PRINTED OR MILLED? A SIDE-BY-SIDE LOOK AT SURGICAL GUIDES FOR DENTAL IMPLANTS

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ABSTRACT

Computer-guided surgery has transformed dental implantology by improving accuracy and safety through the use of digitally planned surgical guides. This review compares two fabrication techniques, namely additive manufacturing (3D-printing) and subtractive manufacturing (milling), in terms of accuracy, cost, clinical outcomes, patient satisfaction, and workflow efficiency. A comprehensive literature search identified studies and reviews directly comparing 3D-printed and CAD/CAM-milled surgical guides. Both methods demonstrated comparable dimensional accuracy, with reported deviations typically within 1–2 mm at the implant apex (within clinically acceptable limits). Some studies found milled surgical guides slightly more consistent and precise, while others reported no statistically significant differences. Cost analyses revealed a substantial advantage for 3D printing due to lower material and equipment expenses, facilitating wider clinical adoption. Both guide types produced similar implant survival rates and postoperative comfort, confirming that clinical outcomes and patient satisfaction are influenced more by the guided approach itself than by the fabrication method of the surgical guide. From a practical standpoint, 3D-printing offers greater flexibility and lower cost, while milling provides robust consistency and material strength. Overall, both technologies ensure accurate, predictable implant placement.

INTRODUCTION

Dental implant placement has been revolutionized by the use of computer-guided surgical guides, which enhance accuracy and safety compared to freehand surgery. By using preoperative cone-beam computed tomography (CBCT) and digital implant planning, surgical guides help avoid critical anatomic structures and mispositioned implants, thereby reducing complications such as nerve injury, sinus perforation, or improper angulation. This leads to shorter surgeries, reduced anxiety and pain for the patient, and overall improved clinical outcomes. At the moment, two main fabrication technologies are used to produce these guides: additive manufacturing (3D printing) and subtractive manufacturing (milling). Both methods rely on the same digital planning data but differ in how the physical guide is created. This review aims to compare 3D-printed and CAD/CAM milled surgical guides for dental implant placement in terms of accuracy, cost, clinical outcomes, patient satisfaction, and manufacturing workflow.

Historically, stereolithographic 3D printing (a form of rapid prototyping) has been widely used to fabricate implant guides, while newer CAD/CAM milling techniques have also been developed. Each method has potential advantages: 3D printing allows complex shapes and in-house production at low cost, whereas milling can produce guides with high material density and may avoid some data conversion errors by using coordinated fabrication methods. Given the growing adoption of in-office digital dentistry equipment, clinicians are interested in whether one method offers superior outcomes or efficiency over the other. This review gathered data from recent studies on guided implant surgery to evaluate differences between 3D-printed surgical guides and milled surgical guides.

MATERIALS AND METHODS

A literature review was conducted to compare 3D-printed surgical guides and milled surgical guides for dental implants. An electronic search of the relevant journals was performed using keywords such as “3D printed implant guide”, “milled CAD/CAM surgical template”, “accuracy”, “cost”, “clinical outcome”, and “patient satisfaction”. Inclusion criteria focused on studies that directly compared guides fabricated by 3D-printing technique versus milling technique, as well as high-quality reviews or meta-analyses on guided implant surgery.

Key data were extracted on accuracy, cost factors, clinical outcomes (implant success and complications), patient-related outcomes (satisfaction or comfort), and manufacturing workflow differences. Both in vitro accuracy studies and clinical trials were considered. The search revealed multiple in vitro comparative studies[6,7], cost analyses from industry reports[3], and clinical evaluations of guided surgery outcomes[2,7].

