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Research paper

Selective laser sintering at the Point-of-Care 3D printing laboratory in hospitals for cranio-maxillo-facial surgery: A further step into industrial additive manufacturing made available to clinicians

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A B S T R A C T

Additive manufacturing has developed rapidly in recent years and has many useful applications in the clinical field. In particular, cranio-maxillo-facial (CMF) surgery requires high precision, which can be obtained with 3D printed patient-specific surgical guides and anatomical models. Among the many different printing options, selective laser sintering (SLS) seems to be rarely used in point-of-care applications, considering its apparent characteristics.

This article examines the advantages and disadvantages of SLS printers for CMF point-of-care (PoC) by reviewing the literature and comparing in-house printed SLS and stereolithography (SLA) prints.

The investigation showed that the easily sterilizable and robust materials processed by SLS printing are well suited for CMF surgical guides and have clear advantages over SLA parts.

Some barriers to the use of SLS printers in PoC are likely to be the slightly higher complexity and cost.

However, these will decrease as 3D printing technology advances and surgeon acceptance increases, making SLS a practical PoC tool.

1. Introduction

In recent years, the continuous improvement of the additive manufacturing (AM) industry has led to a substantial modification of the 3D printing landscape: at first, this technology was mostly limited to an industrial setting, owing to the cost of 3D printer prototypes and the strict technical knowledge necessary to prepare, print and process parts using AM. The development of 3D printing among hospitals urged 3D printers manufacturers to engineer such technology into more compact shapes, with an overall simplification of procedures to enable this possibility for healthcare providers. In the medical literature, 3D printing performed within a healthcare institution, with or without dedicated personnel, and outside an industrial setting is commonly referred to as “point-of-care (PoC) 3D printing”. Currently, there are hundreds of PoC 3D printing labs in the world, according to last surveys. In hospitals, 3D printing is generally used for surgical planning and training, as it enables the creation of patient-specific anatomical models, allowing surgeons to visualize and plan complex procedures more accurately. Surgeons are able to translate medical imaging data, such as those from CT or MRI scans, to produce 3D-printed models that replicate patient-specific anatomy, and the same models can also be used as simulators for training before the actual surgery is performed [1].

Cranio-Maxillo-Facial (CMF) Surgery is surely one of the fields in medicine that drew the highest advantage from 3D printing. Given the

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need of precision surgery and the highly complex geometries of the facial region, nowadays an increasing number of surgical procedures relies on surgical guides that can be designed by physicians using medically certified software and printed in an in-hospital (or in-house) 3D laboratory using a variety of commonly available printers on the market[2,3].

Stereolithography (SLA), invented in the 1980s, still stands today as the most widespread 3D printing technology in PoC 3D labs together with Fused Deposition Modeling (FDM), and remains highly favored among healthcare professionals. SLA resin 3D printers employ a laser to solidify liquid resin, a process known as photopolymerization, producing highly accurate parts (up to 25 μm) and a clean geometry without residuals. SLA has however an unfavorable limitation, as it needs to add supports to the model to avoid gravitational collapse during solidification of the fluid resin. Support removal creates artifacts on the model surface and can be highly time consuming, especially in complex geometries. Moreover, the removal of supports in cavities or along very thin structures, for instance paranasal sinuses within the skull, can be almost impossible.

SLA desktop printers are user-friendly ("plug and play"), allowing for swift printing. Minimal training is required for setup, maintenance, and machine operation. Printed parts exhibit a relatively smooth surface finish [4].

Selective laser sintering (SLS) 3D printers, on the other hand, utilize a high-power laser to fuse small polymer powder particles, to form a solid structure. They have the unquestionable advantage of printing without adding supports, allowing for greater design freedom. An advanced user is necessary for build setup, maintenance, and machine operation. The cost of SLS machines is notably higher, and this technology is commonly limited to an exclusive industrial setting.

