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Review

Contribution of 3D printing for the surgical management of jaws cysts and benign tumors: A systematic review of the literature

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ABSTRACT

Background: Three-dimensional (3D) printing is now a widely recognized surgical tool in oral and maxillofacial surgery. However, little is known about its benefits for the surgical management of benign maxillary and mandibular tumors and cysts.
Purpose: The objective of this systematic review was to assess the contribution of 3D printing in the management of benign jaw lesions.
Methods: A systematic review, registered in PROSPERO, was conducted using PubMed and Scopus databases, up to December 2022, by following PRISMA guidelines. Studies reporting 3D printing applications for the surgical management of benign jaw lesions were considered.
Results: This review included thirteen studies involving 74 patients. The principal use of 3D printing was to produce anatomical models, intraoperative surgical guides, or both, allowing for the successful removal of maxillary and mandibular lesions. The greatest reported benefits of printed models were the visualization of the lesion and its anatomical relationships to anticipate intraoperative risks. Surgical guides were designed as drilling locating guides or osteotomy cutting guides and contributed to decreasing operating time and improving the accuracy of the surgery.
Conclusion: Using 3D printing technologies to manage benign jaw lesions results in less invasive procedures by facilitating precise osteotomies, reducing operating times, and complications. More studies with higher levels of evidence are needed to confirm our results.

1. Introduction

Three-dimensional printing, also known as additive manufacturing, is a process by which an object is produced layer by layer based on a digital fabrication workflow. In the medical field, this enables the creation of customized and personalized medical devices, patient-specific anatomical models, and surgical simulation models to aid in surgeries [1,2]. The advances in 3D printing technology over the last two decades, partly due to the improvements in 3D imaging and the ever-increasing data processing capabilities of computers, have profoundly impacted surgical practices. The widespread availability of computer-aided design (CAD) software and the decreasing hardware cost have facilitated the integration of 3D printing into various medical specialties such as maxillofacial surgery, orthopedic surgery, cardiovascular surgery, the management of renal diseases, neurosurgery, plastic and reconstructive surgery [2–6].

In oral and maxillofacial surgery, the four main applications of this technology are for dental implant surgery, orthognathic surgery, mandibular reconstruction, mainly using free fibula transfers, and midface reconstruction [7,8]. In these indications, 3D printing facilitates preoperative planning, simulation, and the pre-bending of osteosynthesis plates through the creation of anatomical models, surgical guides for osteotomy lines and screw placement, personalized implants, and drilling orientation for correct implant placement [6,9].

The literature on the topic has shown that 3D printing reduces surgical time, increases safety and accuracy, and improves esthetic outcomes [7,9]. Despite the extensive body of literature supporting the use of 3D printing in oral and maxillofacial surgery for the treatment of malignant tumors, few studies have investigated its contribution to the management of benign jaw bone lesions.

The primary objective of this study was to conduct a systematic review of the literature to evaluate the clinical impact of 3D printing in the surgical management of benign bone lesions of the jaws. The

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secondary objective was to review the various techniques and printing materials used in this indication.

2. Materials and method

2.1. Study protocol

To address the research purpose, the investigators designed and conducted a systematic review of the literature. The protocol for this review was registered in PROSPERO (CRD42022309080) and followed the PRISMA guidelines [10].

A research question was formulated using the PICO method: "What are the benefits of 3D printing for the surgical management of benign maxillary and mandibular bone lesions in oral surgery?"

P (Patient): Patients with a benign maxillary or mandibular bone tumor.

I (Intervention): Surgical management

C (Comparison): Procedures without a surgical guide

O (Outcomes): The benefits of 3D printing

2.2. Search strategy

An electronic search of the literature was conducted using the PubMed and Scopus databases. The investigators searched the databases until December 27, 2022, using the following equation: (("guided surgery") OR ("digital design") OR ("virtual surgical planning") OR ("computer-assisted planning") OR (CAD/CAM) OR ("3D printed model") OR ("three-dimensional printing") OR ("Additive manufacturing") OR ("rapid prototyping")) AND (("jaw cyst") OR ("odontogenic tumor") OR ("benign jaw tumor") OR ("mandibular cyst") OR ("mandibular tumor")) NOT ((scapular) OR (fibula) OR (malignant))

Additional relevant research articles were added after conducting a manual search.

2.3. Study selection

Studies were included if they analyzed the contribution of 3D printing in the management of benign maxillary or mandibular bone lesions, if they were conducted on human subjects, and if they were published in English. Prospective randomized studies, retrospective studies, case series and case reports were included in this research.

Studies involving the excision of malignant jaw bone lesions or articles in which the use of 3D printing focused solely on jaw reconstruction and with an extra-oral approach were excluded. Studies using anatomical models without surgical purpose were also excluded.

