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REVIEW ARTICLE - MEDICAL TECHNIQUES

Methods of Additive Manufacturing for Dental Co-Cr Alloys: Systematic Review

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Abstract

Additive manufacturing is a popular method of producing items directly from digital models through a layer-by-layer material build-up process.
To evaluate the Current State of Knowledge on Dental Co-Cr Alloy Additive Manufacturing Techniques.
Innovative additive printing technologies have made it possible to produce intricate dental components customized for each patient. This study investigated the manufacturing method (build orientation and process parameters), post-processing techniques, and metallic powders utilized in dental applications (stress relieving, surface finishing). The databases PubMed, Science Direct, Mendeley, and Google Scholar were used to carry out an electronic search. A manual search of pertinent article citations was also carried out; inclination angle, stress relieving, heat treatment, cobalt-chromium, selective laser melting, selective laser sintering, and powder bed fusion, dentistry were some of the keywords utilized. Although this publication tries to contain the most recent study from the previous eleven years (2010–2021), and to explain the materials powders and metal used in dental applications.
A cutting-edge technique called additive manufacturing uses a layer-by-layer approach to material build-up to produce things directly from digital models. It is missing a tool, a manufacturing process that produces fully thick metallic components quickly and with good precision. Qualities of additive aspects of production such component design flexibility, part complexity, light- weighting, component consolidation, and functional design are generating specific interest in the additive fabrication of metal for use in automotive, marine, oil & gas, and aerospace industries during powder bed fusion, each layer of the powder bed is only partially fused employing a laser or electron beam as an energy source, the recent and most promising additive manufacturing technologies utilized to produce intricate, low-volume, tiny metallic parts.
By using computer-aided design (CAD) technology, recent developments in digital dentistry have changed dental offices and dental laboratories, by utilizing 3D printing because precise metal framework fitting and technique faster.

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Keywords: Dentistry; Selective laser sintering; Electron beam melting; Selective laser melting; Cobalt–chromium; Powder bed fusion.

1. Introduction

The superior corrosion resistance and mechanical qualities, such as high stiffness, Co-Cr based alloys are extensively utilized in dentistry because use in this study sample of Co-Cr 3D printer metal. The lost wax- casting method has remained the most popular method of processing dental metal since its invention in 1907 [1]. Unfortunately, this method is ineffective. Some limits exist, one of which is that metal shrinks when it transitions from liquid to solid state. When preparing the part for casting, keep in mind that it will shrink during the solid phase.
Additionally, porosity and other flaws are commonly seen in the cast element's structure [2, 3]. The process is time-consuming and needs certain operator skills [4], and Co-Cr alloys are difficult to work with. Due to their great hardness, they are intractable to manage [5].
Today, computer-aided design and computer-aided manufacturing (CAD-CAM) is used to process metallic materials [6,7].
Subtractive manufacturing techniques, such as milling and additive manufacturing (AM) methods, such as powder bed fusion are both covered by CAD–CAM technology [8, 9]. Milling is the process of mechanically cutting a block to the desired geometry using instruments such as saws, lathes, grinders, and drill presses. The procedure is managed by software. As opposed to casting, this helps to reduce defects. The blanks have porosity as a result of their high industrial standards [10, 11]. On the other hand, when compared to casting and additive manufacturing, the approach is associated with more material waste and various limits in large projects [8].
Additive manufacturing (AM) technologies, sometimes known as three-dimensional (3D) printing is a type of additive manufacturing that Builds tangible products from their computer-aided design in a single step. The goods are manufactured using this method by layering materials on top of each other, based on 3D design's sliced data [12, 13]. As a result, this technology is employed to create complex items, which made it gain popularity in dentistry and produce new possibilities for using Polymers, ceramics, metal alloys, and composites can all be used in additive manufacturing [14]. The development of biological ink is the focus of new methodologies [13], [15].
Additive manufacturing's most typical applications are Stereolithography (SLA), Fused Deposition Modeling (FDM), powder bed metallurgy, Ink-jet printing (IJP), and fusion (PBF) all of these techniques utilized in dentistry [16]. Powder bed fusion (PBF) is most often utilized for dental metal processing [17, 18]. According to CAD, powder bed fusion consolidates metallic powder to create 3D objects (layer by layer).