RESULTS

Accuracy

Dimensional accuracy of implant placement using 3D-printed surgical guides vs milled surgical guides has been investigated in several studies. Overall, both fabrication methods achieve comparable accuracy in translating virtual implant plans to the patient. For example, a 2020 pilot clinical trial using CNC-milled guides in edentulous jaws reported average deviations of ~1.5 mm at the implant apex with no complications, and concluded that milled guides provided accuracy comparable to stereolithographic (SLA) 3D-printed surgical guides[2]. Similarly, an in vitro study by Mukai et al. (2021) found no statistically significant difference in overall guide precision between milled and 3D-printed guides[7]. The average deviations in guide fit or implant transfer accuracy were on the order of a few tenths of a millimeter for both methods[1,4], which is generally within clinically acceptable limits.

Some differences have been noted in specific accuracy parameters. Abduo and Lau (2020) observed that milled guides were more accurate than printed guides on certain measurements, including internal surface fit and sleeve position, with milled templates showing significantly less vertical and horizontal deviation at sleeve midpoints[6]. This suggests milling may have a slight edge in dimensional precision of the guide, potentially due to the elimination of layer-printing artifacts. Additionally, one study reported that while the average errors of milled and printed surgical guides were similar, 3D-printed guides showed greater variance in errors (higher coefficient of variation) than milled guides[5]. In other words, milling produced more consistent results across samples, whereas printed guides had slightly more variability in accuracy. However, other research does not corroborate a significant accuracy gap. Park et al. (2014) directly compared five-axis milled surgical guides to SLA-printed surgical guides and found no significant difference in the implant placement errors between the two fabrication techniques[17]. They reported average horizontal and vertical deviations of approximately 0.14–0.20 mm for milled surgical guides, which were comparable to those of the printed surgical guides[1].

Cost

Cost efficiency is a key distinction between 3D printing and milling for surgical guides. 3D-printed guides generally offer a significant cost advantage over traditional lab-fabricated or milled guides. The materials for resin printing are less expensive per guide, and desktop 3D printers are relatively affordable for dental practices. 3D-printed guides are substantially more cost-effective on a per-case basis. The cost difference can be hundreds of dollars less for a printed guide relative to a milled guide[3]. Koch et al. (2018) demonstrated that surgical templates could be fabricated with low-cost 3D printers without sacrificing accuracy, highlighting the cost-effectiveness of additive manufacturing for guides[6]. The lower material cost of printed guides enables wider adoption of guided surgery, especially in practices that found the high price of commercial milled guides prohibitive[3].

Milled guides, on the other hand, involve higher material and production costs. Milling a guide typically requires specialized acrylic or polymer blocks and the use of an expensive milling machine or a fee to a milling center. These machines and materials entail substantial upfront and maintenance costs, which are reflected in the higher price of each milled surgical guide. Milling also inherently produces waste (since material is cut away) and may require tools (burs) that add to the expense. For clinicians who do not own a milling unit, ordering a CAD/CAM milled guide from a lab incurs laboratory fees that exceed the cost of printing. As a result, cost considerations often drive clinicians toward 3D printing for guide fabrication[3]. In fact, the affordability of in-house 3D printing has been cited as a reason guided implant surgery is becoming more accessible and routine in smaller dental offices[3]. It should be noted that while printing is cheaper per guide, there is still an initial investment in a printer and resin curing equipment; however, this cost is recouped quickly if surgical guides are used regularly due to the high cost of alternatives[3]. Milling equipment, by comparison, has a higher cost barrier to entry for

Clinics aiming to adopt guided surgery widely often find that investing in a 3D printing workflow represents a better return on investment than relying on third-party milled guides[3]. Milling may still be preferred in certain scenarios (for example, if an in-house milling system is already available or if extremely high precision for complex cases is demanded), but from a cost perspective, additive manufacturing is generally the more cost- efficient choice.

Clinical Outcomes

Both 3D-printed and milled surgical guides facilitate improved clinical outcomes in implant surgery by enabling more precise implant placement compared to freehand techniques. The use of any digitally planned guide, regardless of fabrication method, helps reduce surgical errors and complications, which can translate to better long-term results. For instance, guided implant placement has been associated with lower risk of damage to vital structures, more accurate prosthetic positioning, and reduced need for corrective surgeries[3,7]. By improving implant positioning, guides also contribute to optimal load distribution and may reduce biomechanical complications over time[7].