2.4. Screening of studies and data collection

The selection of articles, according to the inclusion and exclusion criteria defined above, was carried out independently by the three reviewers (MF, OT, and SG) for the title, abstract, and full-text screening stages. The initial search yielded a first list (list 0). A second list was obtained by selection based on titles and their abstracts (list 1). A third list was yielded after reading the full-text articles (list 2). In addition, the electronic search was complemented by a manual search (list 3).

For eligible articles, the following data were recorded: the publication date, author's nationality, study design and number of patients, the type of lesions and their localization, application of 3D printing, the clinical criteria that had been evaluated, and the obtained outcomes. Data pertaining to the printing systems and materials used were also extracted.

When data were missing in the text, the corresponding author was contacted to request them.

2.5. Quality assessment

The Cochrane risk-of-bias tool for randomized trials RoB 2 scale was chosen for RCTs to assess the level of evidence of studies. The quality of retrospective studies was assessed with the Newcastle-Ottawa scale. The quality of included case reports was assessed by JBI (Joanna Briggs Institute) Critical Appraisal Checklist for case reports. A summary of the risk of bias of the included studies was thus performed.

2.6. Data analysis

A narrative synthesis of the data was performed due to the heterogeneity of the study methods and therefore did not allow quantitative analysis of the data.

3. Results

The initial search yielded 78 results on PubMed and 349 results on Scopus. After merging the two searches, the duplicates (n = 27) were eliminated using the Rayyan systematic review tool, thus leaving 400 articles. The first selection, based on the reading of the titles and abstracts, allowed us to retain 24 articles. After reading the full text, nine articles were retained, and four articles were included after a complementary manual search. Therefore, our review was based on the analysis of 13 articles involving 74 patients. The selection process is shown in Fig. 1.

3.1. General information about the included studies

All articles were published between January 2017 and December 2022. Among the 13 selected articles: one study was a randomized clinical trial [11], one was a comparative retrospective study [12], one was a prospective clinical trial (Clinical trial registration number: NCT05253261) [13], two were case-series [14,15], six studies were case reports [16–21], and there were two technical notes [22,23] (Table 1). The risk of bias in the included studies ranged from "low" to "some concerns". A summary of the risk of bias is provided in Fig. 2. The follow-up time of the studies ranged from 3 weeks to 4 years. The age of the patients ranged from 5 to 35 years.

3.2. Clinical indications

Four studies reported a benefit of using 3D printed devices for the removal of benign odontogenic tumors such as cementoblastoma, odontoma, and ameloblastic fibro-odontoma [14,16,19,22] (Table 2). Four articles discussed the application of 3D printing technologies for the removal of deeply impacted mesiodens or supernumerary teeth [11,12,15,23], and three articles focused on jaw cysts enucleation. One study evaluated the use of 3D-printed guides for bone remodeling of facial deformities caused by multifocal brown tumors in a patient with hyperparathyroidism [18]. Finally, one study investigated the feasibility of a 3D printed personalized appliance to decompress odontogenic cysts [13] (Table 2). Surgical management of jaw lesions was performed under local anesthesia in two studies [12,17] and under general anesthesia in seven studies [11,13–15,19,21,22]. Three studies did not report the type of anesthesia [18,20,23].

3.3. Benefit and application of 3D printing: fields of application

3D printing was primarily used to produce anatomical models in 6 studies [14,16,18–21], intraoperative surgical guides in 9 studies [11,12,14,15,17,18,20,22,23] and a postoperative decompression appliance in one study [13] (Table 1).