Recent advances led to technological improvement of 3D printers that, along with the increasing demand in the market for a more widespread use of 3D printing, drove companies to invest in point-of-care SLS machines to spread advanced 3D printing technologies beyond SLA and FDM.

Yet SLS has the potential to significantly improve the quality of anatomical models and surgical devices manufactured using 3D printing, evidence in the literature for the use of SLS in PoC labs is scant. With this paper, the authors perform a review aiming to summarize current trends in SLS PoC 3D printing and discuss the importance of SLS printing in a CMF PoC 3D Lab in the future.

2. Materials and methods

This study has a mixed design, and it consists of a systematic review of the use of SLS in-house 3D printing reported in CMF surgery to define the evidence and role of this technology in healthcare. The second part of this study compared in-house 3D printing performed using SLA and SLS in paired samples consisting of various anatomical procedures performed at our institution.

2.1. Defining the appropriate evidence context for POC SLS in CMF surgery

A search query was defined using a combination of Boolean operators for the main literature databases, including PubMed-Medline and ScienceDirect according to the following model or a combination of its blocks according to the syntax of the search engine:

(SLS or selective laser sintering) AND (3D Printing OR 3DP OR additive manufacturing) AND (in-hospital OR "in hospital" OR "point of care") AND (CMF or cranio-maxillo-facial surgery OR maxillofacial). A broader search was performed in Embase using Emtree by combining two queries as follows: *'selective laser sintering'/exp AND ''maxillofacial surgery'/exp* and *'point of care'/exp*

Literature data were exported from such study repositories as BibTex (.bib) files, to be subsequently imported into a citation manager (EndNote 21, Clarivate Analytics, London, UK) for duplicate removal and full-text retrieval. The search strategy was conducted according to the PRISMA statement for systematic reviews.

Inclusion criteria were as follows: original studies (case reports, case series, cohort studies, clinical trials), English language, studies after 2015 studies performed in CMF, use of an SLS printer inferior to 100.000 $, and mention of the 3D printer model.

Exclusion criteria were: review studies (narrative or systematic review, metanalyses), language other than English, studies performed in fields other than CMF, use of industrial SLS printer, studies before 2015, 3D printed model not mentioned.

2.2. Printing protocols for POC SLA and SLS

For this study, 3 models of CMF procedures performed at the 3D Lab in the Maxillofacial Surgery Clinic of the Academic Hospital of Udine, were 3D printed using both SLA and SLS machines designed for an in-house setting according to well-established study protocols.

Formlabs Form 3BL was used at the 3D lab of the Academic Hospital of Udine and prints were performed by a trained medical professional (A.T), while Formlabs Fuse 1+ was used by a certified engineer (E.M.) at Formlabs HQ in Budapest.

All 3D models met the following conditions: craniofacial tumor including either the skull or the mandible; imaging based on multidetector CT scan performed at the University Hospital of Udine; segmentation using Materialise Mimics 25.0 (Materialise, Leuven, BE) medical version and performed by the same medical professional (A.T.), 3D printing preprocessing in Preform software (Formlabs, Somerville, MA) (Fig. 1 and 2).

Parts produced using Form 3BL were printed using the Biomed White Resin, which is cleared for medical applications), whereas parts manufactured using the Fuse 1+ were printed using Nylon 12 powder.

2.3. Technical differences between for POC SLA and SLS

Both Form 3BL and Fuse1+ are 3D printers designed for a PoC setting and can be easily installed in a hospital 3D lab, each one representing the top level respectively for SLA and SLS.

As for 3D printing, the following are technical specifications for the Form 3BL: Build Volume: 33.5 × 20 × 30 cm, Printer Dimensions: 77 × 52 × 74 cm, Weight: 54.4 kg, Layer Thickness (Axis Resolution): 25 – 300 μm, Internal Temperature: Auto-heats to 35 °C, Operating Environment: 18 – 28 °C.

