes for tibial plateau fractures.

Sheng-nai zheng et.al., [39] Hip fractures are a prevalent health issue in elderly patients with osteoporosis, leading to dysfunction and high morbidity. Intertrochanteric fractures (ITF) are common in this population and often require surgical treatment due to high complication rates with conservative management. Intramedullary fixation has been shown to have advantages over extramedullary fixation in ITF treatment, including minimal invasiveness and mechanical superiority. A follow-up study found satisfactory bone healing and good hip function in patients treated with intramedullary fixation, with no screw cutout or fracture displacement observed. This suggests that intramedullary fixation is a effective treatment option for ITF in elderly patients.

Simone Tassani et.al., [40] Trabecular mechanical behavior is crucial for assessing bone fracture risk. Various studies have analyzed the mechanical behavior of trabecular bone structure (Goldstein et al., 1993; Goulet et al., 1994; Ciarelli et al., 2000; Matsuura et al., 2007; Perilli et al., 2008). Parameters related to fracture zone identification and prediction have been used in clinical studies. A registration scheme was applied to TestSets, achieving complete matching with no identified fracture zones and a mean registration error of 0.002%. This verifies the accuracy of the registration scheme, contributing to improved fracture risk assessment.

III. Conclusion

The integration of PEEK in 3D printing technologies has demonstrated significant potential for advancing biomedical applications. Researchers have highlighted the material's nearto-bone mechanical properties, chemical resistance, and radiolucency, making it a promising candidate for medical devices. The study concludes that while conventional manufacturing technologies face challenges in producing complex biomedical geometries, 3D printing offers a viable solution. The continued exploration and development of specialized 3D printers and techniques are essential for fully harnessing PEEK's capabilities, paving the way for innovative and effective biomedical solutions. The future of PEEK in the biomedical industry looks promising, with its unique properties and the advancements in 3D printing technology providing new opportunities for medical device manufacturing.

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