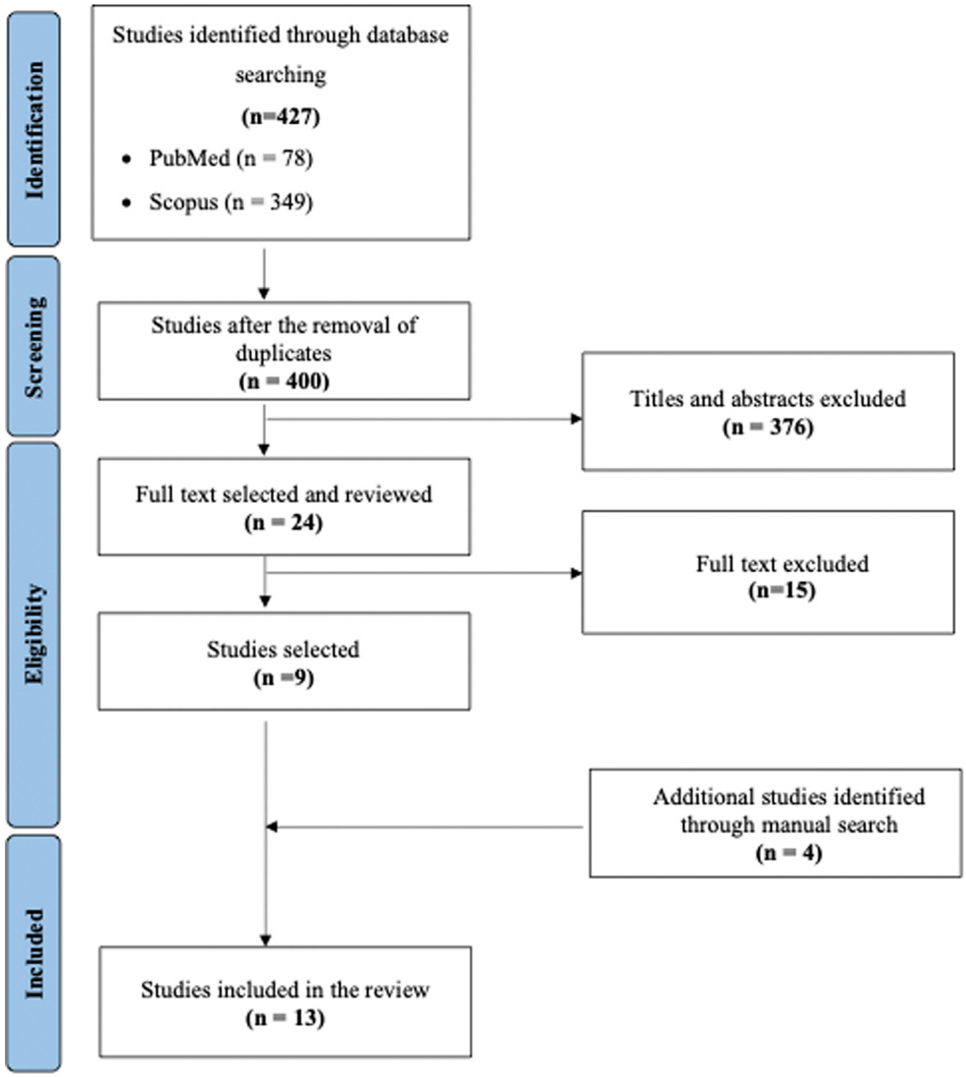

Fig. 1. PRISMA flowchart of the included studies.

3.3.1. Preoperative simulation and planning

Six studies highlighted the benefit of 3D printing to produce anatomical models before surgery [14,16,18–21]. They showed that 3D printed models improved overall understanding and recognition of anatomical structures in space. The purpose was to better visualize the anatomical relationships of the lesion with the inferior alveolar nerve [16,18,19], with the nasal cavity and maxillary sinus [21], with dental roots [18], and to anticipate the risk of bone fracture [16]. Anatomical models could also be used to pre-bend a plate for reconstruction after resection of the lesion [14].

The most cited advantage of 3D printing in the included studies was the ability to plan the surgical procedure [16,18–23]. Several surgeons reported that the printed model allowed for better visualization of anatomical relationships, facilitating preoperative planning and therapeutic decision by anticipating potential difficulties and anatomic variations [16,18,19]. One study highlighted the benefit of using a hybrid 3D-printing model consisting of the jaw bone, the tumor, and the inferior alveolar nerve for surgical training [19]. Finally, the combination of a printed anatomical model coupled with the use of virtual reality during the procedure was demonstrated in one study [21].

3.3.2. Contribution during surgery

Different types of intraoperative guides were designed to reduce the risk of injury to the adjacent anatomical structures during removal of the lesion and, thus, resulted in a more accurate and safer operative procedure. The main types were drilling locating guides, and osteotomy cutting guides. Most of the included studies designed a tooth-supported guide [11,12,15,17,20,23], whereas few authors used bone-supported guides [14,18]. Among them, Omara et al. placed the osteotomy location guide on the exposed bone and fixed it in position with two screws [14].

Two studies used a drilling locating guide fabricated according to the lesion's position, orientation, and depth [15,18]. This guide enabled the precise localization of the lesion with an initial ostectomy using a pilot drill through the locating guide. Then, the guide was removed to perform a larger ostectomy necessary for lesion removal. One study mentioned the use of a printed drilling locating guide with multiple holes to perform an osteoplasty on a patient with multifocal brown tumors. The surgical guide was designed with several holes to individually mark the desired depths and positions for the selective removal of bone [18].

Seven studies used an intraoperative surgical guide for osteotomy tracing [11,12,14,17,20,22,23]. This resulted in a more accurate osteotomy and a less invasive approach. Furthermore, three studies used the cutting guide in association with piezosurgery or a reciprocating saw to reposition the bone after lesion removal [12,14,17].

Three studies investigated the accuracy of the osteotomy using an intraoperative surgical guide by noting whether an additional

Table 1
Characteristics of the included studies. RCT: Randomized control trial; NC: Not communicated.