Studies of guided surgery consistently report high implant survival rates and low complication rates when using guides. Chai et al. (2020) placed 44 implants with milled guides in edentulous jaws and noted 100% implant survival with no surgical or immediate prosthetic complications in their series[2]. Similar success can be achieved with 3D-printed guides, as accuracy of placement is comparable. Current evidence does not indicate any difference in long-term implant success between 3D-printed and milled guides, since the critical factor is accurate implant positioning, which both methods achieve. No direct clinical trials have reported divergent implant survival or osseointegration outcomes attributable to the guide fabrication technique. In other words, a properly planned and fabricated guide; whether milled or 3D-printed; should recreate the intended implant positioning and thereby a similar clinical result.

Postoperative morbidity and patient recovery also tend to be improved with guided surgery (versus freehand), but they are not meaningfully different when comparing 3D-printed surgical guides with milled surgical guides. The surgical invasiveness is reduced in guided procedures (due to smaller incisions or flapless approaches and shorter surgery duration), which leads to less postoperative pain and swelling[7]. Both 3D-printed and milled surgical guides equally enable these minimally invasive techniques. There is no indication that one type of guide causes different tissue healing or infection rates than the other, as both use biocompatible guide materials that are safe for medical use.

Patient Satisfaction

Using a surgical guide generally enhances patient satisfaction with the implant treatment experience, and this benefit applies to both 3D-printed and milled guides. Guided surgery typically results in shorter procedure times and less invasive surgery, which patients appreciate[3]. For example, reports have documented that complex surgeries requiring multiple implants can be simplified with surgical guides, reducing the surgery time significantly (for example, a case that would normally take two hours reduced to 30 minutes with a dual-guide approach)[3]. A faster, smoother surgery means patients spend less time under anesthesia or less chair time and often have easier recoveries. The precision of the surgical guides also reduces the likelihood of unexpected intraoperative events (such as the need to adjust implant position or increase the length of an incision), which in turn lowers patient anxiety and discomfort[7]. Patients often experience less pain and swelling postoperatively when a surgical guide is used because tissue handling is more precise and flapless techniques can be employed[7]. These factors contribute to higher patient satisfaction and willingness to undergo implant procedures with guided technology.

When comparing 3D-printed vs milled guides from the perspective of the patient, there is no notable difference in comfort or satisfaction as long as the surgical guide fits well. Both types of guides serve the same function during surgery and are made of similar rigid biocompatible materials. The fit and stability of the guide in the mouth are critical to patient comfort: a well-fitted surgical guide (either printed or milled) will be only minimally bulky and will stay stable during the procedure. Studies indicate that a properly designed guide does not cause significant discomfort regardless of fabrication method[7]. If anything, differences might arise from surface texture or finish (a milled guide may have a very smooth internal surface, whereas a 3D-printed guide has a layered texture) but in practice surgical guides are usually polished/finished and any minor texture differences are not perceivable by the patient. Both types can be adjusted or relieved if pressure points exist, ensuring comfort.

Manufacturing Workflow

From a practical standpoint, 3D-printing offers greater flexibility and lower barriers to entry. A dentist with a moderate investment can set up a small 3D printing lab and fabricate guides on demand, integrating with digital scans from an intraoral scanner and planning software[3]. The workflow is highly digital and can be streamlined: for example, after virtual planning, the guide STL can be printed overnight and ready the next morning for surgery. This decentralization means even clinics without access to large milling machines can adopt guided surgery. Milling workflows are often tied to specific systems (for example, certain implant companies or software provide a closed-loop from planning to milling). In-office milling of surgical guides is less common than printing because the equipment is costly and often the size/geometry of surgical guides pushes the limits of chairside mills. Some integrated systems (such as CEREC Guide in early iterations) milled guides with a limited approach (for example, one hole at a time in a standardized acrylic block), but many of these have since shifted to 3D-printing for more complex or full-arch guides.

