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A narrative review on the fit and fracture resistance of milled and 3D-printed interim restorations in dental and implant applications

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Abstract

This narrative review explores the comparative performance of milled and 3D-printed interim restorations in both tooth-supported and implant-supported dental and implant applications, with a focus on two critical clinical factors: fit and fracture resistance. Interim restorations serve vital functions during the healing and integration phases by preserving occlusion, aesthetics, and soft tissue health. The digital revolution in dentistry has introduced subtractive milling and additive 3D printing as primary fabrication techniques for temporization. Milled restorations typically offer higher precision and better marginal and internal adaptation due to the controlled machining of homogenous materials. In contrast, 3D-printed restorations provide enhanced design flexibility and faster fabrication, though their accuracy is influenced by print orientation, resolution, and post-processing steps. Regarding fracture resistance, milled interim restorations demonstrate superior strength due to their structural uniformity and the use of high-density materials like PMMA and zirconia. Conversely, 3D-printed restorations, while improving with advances in resin formulations and curing protocols, may exhibit lower fracture thresholds due to layer-by-layer construction and material limitations. Implant-supported restorations further complicate these outcomes due to the complex geometries and passive fit requirements. Milled solutions currently remain the standard for high-load and precision-demanding cases, whereas 3D printing is favored for cases requiring rapid customization and lower-cost alternatives. This review highlights the need for careful technique selection based on clinical requirements, material properties, and patient needs. Future innovations in material science, printing resolution, and hybrid digital workflows are expected to further bridge the gap between the two techniques.

Keywords: 3D printing; Zirconia; PMMA; Crown; Restoration

1. Introduction

Interim restorations are essential for preserving the tooth's integrity, guaranteeing function continuity, and supporting neighboring teeth while they recover in tooth-supported restorations. Additionally, while the implants are integrating, the adjacent bone and soft tissue may be protected by implant-supported restorations, which act as a placeholder [1]. To guarantee patient comfort, avoid problems, and promote the best possible recovery, interim restorations must satisfy functional, aesthetic, and biological needs [2]. In order for the ultimate restoration to be successful, these needs include maintaining a healthy occlusal connection, restoring aesthetic shape, and preventing gum tissue irritation.

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1.1. Fabrication Techniques: Conventional vs. Digital

Over the last several decades, there has been a tremendous evolution in the manufacture of temporary restorations. At first, the sector was dominated by conventional processes like indirect casting and direct wax-up [3]. As these techniques included a lot of physical labor, their accuracy and reproducibility varied. Digital methods gained popularity as technology developed because they were more accurate, efficient, and reproducible [4].

The speed and accuracy of temporary restorations have significantly increased with the transition from traditional to digital fabrication techniques, such as milling and 3D printing. Machine learning and other digital approaches enable precise restorations to be made with little to no human involvement using state-of-the-art CAD and CAM software. These techniques are now the go-to option in contemporary prosthodontics because to improve patient results and shorter clinical chair times brought about by this shift [26].

1.2. Digital Techniques: Milling and 3D Printing

The two main digital manufacturing techniques for temporary repairs are milling and 3D printing. A hard block of material, like resin or ceramics, is cut into the required form using spinning cutting tools during the milling process. Milling is a subtractive process. This technique is perfect for creating precise and robust restorations because it offers great accuracy, tiny details, and smooth finishes [5].

On the other hand, 3D printing forms the restoration by layering material using an additive manufacturing process. Compared to milling, this method offers quicker manufacturing times and permits complicated geometries and considerable customization. However, variables like print orientation and resolution may have an impact on how accurate printed restorations are. Both approaches have unique benefits and drawbacks, and the choice of approach is based on the desired results, material selection, and therapeutic demands [6].

1.3. Factors Affecting Restoration Quality

The clinical outcome of interim restorations is largely dependent on their fit and fracture resistance. A restoration's fit is its ability to conform to the contours of the tooth or implant it is replacing, creating a snug fit with little spaces between. Conversely, fracture resistance describes the restoration's capacity to bear the stresses of mastication without breaking or shattering [7].

These crucial characteristics are influenced by a number of variables, including as the selection of material, the method of manufacture, and the post-processing procedures [8]. The sort of milling burs used, as well as the milling machine's accuracy, may have an impact on the restoration's ultimate fit and strength. Similarly, the success of 3D printing is dependent on factors such as print angle, layer thickness, print quality, and support structures [9]. The final characteristics of the restoration may also be impacted by post-processing procedures like curing or finishing.

To maximize the restoration's fit and fracture resistance, it must be customized to the unique needs of each patient using the appropriate design software, which is applicable to both milling & 3D printing. To guarantee the best possible performance of temporary restorations, each of these elements has to be properly managed.