Author, Year, Country	Study type	Patients (number, sex, age in years)	Application	Variable evaluated	Outcomes
Liu et al., 2022 [11], China	RCT	- *N* = 40 Group I (*N* = 20): Surgical guide Group II (*N* = 20): No surgical guide - Sex: 42,5% female - 5–25 years (mean age: 9.5)	- Intraoperative osteotomy guide	- Operative time - Additional osteotomy -Postoperative pain and swelling - Patient satisfaction	- Significative decrease of operating time in Group I - Three time less additional osteotomy in Group I (*N* = 5/20) compared to Group II (*N* = 15/20) - Significant reduction of pain and swelling in Group I - Patient satisfaction significantly higher in group I
Hu et al., 2017 [12], China	Retrospective comparative study	- *N* = 8 Group I (*N* = 4): Surgical guide Group II (*N* = 4): No surgical guide - Sex: 75% female - 14–28 years (mean age: 19.13)	- Intraoperative osteotomy guide	- Success rate - Operative time - Additional osteotomy - Complications	- Successful treatment in both groups - Significative decrease of operating time in Group 1 - No additional osteotomy required in Group 1 (*N* = 0/4) versus one in Group 2 (*N* = 1/4) - No complications in both groups
Omara et al., 2022 [14], Egypt	Case series	- *N* = 10 - Sex-ratio 1:1 - 24–35 years (mean age: 27.0 ± 3.7)	- Anatomical model for pre-bent plate - Intraoperative osteotomy guide	- Success - Operative time -Postoperative pain, edema and trismus - Complications - Radiographic bone healing	- The use of a patient-specific surgical guide and pre-bent plate facilitated the safe buccal cortex separation - Operative time: 39.5 ± 13.01 min - Significant pain decrease over time - Acceptable edema and trismus - Nerve affection (*N* = 1/10) - Complete bone healing and integrity of the osteotomized buccal cortex
Kivovics et al., 2022 [13], Hungary & Israel	Clinical trial	- *N* = 6 - Sex: 5 Males, 1 Female - 15–49 years (mean age: 49)	- Decompression appliance	- Effectiveness of decompression - Complications	- Percentage of volume reduction was 58.84 ± 13.22% following a 6-month-long decompression period - No complications
Jo et al., 2017 [15], South Korea	Case series	- *N* = 2 Case 1: Homemade surgical guide Case 2: 3D-printed surgical guide - Sex-ratio 1:1 - 9 and 12 years	- Intraoperative drilling locating guide	- Sucess - Complications	- Successful treatment in both cases - No complications in both cases
Van Hoe et al., 2020, [16], Belgium & Sweden	Case report	- Male - 19 years	- Anatomical model	- Pre-operative visualization	- Assessment of 2 major intraoperative risks: damage to the inferior alveolar nerve and unexpected intraoperative fracture due to extreme thinning of the vestibular and lingual walls
Lee et al., 2021 [22], South Korea	Technical note	- Male - 5 years	- Intraoperative guide hole osteotomy	- Use and advantages - Complications	- Successful treatment without damaging the adjacent teeth - No complications
Peditto et al., 2020 [17], Itlay	Case report	- Female - 32 years	- Intraoperative osteotomy guide	- Preoperative visualization	- Identification of anatomical structures at

(*continued*)

Table 1 (*Continued*)

Author, Year, Country	Study type	Patients (number, sex, age in years)	Application	Variable evaluated	Outcomes
				- Precision of the osteotomy	risk - Control of the oesteotomy planes
Liu et al., 2019 [23], China	Technical note	- Female - 14 years	- Intraoperative osteotomy guide	- Success	- Successful removal
Wilt et al., 2019 [18], United States	Case report	- Female - 28 years	- Anatomical model - Intraoperative drilling locating guide	- Preoperative visualization - Use and advantages - Complications	- Better understanding and visualization of anatomical relationships - The guides were placed in position without difficulty and a snug fit and allowed the selective removal of bone - No tooth pain and no paresthesia
Yusa et al., 2017 [19], Japan	Case report	- Male - 7 years	- Anatomical model	- Preoperative visualization - Surgical training - Therapeutic decision	- Better visualization of complex spatial relationship between the tumor and surrounding tissue - Successful surgical training - Therapeutic decision was performed based on the analysis of the 3D-printing model and surgical training.
Cohen et al., 2017 [20], United States	Case report	- Male - 35 years	- Anatomical model - Intraoperative osteotomy guide	- Preoperative visualization - Precision of the osteotomy - Complication	- Better visualization of the lesions and their anatomical relationships - Precise location of the lesion but additional osteotomy was necessary - Minimal inferior alveolar nerve hypoesthesia
Sugahara et al., 2020 [21], Japan	Case report	- Female - 27 years	- Anatomical model	- Preoperative visualization	- Better visualization of the lesion and the anatomical relationships

osteotomy was required during the procedure. Liu et al. observed that in the absence of a surgical guide, three times more patients required an additional osteotomy for insufficient lesion exposure compared to the group with a guide [11]. Similarly, Hu et al. noted that an additional osteotomy was only required in the freehand group because of insufficient exposure [12], whereas Cohen et al. completed the buccal osteotomy after guide removal to create a broader access window to the lesion [20].