Another consideration is material and design limitations. Milled surgical guides are constrained by the size of the milling blank and the tool diameter – they might have slightly thicker features or require support bars during milling to prevent movement. Intricate design features like long protruding sleeves or extremely thin windows might be challenging to mill. 3D printing, conversely, can fabricate very complex shapes including hollow lattice structures or delicate features, as long as they are supported during the print process. This means printing can accommodate innovative guide designs (such as stackable surgical guides, or surgical guides with integrated soft tissue supports) with relative ease, whereas milling might not. On the other hand, the solid block material used for milling can be very sturdy and not prone to micro-porosity, whereas printed guides need adequate post-curing to achieve full strength and can be sensitive to resin curing protocols.

DISCUSSION

The comparison of 3D-printed versus milled implant surgical guides reveals that both methods are highly effective, with each having particular strengths. Accuracy outcomes from the literature indicate that while some differences can be measured in vitro, these differences are generally small and unlikely to be clinically significant. Milled guides have been reported in isolated studies to exhibit slightly superior accuracy on certain metrics (such as marginal fit and sleeve positioning)[6], but multiple other studies and reviews find no meaningful discrepancy[7,8]. In practice, both techniques reliably translate digital implant plans to the surgical field with sub-millimeter precision. Instead, the experience of the operator, the guide support type (teeth vs mucosa), and the quality of the planning process may have a larger impact on accuracy and success than the fabrication method itself[7]. Clinicians should ensure proper case selection (for example, using anchor pins or extra stabilization for fully edentulous cases) and adhere to best practices in guide design regardless of whether printing or milling is used.

When considering cost and practical implementation, 3D-printing emerges as a more feasible option for many dental practices. Its cost advantages[3] and flexibility have likely contributed to the democratization of guided implant surgery. The results of this review support that, since the clinical outcomes and accuracy are comparable between 3D-printed and milled surgical guides, the method that can deliver those results more economically and conveniently (often 3D-printing) will be the preferred choice in most scenarios.

However, milling has unique advantages that deserve consideration. The slightly better consistency (less variance) in accuracy of the milled surgical guides[5] could be beneficial in extremely precision-sensitive cases, though it remains unclear if this theoretical benefit reveals noticeable clinical differences. Additionally, milling avoids the layering process of printing, so issues like anisotropic shrinkage or layer delamination do not occur. In situations where absolute rigidity and accuracy are extremely important (for example, certain guided protocols for full-arch with immediate loading) some practitioners might trust the material properties of a milled surgical guide (solid block, potentially fewer microstructural flaws) over a printed one. That said, modern 3D-printed resins (especially when printed with high-quality machines and properly cured) have proven very robust and accurate, as evidenced by thousands of successful guided surgeries worldwide[3].

Another aspect discussed is the manufacturing workflow and turnaround time. In an urgent or same-day implant placement scenario, an in-office milled guide might actually be faster if the equipment is on hand; for instance, milling a small guide could be done in under an hour, whereas even a fast 3D print might take a couple of hours plus post-processing. Yet, not many clinics have the milling capability for guides, whereas an increasing number have a 3D printer. For routine cases, printing a surgical guide a day or two in advance of surgery is straightforward and fits well into digital workflows that already include intraoral scanning and virtual planning. The ease of design iteration with printing (simply edit the STL and reprint) is also an advantage when adjustments are needed. Milling, in contrast, might require starting over with a new block if a design change is made, which is less material-efficient.

The literature on patient-centered outcomes specifically comparing these methods is uncommon; likely because patients cannot tell the difference during use. Our review infers that since both 3D-printed and milled surgical guides enable a guided approach, patient outcomes (pain, satisfaction) depend on guided vs non-guided technique rather than on the guide's fabrication method. Both methods have been successfully used in clinical practice with high patient acceptance.