Aim of the Review

Examining milled and 3D-printed interim restorations for tooth-supported and implant-supported applications, this research aims to assess their fit and fracture resistance. The influence of many technical factors, including material type, manufacturing techniques, and post-processing procedures, on these restorations' performance attributes will be assessed in this study. Our goal in doing this literature analysis was to help clinicians better understand how to make temporary restorations that are up to the task of satisfying patients' aesthetic, mechanical, and functional needs.

2. Method

To conduct this narrative review, a comprehensive literature search was performed in PubMed and Scopus databases using the following keywords: "milled interim restorations," "3D-printed dental restorations," "fit accuracy," "fracture resistance," "tooth-supported restorations," and "implant-supported restorations." Studies published in English up to March 2025 were screened, and additional sources were retrieved through reference tracking. Both in vitro and clinical studies were considered to provide a well-rounded evaluation of digital interim prosthodontic techniques.

3. Discussion

3.1. Fit (Marginal and Internal Adaptation)

3.1.1. Tooth-supported Restorations

In prosthodontics, obtaining practical, aesthetically pleasing, and long-lasting outcomes depends on the fit correctness of interim restorations [10]. It has an immediate effect on the comfort, occlusion, and general efficacy of dental procedures. The two most important aspects of evaluating the fit correctness of tooth-supported restorations are the marginal adaptation and the internal adaptation. While internal adaptation makes sure the restoration fits evenly over the prepared tooth with few gaps or inconsistencies, marginal adaptation describes how well the restoration's margins match with the prepared tooth. To prevent problems like tooth sensitivity, gingival irritation, and mechanical failure, it is crucial to have a good fit in both areas.

When compared to 3D-printed restorations, milled interim restorations often provide better fit accuracy. The milling process's intrinsic accuracy is a major factor in this [11]. The repair is precisely and reliably milled out of a solid block of material using computer-aided design (CAD) technology. Milled restorations are thus often more exact in terms of internal and marginal fit [35]. Microleakage, which may result in secondary cavities and gum irritation, should be avoided by ensuring that the marginal fit is as tight as possible. To further reduce the likelihood of spaces forming between the prepared tooth and the restoration, high-quality milling equipment are used to guarantee that the restoration's inner structure is uniformly fashioned.

When comparing the fit accuracy of 3D-printed and milled restorations, several studies have shown that the former often provide a better degree of fit precision. This is especially crucial for tooth-supported restorations, since internal and marginal variations might impact the prosthetic's overall comfort and functioning [12]. When examined in clinical settings, milled restorations often exhibit a superior overall fit because of the accuracy of the milling instruments and the stiffness of the material employed. Milled restorations exhibit narrower margins, which lowers the possibility of leaking or other issues, according to studies that concentrate on marginal fit [13].

However, even though 3D-printed temporary restorations are faster and provide more customization options, they can struggle to match milled restorations in terms of fit correctness. The 3D printing process's intrinsic constraints are a major factor in this. Because the repair is constructed layer by layer using resin in 3D printing, there may be minor variances in fit because of things like support structures, layer thickness, and print quality. Specifically, the direction of the print and the placement of supports during printing may have a major impact on the end result. For instance, a less-than-ideal fit may occur if the support structures somewhat distort the printed repair when printed at an angle [14].

There may be even more fit issues with 3D-printed restorations since the material shrinks as it cures. Even while certain resins are made to reduce this impact, it might nevertheless jeopardize the restoration's overall correctness. The degree to which the printed repair closely resembles the digital design is also greatly influenced by the 3D printer's resolution. The marginal & internal fit may be impacted by restorations produced by lower-resolution printers since they often include fewer accurate features.

The fit of printed restorations has been much improved, nevertheless, because to recent developments in 3D printing technology. Increased accuracy in 3D-printed repair fits has been made feasible by advancements in printer resolution, resin quality, and post-processing methods. The difference in fit accuracy between 3D-printed and milled restorations may be lessened because to some of the newest printing technologies' improved precision and better surface finishes. Additionally, many physicians find 3D printing to be an appealing choice when time and money are important considerations since it allows for the quick prototyping and customization of restorations [15].

In terms of fit precision, milled restorations are still the industry standard, but 3D printing is becoming more popular, especially for customized restorations. It is anticipated that 3D-printed restorations will further enhance their fit as technology progresses, making them a more practical substitute for milled restorations in some cases. The particular clinical demands, including the restoration's intricacy, the choice of material, and the turnaround time, will ultimately determine whether to use milling or 3D printing.