Two studies assessed the impact of surgical guides on operative time. Liu et al. reported a significant reduction in operative time with the use of intraoperative guides compared to the freehand surgery group (23.35±5.39 min and 29.60±9.76 min respectively, p = 0.0194) [11]. Hu et al. also observed a significant reduction in operative time using intraoperative guides compared to the freehand surgery group (11.50±1.29 min and 15.75±1.71 min, respectively, p = 0.021) [12].

Two studies suggested the benefit of making additional components to the osteotomy cutting guides. One study designed a surgical guide composed of an incision guide connected to the osteotomy guide [11]. The incision guide plate was designed as an arch shape to guarantee the flap's blood supply and ensure space for osteotomy locating guide placement. Another study proposed two additional components for osteotomy guide [22]. First, an extension arm in order to retract the cheek and the flaps to enhance the exposure of the surgical field. Secondly, a bite block to precisely fit on the mandibular teeth, therefore maintaining adequate mouth opening and guide stabilization by interposing silicon-based material between the guide and the maxillary teeth.

Finally, one study suggested using a personalized removable 3D-printed appliance to decompress odontogenic cysts [13]. The removable devices contained a tube for facilitated access and could be designed to replace a missing tooth as well.

3.3.3. *Contribution in the postoperative period*

Eight studies looked at the contribution of 3D printing in the postoperative period and noted an overall reduction in postoperative complications. Two studies evaluated specific parameters such as postoperative edema and pain objectified by a visual analog scale (VAS). Liu et al. observed a significant reduction in swelling and pain on the 1st, 3rd, and 7th day post-op using a guide compared to the conventional group [11]. Omara et al. reported a reduction in postoperative pain, edema, and trismus but did not include a control group in their study, making it difficult to interpret the value of the results [14]. Complications were assessed in few studies and were rarely reported [12,14,15,18,20,22] (Table 1). Complications, such as injury of the root of permanent teeth, nerve damage, or supernumerary teeth entering the nasal cavity, were assessed by Hu et al. [12]. Both

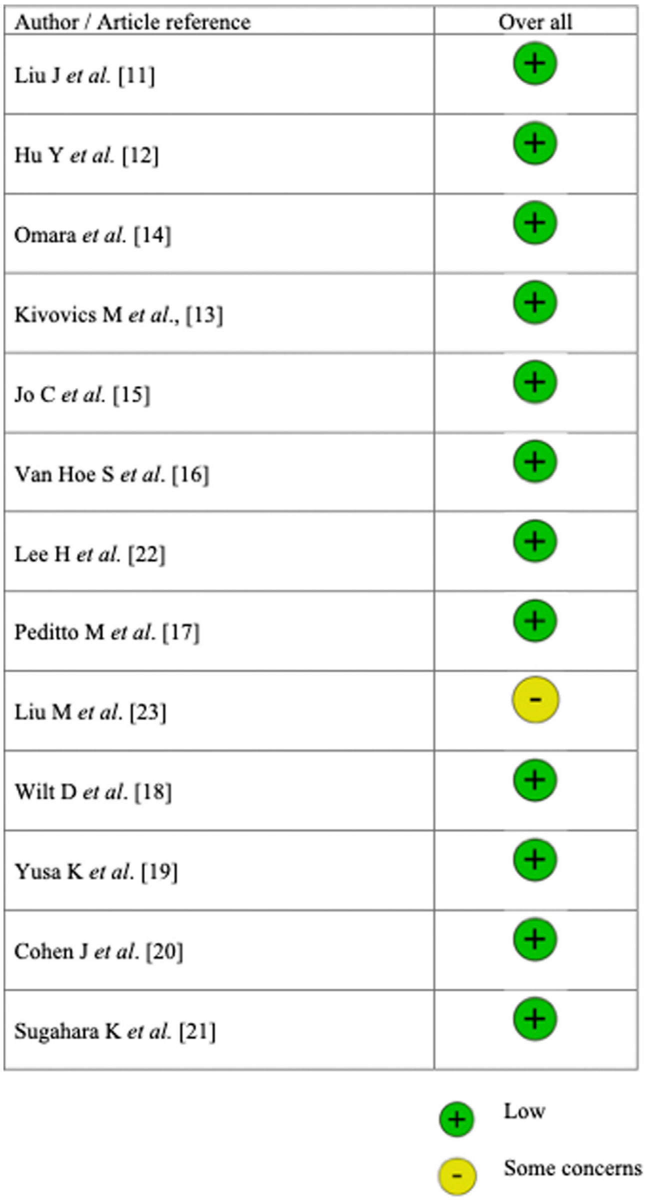

Fig. 2. Summary of the risk of bias assessment of included studies.

conventional and guided approaches for the removal of deeply impacted mesiodens were not accompanied by complications. One study investigated complications such as nerve injury or osteosynthesis plate exposure [14]. Among the ten patients included, they only reported one case of nerve injury. Total nerve recovery was seen four weeks postoperatively. Cohen et al. observed minimal inferior alveolar nerve hypoesthesia following keratocyst removal using a 3D-printed guide [20].