One must also consider possible biases and limitations in the reviewed studies. Many accuracy studies are in vitro, using model simulations to measure deviations. These provide valuable insight but may not capture clinical handling differences. For example, a 3D-printed surgical guide might deform slightly if not thick enough, or a milled guide might require slightly different insertion technique; such nuances are hard to quantify on benchtop measurements but could affect clinical use. The systematic review by Lo Russo et al. (2023) highlighted significant heterogeneity in how accuracy is measured across studies (different definitions of "accuracy" like entry point deviation, apex deviation, angle error, etc., and varying reference points)[6]. This heterogeneity complicates direct comparisons and might explain why results seem conflicting. Standardized evaluation methods and more direct head-to-head clinical trials would be useful to further clarify if any clinically relevant differences exist between 3D-printed and milled surgical guides.

Future research could focus on the longevity and robustness of surgical guides from each method. For example, "how do printed vs milled guides hold up to sterilization and storage?". Preliminary data suggest that common printable dental resins, like autoclavable surgical guide resins, remain dimensionally stable through sterilization[3], and milled acrylic likewise is stable. But extreme temperatures or multiple sterilization cycles could potentially affect some printed resin guides, whereas milled PMMA might be more inert. These factors are minor for single-use guides (most surgical guides are discarded after the one-time surgery), but if a surgical guide needed to be reused or if surgeries are delayed, it could be worth examining.

Our discussion reinforces that the primary benefit is in using guided surgery whenever possible, rather than in the specific fabrication technique of the guide. Both 3D-printed and milled guides are mature technologies that enable accurate, safe implant placement. The differences lie in practical aspects: cost, convenience, and workflow. For most clinicians and patients, 3D-printing offers a convenient, low-cost solution without compromising accuracy or outcomes, which explains its growing popularity. Milled surgical guides remain a gold-standard option in certain contexts, backed by evidence of excellent accuracy and consistency, but their higher cost and logistical requirements limit widespread use.

CONCLUSIONS

3D-printed and milled surgical guides are both highly effective tools for improving the precision of dental implant placement, and the current evidence indicates that they result in comparable clinical outcomes. Both methods significantly enhance surgical accuracy, reduce the risk of complications, and improve patient experience compared to freehand implant surgery. The choice between 3D-printing and milling for surgical guide fabrication therefore comes down to practical considerations more than differences in efficacy. 3D-printing offers greater cost-efficiency and flexibility, enabling in-office production of surgical guides at a fraction of the cost compared to the milled surgical guides. It allows more clinicians to adopt guided surgery and tailor the workflow to their schedule. Milling, while more expensive, can provide highly consistent accuracy and utilizes a robust workflow that avoids some data conversion steps, making it a reliable option for those with access to the necessary equipment or for laboratories serving many clients.

From an accuracy standpoint, no clinically significant difference has been firmly established between the two fabrication methods. Both can deliver implant placements within acceptable deviation ranges when used properly. Therefore, clinicians can be confident in the guidance provided by either type of guide – the crucial factor is meticulous digital planning and proper surgical execution. In terms of patient outcomes, both 3D-printed and milled surgical guides contribute to high implant success rates and patient satisfaction through the shared mechanism of improved surgical precision.

In summary, 3D-printed vs milled guides represent two paths to the same goal: safer, more predictable implant surgery. Each has its advantages, with 3D-printing being the more cost-effective and accessible approach for most, and milling offering exceptional accuracy and a proven track record in specialized settings.

As digital dentistry continues to advance, we anticipate that both techniques will further improve, perhaps integrating features of each other (for example, hybrid workflows or new materials). For now, the evidence supports that either method can be employed without compromise to quality, allowing practitioners to choose the option that best fits their practice model and resources. The ultimate beneficiary is the patient, who receives the implant with minimal risk and maximal precision, regardless of how the guide was made.

CONFLICT OF INTEREST: I undersign, certificate that I do not have any financial or personal relationships that might bias the content of this work.

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