Nomenclature			
SLS	Selective laser sintering	Co-Cr	cobalt–chromium
EBM	electron beam melting	AM	Additive manufacturing
SLM	selective laser melting	PBF	Powder bed fusion
FDM	Fused Deposition Modeling	IJP	Ink-jet printing

Additive manufacturing processes have opened up new avenues for the creation of complicated components that are individually suited to the patient. This paper focuses on the metallic powders used in dental applications for a crown, bridge or removable partial denture.

2. Materials and methods

This work was carried out using the PubMed databases, Science Direct, Google Scholar and Mendeley. Additionally, a manual examination of relevant articles was citations done, a few of the words chosen included: Dentistry, selective laser sintering, selective laser melting (or SLM), inclination angle, stress alleviation, heat treatment, cobalt-chromium, and powder bed fusion (or PBF). Earlier articles were also chosen, even though this publication aims to provide the most recent research from the previous eleven years (2010–2021).
Over 1200 results were found after the search, as then reviewed for title or summary. Based on their applicability, more than 46 papers were picked for this review. The exclusion criteria included non-dental (or non-medical) applications and the articles on 3D printing of metal alloys other than Co–Cr. The results were based on a descriptive analysis of the techniques and materials of additive manufacturing, fabrication process and post-processing strategies. The purpose of this review is to provide a practical and scientific overview of 3D printing technologies. We summarized the classification and characteristics of 3D printing technologies used in dentistry in this review. Based on the first part of the 3D printing technology, it also introduced various factors affecting 3D printing.
Powder Bed Fusion (PBF) was divided into three sections: Selective Laser Sintering (SLS), Selective Laser Melting (SLM), and Electron Beam Melting (EBM). As shown in Table 1, they have the potential to be refined into specialized 3D printing technologies, such as SLM, SLS, and EBM, each with their own set of benefits, classification, and materials.

Table 1 Techniques, classification, materials, and primary benefits of 3D printing technologies

Techniques	Classification	Materials	Advantages
Powder bed fusion	SLM	Metal	Less complicated than casting. Enhanced mechanical properties and comparable metal-ceramic bond strength [2, 10]. Allow for customized prostheses without the need for considerable manual pre- or post-processing [50].
Powder bed fusion	SLS	Metal	It allows reducing the time. Allows to increase the accuracy of the manufactured element relative to the design. Reduces weight and post-production time [14]. Materials are inexpensive. The ability to be colored. Build models can be utilized directly for casting. Toxicology is low [49].
Powder bed fusion	EBM	Metal	Quicker printing rates. Build high-quality metal components. Reduces residual stresses. [16].

3. Powder Bed Fusion (PBF)

Powder Bed Fusion (PBF) occurs in an inert or partial vacuum environment. An energy source is used to scan each layer of the structure (laser or electron beam). The Powder Bed Fusion (PBF) contains the basic component (Powder chamber and build chamber), to shield the molten metal, (see Fig. 1). Already dispersed powder to melt the material selectively according to the digitally acquired portion cross- section model component after scanning one layer, the piston of the building chamber descends, and the piston of the powder chamber ascends by defined layer thickness. The coating mechanism or roller spreads powder across the construction. The energy source scans the chamber once more. This cycle is performed layer by layer until the entire section is formed. This procedure produces powder cake, and the part is not visible until the extra powder is removed. In PBF-based procedures, the build time required to manufacture a part is greater. When compared to Directed Energy Deposition (DED) technologies, but with greater complexity and a superior surface polish can be obtained with minimal effort post-processing. Several pieces can be assembled so that the construction chamber can be completely exploited [20, 21]. These methods require support (of the same material as the part) to avoid molten material collapse on overhanging surfaces, distribute heat, and prevent deformities. During the pre-processing phase, supports can be generated and adjusted to meet the needs of the part, and they must be removed mechanically during the post-processing phase [20]. After the support is removed, the part may go through post processing. Depending on the situation, treatments such as shot peening, polishing, machining, and heat treatment may be used.