As for the Fuse 1+, Build volume: 16.5 × 16.5 × 30 cm, Layer thickness (axis resolution): 110 μm, Dimensions of printer: 64.5 × 68.5 × 107 cm (165.5 cm with stand), Recommended Operating Footprint (*W* × *D* × *H*): 145.5 × 149.5 × 167.5 cm to allow access to the front and sides of the printer, Weight: 114 kg (without build chamber or powder), Operating environment: 18 – 28 °C.

This study used Formlabs Form 3BL as reference for the PoC SLA and Formlabs Fuse 1+ for PoC SLS.

Post-processing SLA prints involves a washing station (Form Wash) for the removal of uncured resin from the part, a post-curing station (Form Cure) to optimize mechanical properties (both of which can be automated), and a workbench equipped with finishing tools for part and support removal.

For SLS prints, a post-processing station is available to clean the parts by removing excess powder and recover the material. In some cases, the use of a media blasting cabinet, utilizing compressed air and an abrasive media, is recommended.

3. Results

3.1. Results of systematic review

Using the aforementioned query, the initial search across all

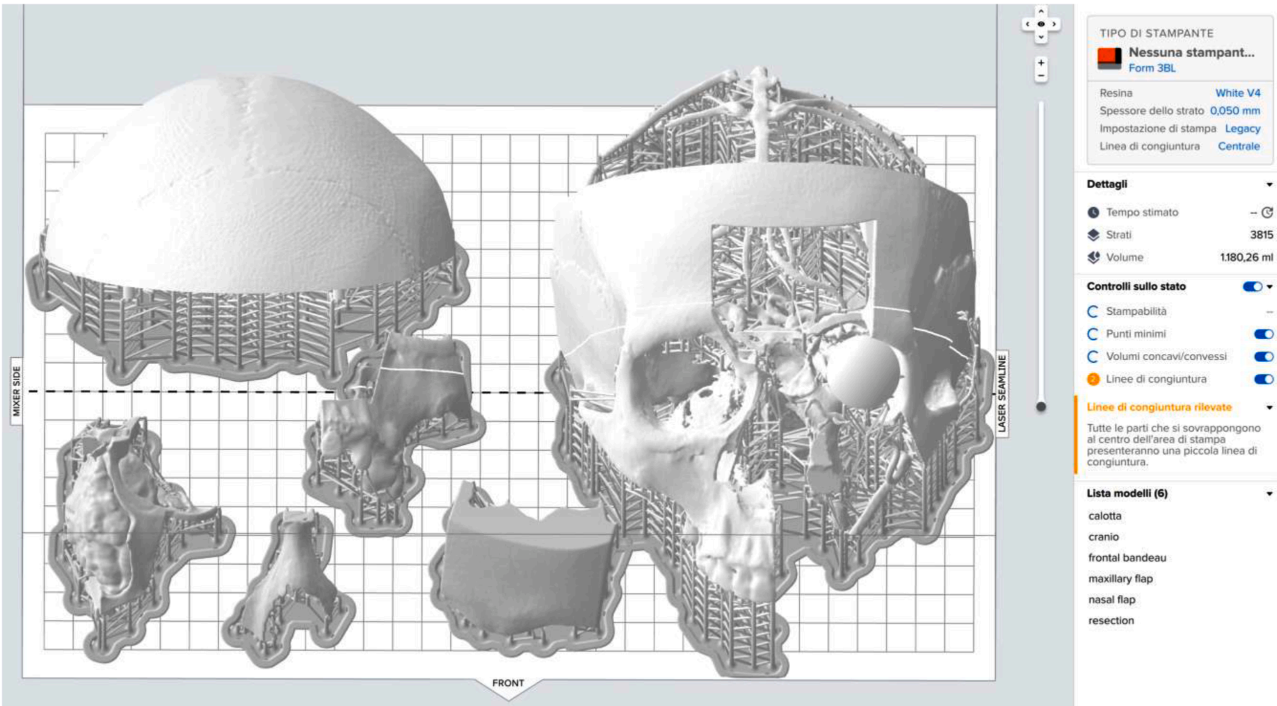

Fig. 1. 3D print preprocessing set according to the SLA printer Form 3BL. Notable is the dense network of support structures that need to be removed after the print is complete, some of which are not accessible, especially within cavities and along thin structures.