Finally, one study investigated patient satisfaction using a satisfaction survey score out of 10. Patient satisfaction was significantly higher in the surgical guide group than the freehand group ($p = 0.0152$) [11].

3.3.4. *Adverse events*

Three studies reported the occurrence of adverse events related to 3D printed devices. Liu et al. reported one case of fracture of the guide during surgery among the 20 printed guides used in this study. They also noted that three patients had errors in image acquisition during presurgical procedures, which led to inadequate exposure of the deeply impacted supernumerary teeth [11].

Table 2
Type of lesions and their localization of the included studies.

Author, Year	Type of lesion (*n*= number of lesions)	Localization
Liu et al., 2022 [11]	Supernumerary teeth ($n = 40$)	Anterior maxilla
Hu et al., 2017 [12]	Mesiodens ($n = 8$)	Anterior maxilla
Omara et al., 2022 [14]	Complex odontomas ($n = 6$), Cementoblastomas ($n = 4$),	Mandible
Kivovics et al. 2022 [13]	Odontogenic cysts ($n = 6$)	Maxilla and mandible
Jo et al., 2017 [15]	Mesiodens ($n = 2$)	Anterior maxilla
Van Hoe et al., 2020, [16]	Cementoblastoma ($n = 1$)	Mandible
Lee et al., 2021 [22]	Compound Odontoma ($n = 1$)	Mandible
Peditto et al., 2020 [17]	Odontogenic cysts ($n = 1$)	Mandible
Liu et al., 2019[23]	Supernumerary teeth ($n = 4$)	Maxilla and mandible
Wilt et al., 2019 [18]	Multifocal brown tumor ($n = 1$)	Maxilla and mandible
Yusa et al., 2017 [19]	Ameloblastic fibro- odontoma ($n = 1$)	Mandible
Cohen et al., 2017 [20]	Keratocysts ($n = 2$)	Mandible
Sugahara et al., 2020 [21]	Calcifying odontogenic cyst ($n = 1$)	Maxilla

Kivovics et al. reported biomechanical complications of the decompression devices in two of the six reported cases [13]. In one case, the clasps of the removable personalized appliance fractured one month after the surgery. In another case, the appliance tube broke off the denture baseplate three months after the surgery, requiring rapid prototyping of a new appliance from the original plan. No adverse events were noted by Peditto et al. in their case report study [17].

3.4. *Printing modalities*

Image processing software, printing materials, and techniques are summarized in Table 3. This systematic review highlighted that several studies did not clearly report the additive manufacturing method and materials used. In regards to the different printing techniques, three studies used stereolithography (SLA), one for the fabrication of a model and the others for a surgical guide, three studies used polyjet technology for the realization of anatomical models, two used the Digital Light Processing technique (DLP) for the fabrication of a guide, and one study used the Color jet printing technique for the fabrication of a model. For the DLP and SLA techniques, resins were used. For the polyjet technique, a transparent biocompatible photopolymer material MED 610 from Stratasys was used. For the Color jet printing technique, two types of materials were used to print the 3D model. The mandibular bone was made with zp151 powder and the tumor with RTV silicone gum to obtain different textures and colors.

Few studies provided details for printing time and associated cost. The printing of a 3D anatomical model varied from 30 min for the DLP technique to 4–5 h for the color jet printing technique, depending on the complexity of the model to be printed and the technology used.

According to the authors, the cost of printing ranged from 3 USD [22] to 30 [21] or 150 USD [23], depending on the technology used. The highest cost corresponds to the color jet printing technique, which allowed an anatomical model to be printed with different textures and colors for training purposes on a model and preoperative visualization.

4. Discussion

This systematic review aimed to assess the contribution of 3D printing in the surgical management of benign jaw bone lesions.

The outcomes highlighted two major applications of 3D printing for managing benign jaw lesions in the preoperative (anatomic

Table 3
3D printing modalities of the included studies. CBCT: Cone Beam CT; CT: Computerized tomography; DLP: Digital Light Processing; FDM: Fused Deposition Modelling; NC: Not communicated; SLA: Stereolithography.