3.1. Selective Laser Sintering (SLS)

Selective Laser Sintering (SLS) this technique was created at the University of Texas and has been in use since the middle of the 1980. The basic component of the device is (powder delivery piston, powdered material), (see Fig. 2). By using a scanning laser to fuse a thin material powder, structures are built up gradually. A fresh fine coating of material is evenly distributed across the surface as a powder bed descends. It is possible to achieve a high level of resolution (60 m). The surrounding powder serves as a support for the printed structures; thus, no additional material is needed [22]. Polymer scaffolds are used in the fabrication of facial prostheses (poly amide or poly Caprolactone, anatomical study models, dental models, cutting and drilling guides, and engineering/design prototypes) are all made using selective laser sintering [23].
The materials utilized are easily autoclavable, the printed products have completed mechanical functionality, and if used in large quantities, the materials are less expensive. Powders are untidy and pose a greater risk of inhalation. Additionally, technology is expensive and considerable environmental conditions, such as compressed air, are needed [23, 24].

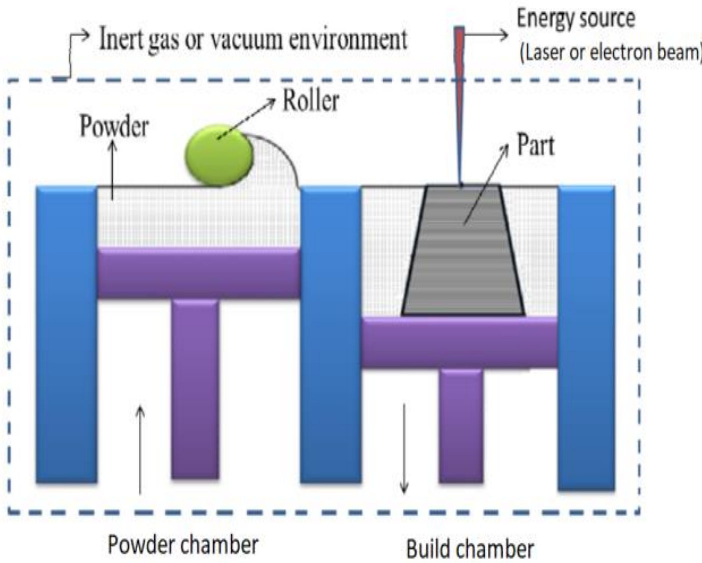

Fig 1. Powder Bed Fusion chamber [48]

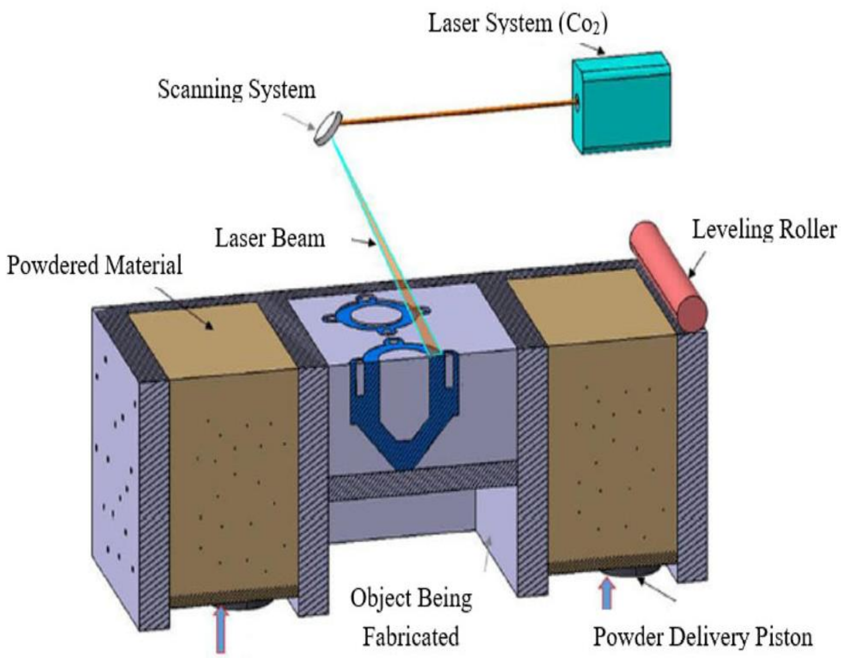

Fig 2. Selective Laser Sintering System [47]