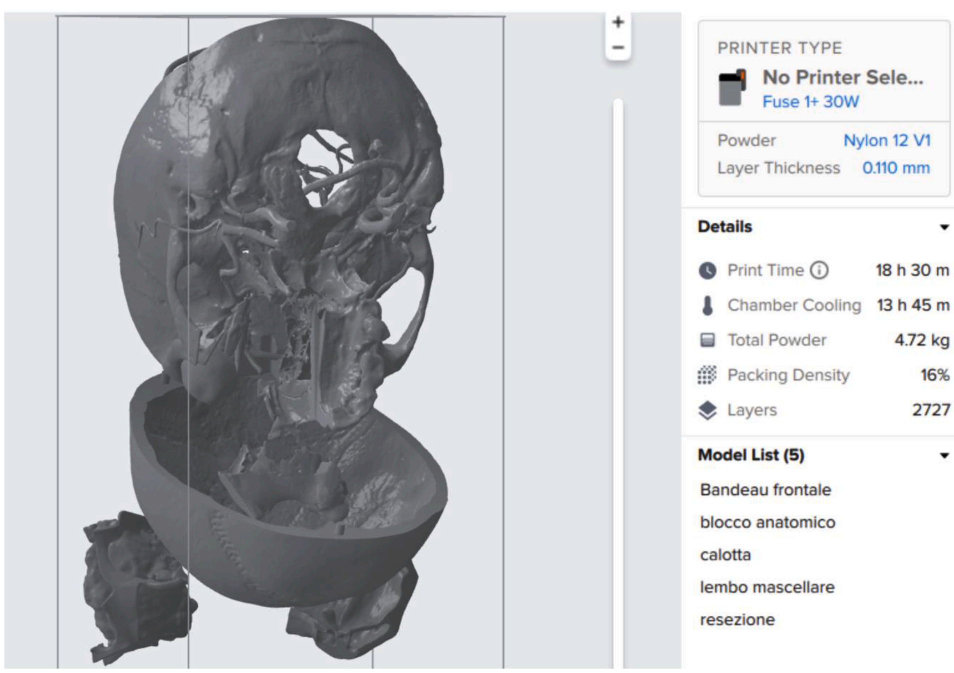

Fig. 2. 3D print preprocessing set according to the SLS printer Fuse 1+. This technology also allows parts to be stacked above each other along the z axis and, most importantly, no support structures are necessary.

databases included 36 papers. 2 duplicates were removed yielding 34 papers. The application of inclusion and exclusion criteria to full-text papers did not retrieve any eligible paper, as in many cases studies belong to areas external to CMF, including biology and mechanical engineering (20), whereas several studies are reviews, both narrative and systematic ($n = 5$). Other papers report the use of industrial SLS printers which fall outside the scope of this paper ($n = 4$). Last, in several cases SLS is presented as 3D printing technology, but there is no mention of the model used ($n = 2$).

Fig. 3 displays the search strategy implemented in this paper using the PRISMA flowchart.

3.2. Differences in performance for POC SLA and SLS

The comparison between SLA and SLS printed models revealed superimposable detail rendering when printed at maximum detail. SLA