Author, Year	Image acquisition technique	Image processing software	3D printer	3D printing technique	Material
Liu J et al., 2022 [11]	CBCT	Mimics (materialize, Leuven, Belgium)	NC	NC	NC
Hu Y et al., 2017 [12]	CBCT/ CT	Mimics (materialize, Leuven, Belgium)	NC	NC	NC
Omara et al., 2022 [14]	CBCT	Mimics (materialize, Leuven, Belgium)	FORMIGA P110 (EOS e-manufacturing solutions, Munich, Germany)	FDM	Polyamide2200 (EOS e-manufacturing solutions, Munich, Germany)
Kivovics M et al., 2022 [13]	CBCT	NC	RapidShape S30 (RapidShape Gmbh, Heimsheim, Germany)	DLP	SHERAprint-ortho (SHERA Werkstoff-Technologie GmbH, Lemforde, Germany)
Jo C et al., 2017 [15]	CBCT	Implant studio (3Shape, Copenhagen, Denmark)	ProJet 3510 HDMax (3D Systems, Rock Hill, SC)	Material jetting	NC
Van Hoe S et al.,2020 [16]	CBCT	Proplan (materialize, Leuven, Belgium)	Objet 350 Connex (Stratasys, Eden Prairie, MN)	Polyjet	NC
Lee H et al., 2021 [22]	CBCT	Blue Sky Plan (Blue Sky Bio LLC, Grayslake, IL, USA).	Nextdent 5100 (3D Systems, Rock Hill, SC, USA)	DLP	NextDent SG (3D Systems, Rock Hill, SC, USA)
Peditto M et al., 2020 [17]	CT	Mimics (materialize, Leuven, Belgium)	Form 2 (Formlabs Inc., Somerville, Massachusetts, USA)	SLA	Resin
Liu M et al., 2019 [23]	CT	JOYE3D (Hubei Huaqiang High-tech Co. Ltd, Yichang, China)	NC	NC	NC
Wilt D et al., 2019 [18]	CT	3D systems virtual surgical planning (Littleton, CO)	NC	SLA	NC
Yusa K et al., 2017 [19]	CT	Zed View (LEXI, Co. Ltd., Tokyo, Japan)	Zprinter 450 (Z Corporation, Waltham, Ma, USA)	Binder jetting (Color jet printing)	Bone: Powder zp151 (3D systems, Rock Hill, SC, USA) Tumor: RTV silicone gum (Shin-Etsu Chemical Co., Ltd., Japan)
Cohen J et al., 2017 [20]	CT	NC	NC	SLA	NC
Sugahara K et al., 2020 [21]	CT	Mimics (materialize, Leuven, Belgium)	Objet 260 Connex (Stratasys, Eden Prairie, MN)	Polyjet	Transparent, biocompatible material MED 610 Stratasys

model) and intraoperative (surgical guide) phases. Louvrier et al. observed similar results when investigating the different applications of 3D printing in maxillofacial surgery: 59% of the authors used 3D printing to produce surgical guides and 34% to create anatomical models [7]. The trend that emerges from our results on the contribution of 3D printing is that the majority of articles emphasize the precision and predictability of the surgery as well as improving the safety of the procedure either by using anatomical models to simulate the excision or by using an intraoperative guide or by combining the two.

In our review, 46% of the included studies showed the benefit of anatomical model printing for preoperative simulation of jaw lesion removal. The improved understanding of patient-specific 3D anatomy offered by 3D printing allowed surgeons to anticipate potential intraoperative complications, such as the risk of nerve damage or a bone fracture that may occur during surgery [16]. Thus, it may help reduce the stress level for the operator. Several studies reported the benefit of better visualization of the anatomical relationships between the lesion and the at-risk anatomical structures such as the inferior alveolar nerve [16,18,19], the nasal cavity, maxillary sinus [21], and adjacent dental roots [18]. Another possibility offered by anatomical models is the ability to bend a reconstructive plate prior to surgery, allowing an optimal plate application on the bony fragment for reconstruction [14]. This simple and economical preoperative method for preshaping a reconstructive plate is already applied to mandibular reconstructive surgery with fibula free flaps [24,25]. Anatomical models are also a valuable tool for decision-making related to surgical strategy [19].

The second major application of 3D printing was surgical guides for intraoperative use (69% of the included studies). Two main types of surgical guide were designed: drilling location guides, which allows the surgical site to be precisely located, and osteotomy locating guides or cutting guides, which is used to delineate the osteotomy lines. Despite their benign nature, the excision of jaw cyst or tumoral lesions could require wide surgical access and extensive bone removal [14]. One of the most reported benefits was a more precise localization of the bone lesion and a better precision of the osteotomy tracing, thus leading to a less invasive approach. Another advantage of the cutting guide is that it allows the operator to reposition the bone lid after lesion removal [12,14,17], resulting in a bone-sparing approach [26]. Studies comparing two groups with 3D printing surgical versus freehand group showed a similar success rate for the resection, but additional osteotomies were required because of the insufficient exposure of the benign bone lesion without the surgical guide [11,12]. However, although intraoperative guide-assisted surgeries are more accurate than conventional methods, it should be noted that they can be complicated because errors can occur pre- or intraoperatively. Preoperatively, errors can occur during manual or digital impression taking, CBCT overlay, and 3D image acquisition or processing. Other errors can occur during surgery if the guide is tilted, which can happen if the support is not stable during the excision procedure. It should be noted that most of the guides used in the present review were designed with dental support for optimal positioning accuracy. There are mainly three types of oral surgical guides based on their supporting surfaces: i) tooth-supported surgical guides, where the surgical guide is placed on the remaining teeth, ii) bone-supported surgical guide: the surgical guide is placed on the bone after raising a mucoperiosteal flap and iii) mucosa-supported surgical guides: the surgical guide is positioned on top of the mucosa [27]. The tooth-supported guides show the highest accuracy compared with the two other guides [28].