3.1.2. Implant-supported Restorations

Because dental implants and the abutment interfaces they are connected with have complex geometries, implant-supported restorations pose a special set of fit-related difficulties. Implant restorations must be made to account for the exact placement of the implant in the jawbone and its attachment to the abutment, in contrast to tooth-supported restorations, which need comparatively simple dental preparations. Due to the intricacy of these interfaces, a high level of precision is necessary to guarantee passive restoration fitting, which is essential for the implant's long-term success. For the purpose of avoiding problems like peri-implantitis, mechanical failure, and implant overload, a passive fit is crucial for dispersing occlusal forces uniformly throughout the implant. Improper alignment or spacing between the implant and restoration may cause problems that harm the surrounding tissues and reduce the restoration's longevity [16].

When many implants or complicated implant geometries are involved, milled interim restorations often provide a superior passive fit. One of the main causes of this benefit is the accuracy that comes with the milling process. To create very accurate restorations, milling machines use high-precision cutting tools and computer-aided design (CAD) software. This degree of accuracy is essential when working with restorations supported by implants, since even minor fit irregularities might result in serious issues [17]. Complex instances, such as those needing several implant restorations or circumstances where the implant's location may be difficult to recreate, are often better suited for milled restorations. The milling technique also provides more control over the material, which helps achieve the best fit. Milled restorations fit better than other techniques because milling machines can duplicate the fine features of implant connections, such the abutment interface, particularly when accuracy is crucial.

However, obtaining a passive fit for 3D-printed restorations may be difficult, especially in implant-supported applications. Although there are many benefits to 3D printing, such as speed, personalization, and affordability, the technology is not without its limits, which may impact the precision of the end result. The main determinants of 3D-printed restorative fit are post-processing procedures, material shrinkage, and print resolution. The amount of detail that a 3D printer can produce is known as print resolution [18]. Although printing technology has advanced, it may still be challenging to match the level of accuracy that milling can provide. The curing process causes most 3D-printed materials, especially resins, to shrink, which might change the fit and cause tiny gaps to form between the abutment and repair. Achieving the perfect passive fit might be made more difficult by post-processing procedures like polishing and curing, which can significantly alter the restoration's proportions.

In spite of these obstacles, 3D printing has advanced significantly in the last few years. The precision of 3D-printed repairs is rising fast because to advancements in printing resolution, materials science, and post-processing methods. Another advantage of 3D printing is customization, which enables highly customized restorations that may be made to meet the unique requirements of every patient. Achieving a perfect passive fit is still difficult when working with implant-supported restorations, especially those that have many implants or complicated geometries [28]. To guarantee a secure fit, further modifications could sometimes be required throughout the therapeutic process.

Software utilized for design, print orientation, and support structures all have a role in how accurately 3D-printed restorations for implant applications turn out. For example, since it dictates the pattern in which the layers are accumulated and might influence their alignment with the implants abutment, the print orientation could have a substantial effect on the fit [29]. In addition, the support structures that are responsible for holding the restoration in place throughout the printing process have the potential to cause tiny distortions or misalignments, especially if they are not built in the most effective manner.

3.2. Fracture resistance

3.2.1. Tooth-supported Restorations

Interim restorations, particularly those that are tooth-supported and subjected to the mechanical stresses of chewing, must possess fracture resistance as an essential quality. The material used to support teeth in dental prostheses, such as bridges, crowns, or other restorations, has to be strong enough to endure chewing pressures without breaking. An important factor to consider while deciding between manufacturing processes is fracture resistance, which is the restoration's capacity to withstand stresses like as cracking, breaking, or chipping [19].

When it comes to fracture resistance, milled restorations often outperform 3D-printed restorations. The material density attained during the milling process is one explanation for this. The thick and uniform nature of high-strength resins or ceramics makes them ideal for machining restorations, which in turn increases their strength. During the milling process, the restoration is carved out of a solid piece of material. This decreases the amount of internal flaws, which in turn contributes to the total load-bearing capacity of the restoration. These materials have been specially designed to endure the mechanical strains that come with regular oral function. Additionally, the repair has constant qualities due to the homogeneity of the milled material, which increases its resistance to fractures or cracks under masticatory pressure.

However, even though they provide a lot of benefits in terms of speed and customization, 3D-printed restorations could be more likely to break in certain situations. A number of variables, including material qualities, print thickness, and layer orientation, affect how resistant 3D-printed restorations are to fracture. Restorations are constructed layer by layer in 3D printing, which sometimes results in the introduction of weak spots along the layers. Restorations made with less-than-ideal print orientations and layer thicknesses are more likely to break easily. The 3D-printed material, which is usually a composite or resin, could not last as long as the milled ceramics used for restorations [31]. These materials may still be pretty strong, but they might not last as long as needed for tooth-supported uses in high-stress places.