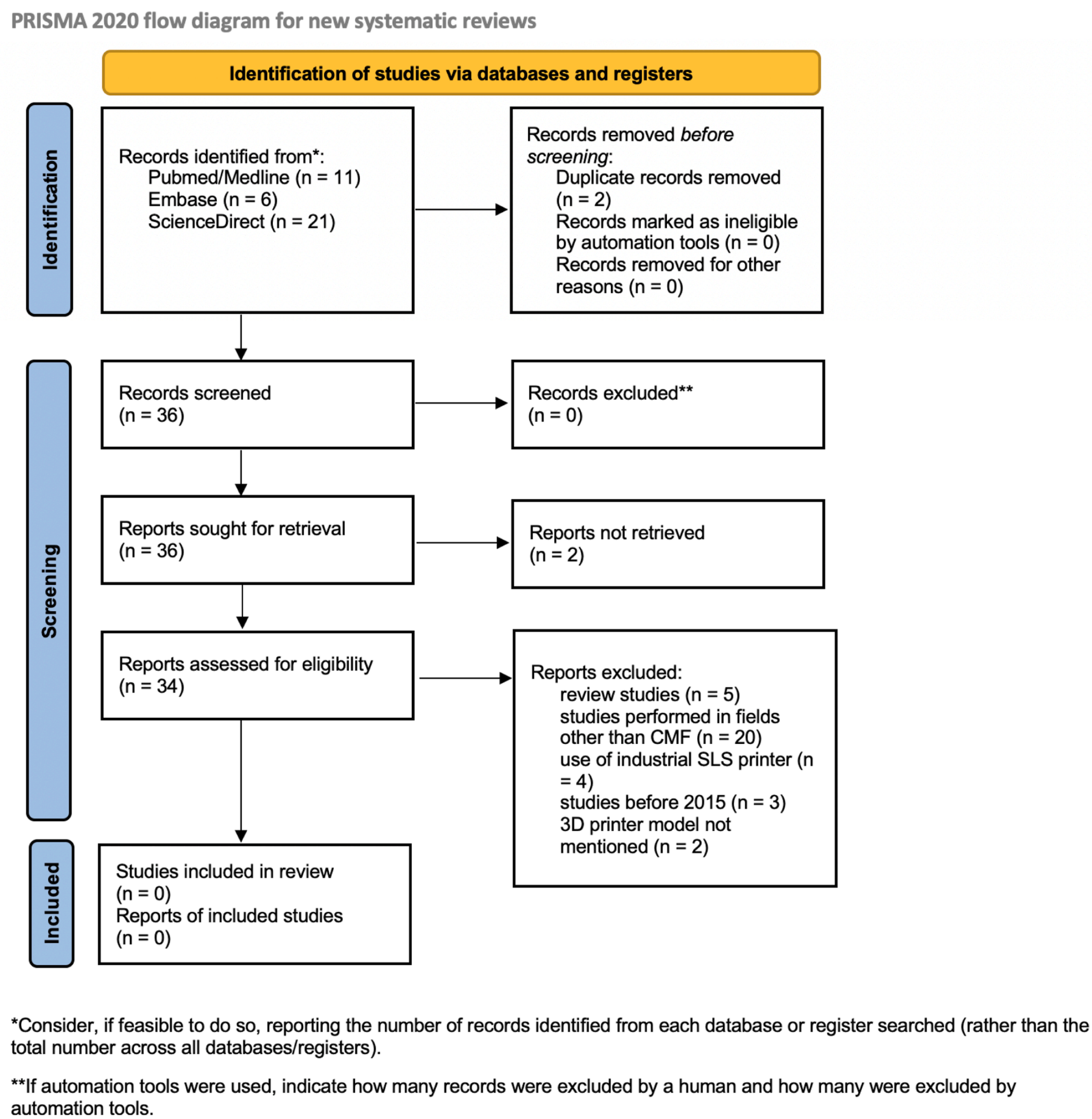

Fig. 3. PRISMA checklist of a systematic search on the use of SLS point-of-care 3D printing for CMF surgery with a scoping purpose.

printed models clearly revealed impressions of preexisting supports after removal, with some supports still left since they were added in non-accessible areas, such as closed spaces (for instance, within paranasal sinuses, but also the intracranial space unless a skullcap cut is planned). Conversely, SLS printers did not have any support structure, thus maximizing the anatomical detail in complex hollow areas as well (Figs. 4 and 5).