In addition to a less invasive approach, the precision of the osteotomy tracing allows the preservation of adjacent anatomic structures such as the inferior alveolar nerve or dental roots. Few complications, such as nerve injury or tooth necrosis were observed in the included studies. 3D printed surgical guides are particularly useful when these bone lesions are diagnosed in children: the accuracy of the surgical guide allows the preservation of adjacent temporary teeth as well as the bud of the permanent teeth in proximity to the lesion [22]. Another benefit of 3D printed guides is found for the removal of lesions that are located either on the palatine side or low on the lingual side, making access difficult to remove them. Surgical guides will increase the precision of the surgery, especially for palatal and lingual approaches where visibility is reduced [23]. The surgical guide technique can therefore reduce the difficulty of surgery for hard-to-reach lesions regardless of the surgeon's skill level or experience [14]. This result is consistent with the study of Park et al., which demonstrated that the accuracy of implant position with a surgical guide was not influenced by the surgeon's level of experience [29].

Our study also shows that the use of 3D printing for benign jaw lesion removal is likely to be associated with a reduction in operating times [11,12]. This benefit has also been emphasized in previous studies concerning 3D printing in oral carcinology or implantology indications [9,30,31]. Although significant, the time savings demonstrated in the present review were only a few minutes [11,12]. This is certainly related to the fact that this type of surgery has a relatively short operating time and that they were performed by a senior surgeon. However, this is still an interesting result, especially for young practitioners for whom this time saving could be greater [12,14]. Furthermore, reducing operating time may decrease acute postoperative complications such as pain, severe edema or infection [32,33].

This systematic review reported the benefits of using 3D-printing devices for the removal of various benign jaw lesions: odontogenic tumors, deeply impacted mesiodens or supernumerary teeth and jaw cysts. Recently, the usefulness of surgical guides for biopsy of such mandibular or maxilla lesions has also been highlighted [34,35]. The use of similar drilling guides has also been reported to access impacted tooth [36] or to perform orthodontic-surgical approach for tooth disimpaction to expose the teeth before placement of an auxiliary attachment [17].

One of the included studies mentioned the use of a 3D printed guide with multiple holes for bone remodeling of facial deformities caused by multifocal brown tumors in a patient with hyperparathyroidism [18]. This type of guide could be applied to other conditions such as fibrous dysplasia or to patients requiring bone recontouring. Finally, only one study suggested the benefit of using a personalized removable 3D printed appliance to decompress odontogenic cysts [13]. This appliance should reduce the discomfort caused by conventional devices. Another benefit is the possibility of designing the appliance in order to replace a missing tooth, which might improve patient satisfaction and quality of life. Furthermore, removable appliances facilitate oral hygiene and cystic cavity rinsing.

Our study focused on the surgical management of benign jaw bone lesions in patients. However, it must be underlined that another interesting aspect of 3D printing technologies in oral and maxillofacial surgery is the fabrication of educational models for training. A systematic review established the educational value of 3D printed models for anatomy training for medical students [37]. This review also showed an improvement in the learning curve and student satisfaction with the 3D model compared to traditional teaching methods. This is consistent with another systematic review dedicated to new pedagogical methods, such as 3D-printing technologies, for surgical training in the field of oral and maxillofacial surgery. The reported benefits were a reduction of the learning time and an increase of the enthusiasm of the students compared to more conventional methods [38,39]. Another use of 3D printing for surgical training is the possibility to expose the trainee to a wide variety of pathologies and situations of gradual complexity levels [38,39]. In this purpose, optimal haptic feedback is the most important feature for training models, and this is highly dependent on the mechanical characteristics of the impression material [6,8].

Our study has some limitations that should be mentioned. This review was at first limited by the low prevalence of this type of bone lesion. Most of the data available are from case reports and case series, including only a small number of patients and without comparators, thus reducing the level of evidence of included studies. Another limitation of our study is that the end-points evaluated differed largely among the studies, making it difficult to draw conclusions.

5. Conclusion

This study established two major applications of 3D printing for the management of benign jaw lesions in the preoperative (anatomic model) and intraoperative (surgical guide) phases. The design of 3D anatomical models appears to be an effective tool for preoperative simulation and training for complex surgery. Using a surgical guide is associated with reduced operating times and increased osteotomy accuracy. However, further studies with higher levels of evidence are needed to confirm these initial results.

Declaration of Competing Interest

The authors report no conflicts of interest

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