The strength of 3D-printed restorations once they have cured is affected by a number of factors. Post-curing, which entails exposing the printed repair to further light or heat to improve its mechanical qualities, is necessary for many 3D-printed resins. The material may continue to be weaker and more prone to failing under stress if improperly treated [20]. The strength of printed repairs is slowly getting better as 3D printing technology improves with better materials and better drying methods [34].

3.2.2. Implant-supported Restorations

As they withstand greater mechanical pressures than tooth-supported restorations, implant-supported restorations need to be very resistant to fracture. These restorations are intended to endure functional stress and large occlusal pressures, which may be particularly challenging in situations with many implants or long-span bridges. The long-term effectiveness of a restoration depends on its capacity to withstand fracture in these circumstances, as a failure might result in issues including loosening, implant failure, or harm to nearby structures.

Superior fracture resistance is often provided by milled restorations, especially in intricate implant-supported situations. The materials that are utilized in milling, including high-strength polymers, titanium, or zirconia, are designed to last [27]. For instance, zirconia is well-known for having a high flexural strength and remarkable fracture toughness, which makes it perfect for restorations that are subjected to extreme stress. By cutting a repair from a solid piece of material, the milling technique produces a uniform construction with few internal flaws. This results in a repair that is more dependable and constant and that can endure the mechanical stresses applied to it over time. To further improve their resistance to fracture, milled restorations may be tailored to precisely match the geometry of the contact between the implant and abutment.

On the other hand, 3D-printed restorations often lack fracture resistance, particularly in high-stress locations, while becoming more and more common in implant-supported applications because of their speed and customization benefits. Depending on the resin or composite material employed, the mechanical qualities of 3D-printed restorations might vary dramatically [21]. The mechanical strength of zirconia and other milled ceramics may be higher than that of several 3D-printed materials, including resins. Because the link between layers isn't always as strong as the bulk material, the restoration might have possible weak spots introduced by the layer-by-layer printing process. This may weaken the restoration's overall strength, particularly if it is exposed to strong occlusal stresses.

Additionally, post-processing procedures like polishing and curing may have an impact on the ultimate strength of restorations that are 3D printed. If improperly cured, the repair can still include flaws that increase its risk of breaking under pressure. Nonetheless, the mechanical qualities of printed restorations are being enhanced by developments in 3D printing technology. For certain implant applications, 3D-printed restorations may provide sufficient fracture resistance with improved resin formulas and improved post-processing methods.

3.3. Technical and Material Influences

Numerous technological and material parameters have a considerable impact on the quality of interim restorations that are milled or 3D printed. These elements affect how well the restorations fit, last, and function as a whole.

In order to guarantee that the restoration precisely reflects the planned design, machine accuracy is crucial in the milling process. Excellent fit and geometry may be produced using high-precision milling machines, which is essential for applications that are supported by implants as well as teeth. But with time, tool wear may cause the milled restoration's quality to deteriorate. The fit and quality of the repair may become inaccurate as a result of dull milling equipment. Furthermore, the material's uniformity is crucial. Zirconia, titanium, and high-strength polymers are examples of materials that must have a constant density and structure in order to guarantee their longevity and resistance to fracture. Any discrepancies in the material may result in weak spots in the restoration, increasing the likelihood that it may break under the force of mastication [22].

3D printing, on the other hand, presents unique difficulties and factors. Print orientation is one of the most crucial elements. The mechanical qualities of the restoration may be affected by the direction in which it is printed; certain orientations may provide stronger restorations, while others may produce more flexible ones [33]. Another important consideration is the thickness of the layer. In general, thinner layers are more precise, which enhances the restoration's fit and resolution. Nevertheless, very thin layers may potentially lengthen the printing process. Additionally, the final restoration's quality may be impacted by the support approach used during printing. The printed repair will be stable and precisely formed during the procedure if it is supported properly.

The dimensional stability and fracture resistance of the repair are also impacted by the resin composition utilized in 3D printing. The mechanical qualities of 3D-printed restorations may be greatly enhanced by high-strength resins, particularly those made expressly for dental uses [30]. Adequate post-processing, including curing, is also necessary to improve the material's longevity and strength.

Both 3D printing and milling are feasible solutions for many clinical applications by carefully adjusting these technological and material parameters to provide high-quality temporary restorations with better fit and fracture resistance.