3.2. Selective Laser Melting (SLM)

Selective laser melting (SLM) is elemental metal, or alloy powder deposition technique is closely followed by an additive CAM continuous layering build-up procedure using laser melting, a finished shape is produced control by a computer [50]. The basic component of the SLM device is (leveling system, unmelted powder bed, and printed part), (see Fig. 3), which is regarded as cutting-edge technology for the production of dental crowns and bridges. The phase conversion is caused by the totally melting in this powder-based fusion process, which uses materials like metals, polycarbonate (PC), polymers, wax, and powdered plastics, among others, in preparation by powder in bed [25]. This method also employs base-applied, densely packed, extremely thin powder coatings. During this process, the laser beam withdraws from the melt pool, causing the molten material to solidify. Consequently, a dense structure form. Once the layer beneath it, the granular substance has melted and merged. another layer is then applied on top of the first layer. In this manner, the technique is carried out once again to generate the final section. In SLM, factors, such as the chemistry of the binder, the size and shape of the particles, how the binder and powder interact, the speed of deposition, and post-processing, among others, are crucial [26, 27]. Nevertheless, SLM is suitable for printing complex structures due to its high-quality printing and precise resolution [28].

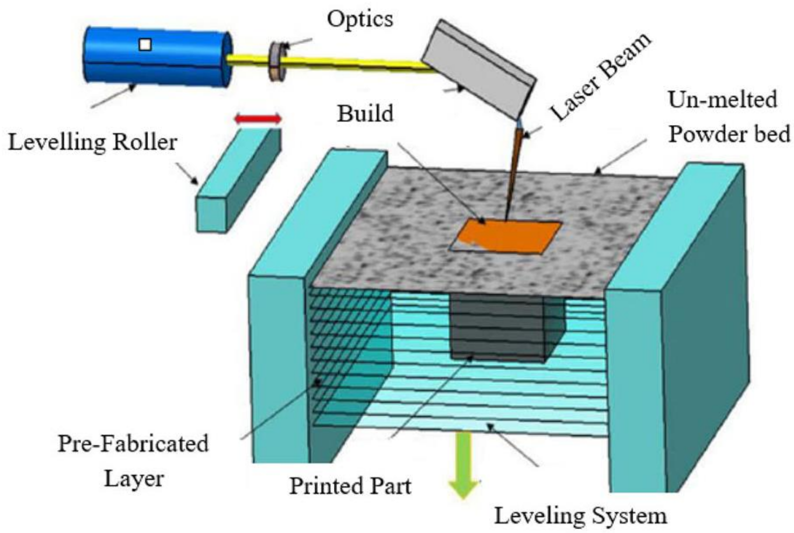

Fig 3. Selective Laser Melting Technique [47]

3.3. Electron Beam Melting (EBM)

Instead of using a laser, the Electron Beam Melting (EBM) method uses an electron beam as its power source [29], (see Fig. 4). In a high vacuum chamber, this electron beam completely liquefies the metal powder by melting it in a series of layers [30]. This technology is used to create personalized implants in the form of porous scaffolds in the fields of orthopedics and oral and maxillofacial surgery [31, 32]. Electron beam additive manufacturing has many advantages. The process uses a beam several times stronger than a laser, which is the primary heat source employed by other metal 3D printing technologies. The increased beam power means faster printing speeds. EBM can construct high-quality metal parts comparable to those made with traditional manufacturing methods, such as casting.

The parts not only possess strong mechanical properties, but they also typically have a high density due to the preheating process and high temperatures reached during printing. Preheating the print bed also minimizes residual stresses, a common issue faced with metal 3D printing, reducing support structures need. EBM creates minimal waste, as most unused powder can be used again, which is especially beneficial considering the substantial costs of the materials used in EBM.

EBM also has its disadvantages and limitations. EBM parts typically have a lower accuracy level compared to some other 3d-printed parts. The thicker layers EBM uses can often result in a rough surface finish, and created parts require extensive post-processing to achieve a smoother surface [31, 32].