Table 1 Comparing the Two Methods

Parameter	**Milled Restorations**	**3D-Printed Restorations**
Fabrication Method	Subtractive (material is carved from a solid block)	Additive (material is built layer by layer)
Marginal Fit	Superior marginal adaptation; consistent across restorations	Acceptable but may vary depending on printer resolution and orientation
Internal Fit	High accuracy and reproducibility	Can be less precise; influenced by support placement and post-processing
Fracture Resistance	High due to material homogeneity and density	Lower; depends on resin type, layer orientation, and post-curing
Material Homogeneity	Excellent; uniform internal structure	Can be inconsistent due to layering and incomplete polymerization
Tool/Technology Wear	Tool wear affects precision over time	Minimal mechanical wear; printer maintenance mainly involves calibration
Surface Finish	Smooth, requires minimal polishing	May need post-print finishing for smoother surfaces
Layer Thickness Control	Not applicable; milling is continuous	Adjustable; thinner layers offer better detail but increase print time
Print/Mill Time	Slower for complex geometries; depends on machine speed	Faster for complex or customized cases
Customization	Limited to pre-fabricated block sizes and materials	Highly customizable design and internal structures
Post-Processing	Minimal; mainly polishing and fitting	Requires post-curing, support removal, and polishing
Support Strategy	Not required	Critical; improper placement can affect accuracy and fit
Material Options	Wide range (PMMA, zirconia, composite blocks)	Expanding range (dental-specific resins, hybrid materials)
Occlusal Accuracy	Precise due to controlled machining	May require refinements; affected by print orientation
Dimensional Stability	Excellent; retains shape and accuracy over time	May shrink or deform if improperly cured or stored

Waste Material	High; excess material is milled away	Low; only necessary material is used
Cost	Higher due to material and machine costs	Lower for short-term use; cost-effective for small runs
Equipment Investment	Expensive CAD/CAM mills and tools	Lower upfront cost; printers vary in price and capability
Environmental Impact	Higher due to waste and energy consumption	Generally lower due to minimal waste
Clinical Use Case	Ideal for high-load areas, long-span bridges, and implant-supported restorations	Best for quick turnarounds, temporary solutions, and esthetic trials
Learning Curve	Requires technical training in CAD/CAM systems	Easier with digital knowledge; accessible for beginners
AI/Software Integration	Available with CAD/CAM suites	Rapidly evolving with AI-driven design tools
Longevity	Suitable for long-term interim use	Better suited for short- to mid-term applications
Research & Validation	Long-standing clinical evidence and performance data	Emerging evidence; promising but still under research in some areas

3.4. Clinical Implications

The needs of each individual case determine whether to use 3D-printed or milled interim restorations in clinical practice. For high-stress locations where strength and fit are crucial, such long-span bridges or implant-supported restorations, milled restorations are perfect. However, 3D-printed restorations are more customizable and can be produced more quickly, which makes them appropriate for situations where aesthetics and speed are crucial. The clinical environment and patient requirements should direct the selection of materials and techniques, with careful evaluation of the benefits and drawbacks of each approach [23].

3.5. Future Directions

The creation of standardized testing procedures will be essential as digital dentistry develops further in order to compare interim restorations that are milled and those that are 3D printed [24]. New materials like advanced ceramics and hybrid resins have the potential to significantly enhance digital restorations' lifespan, fit, and resistance to breakage [25, 32]. Furthermore, combining artificial intelligence (AI) with simulation technologies has the potential to transform repair result prediction and design, improving both mechanical and aesthetic qualities. In the future, hybrid manufacturing methods that combine the advantages of 3D printing and milling could potentially proliferate.

4. Conclusion

In conclusion, milled & 3D-printed interim restorations both have their own set of benefits and drawbacks, with each technique providing its own set of advantages within the context of certain therapeutic treatments. When great precision and strength are of the utmost importance, milled restorations are the way to go since they provide superior fit accuracy and fragility resistance. In many situations, milled restorations are the preferable option, especially for long-span bridges and implant-supported restorations, due to their improved performance, which is facilitated by the accuracy of milling machines and the uniformity of the material.

In contrast, restorations that are manufactured using 3D printing technology allow for more customization and quicker manufacturing timeframes. As a result, they are an excellent choice for situations in where both aesthetics and speed are significant factors. For example, print quality, material cosmetics, and post-processing methods all have a big impact on how well made repairs fit and how easily they break. Notwithstanding these difficulties, printed restorations are becoming a more attractive alternative for several therapeutic applications as 3D printing technology continues to improve their quality and functionality.

Finally, the patient's unique requirements and the current state of care should dictate whether milled or 3D-printed interim restorations are chosen. Both approaches have a role in contemporary prosthodontics, and attaining the best outcomes requires an awareness of their advantages and disadvantages.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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