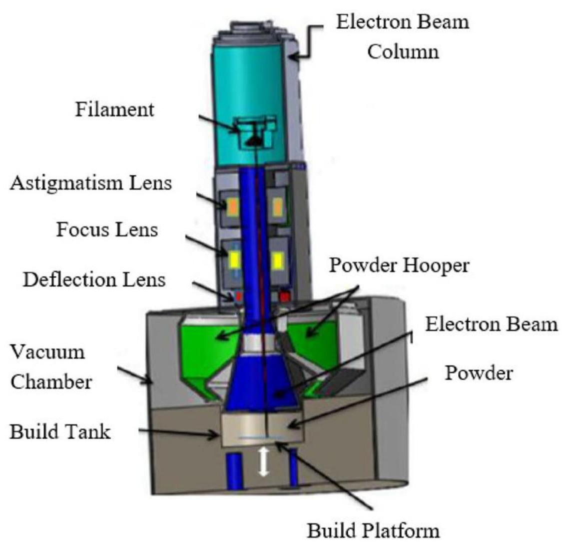

Fig 4. Electron Beam Melting Technique [47]

4. Discussion

The manufacture of metallic fixed-dental prosthesis (FDP) frameworks for the dentistry sector was the main emphasis of this review's summary of technical advancements in additive technologies. As a result, SLS is a generally very adaptable technology that can work with a wide range of different materials and produce very complicated products. Additionally, because the use of SLS and related AM technologies depends on certain knowledge and training, dental workers must undergo distinct training [33]. Moreover, because high-intensity laser or electron beams are used, additive manufacturing (AM) consumes more energy than traditional production for a single dental piece [34, 35]. However, SLS can create multiple items at once, this should make up for the longer production times or use of more energy for each object [36, 37]. Finally, porosity and surface microstructure are two characteristics that distinguish dental products made using SLS from those generated using more traditional methods [38, 39]. The quality and suitability of dental applications may be impacted by this. With the exception of surface qualities, all of these criteria also apply to EBM [40]. Modern dentistry is moving more and more toward using metal-free reconstructions, particularly using zirconium-based materials, and recent studies have shown that both types of FDPs have identical survival rates [41, 42]. All-ceramic materials, however, have a marginally higher failure rate, including fractures and chippings [43]. On the other hand, ceramics cannot take the benefits of SLS for metals, because the approach demands a high laser energy density. Inadequate energy density results in less than 15 % overlap between layers, leading to insufficient bonding strength [44]. This restriction may soon be overcome because of technological development and the growth of AM technologies, such as EBM and DMD [45, 46]. Dental work is impacted by the advent of automation and computerization, which makes it possible to quickly and affordably mass-produce metal-ceramic FDPs using SLS technologies. SLS is a very new technology that has only recently made its way into the dental market. There are still many outstanding technological and practical questions. Dental practitioners must be aware of the potential uses and restrictions of SLS- made dental products, despite technological and material advancements.

5. Conclusion

Current advancements in digital dentistry have improved dental offices and laboratories by enabling computer-aided design (CAD) technology. In order to obtain the necessary measurements for diagnosis and treatment planning for more trustworthy and effective patient care, 3D digital models for 3D printing have been created that are easy to modify. Intraoral scanners (IOS) and lab light scanners were used to make these models. Also, it makes it easier to transmit and retrieve 3D models for use with all dental treatment modalities while removing the need for storage space. As previously stated, metal and plastic are the principal materials employed in this technique. When compared to traditional production, the cost of materials for additive manufacturing is currently relatively expensive. There are numerous elements that affect printing speed. These factors include the orientation of the part and the amount of material to be printed. Other factors may include print nozzle temperature, filament thickness, material to heat, and laser power. Build time is an important factor in determining the cost of additive manufacturing, and several software packages are available for predicting build time. There are two methods for determining build time: thorough analysis and parametric analysis. The detailed analysis makes use of knowledge about the inner workings of a system, whereas parametric analysis makes use of process time and parameters like layer thickness. Estimated build times are often system and material-dependent. In summary, 3D printing is a brilliant example of the profoundly positive effects that the fourth industrial revolution is having on dental patient care. because it is a fast technique with more details and less waste.

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