Average printing time was slightly longer for SLA compared to SLS (27,7 h vs 20 h), while postprocessing time was in favor of SLA (96,7 min vs 5,5 h).

Table 1 summarizes in detail features related to the AM process of 3 CMF models for both SLA and SLS PoC printers.

In regard to the mechanical properties of the materials, Nylon 12 and BioMed White are quite similar. According to the manufacturer, the Young's Modulus for Nylon 12 is 1.85 GPa and for BioMed White it is 2.02 GPa. The ultimate tensile strength for Nylon 12 is 50 MPa and for BioMed White it is 45.8 MPa.

3.3. Cost analysis for POC SLA and SLS

In the context of PoC 3D printing in hospitals, selecting the most cost-effective technology can significantly impact overall production expenses. The comparative analysis between SLA and SLS is based on averaging the cost of 87 models printed with SLA at our institution and performing a calculation to determine the cost if they had been printed using SLS technology. This cost analysis considers various factors, including material costs, machine hour rate and consumables. Both SLA and SLS technologies entail distinct cost structures, which were meticulously analyzed.

- Material Costs: For SLS technology, material costs primarily revolve around fused powder, factoring in the price per kilogram along with additional expenses such as material waste based on poor packing density. Conversely, SLA technology relies on resin consumption.
- Machine Hour Rate: To determine machine hour rate expenses, we incorporate the machine's hourly rate, accounting for energy consumption. The hourly rate was calculated based on average energy prices in Berlin, Germany. For SLS, maintenance costs are included as fixed expenses through a premium service plan offered by manufacturers. Meanwhile, SLA calculations predominantly operate under low force voltage devices, which do not consume a significant amount of energy.

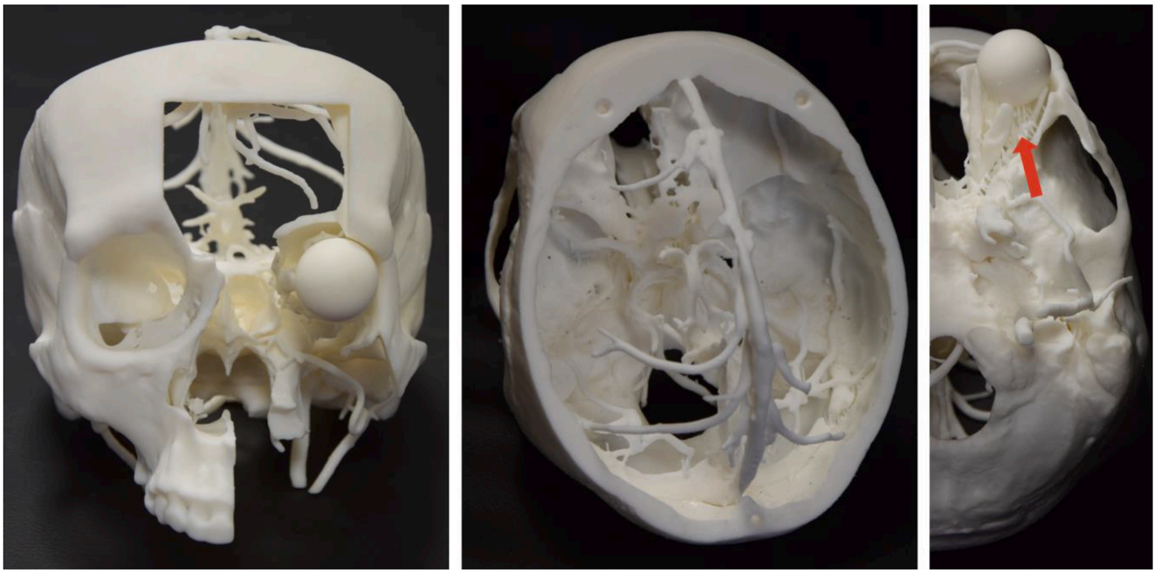

Fig. 4. complex craniofacial resection model printed using a Form 3BL with Biomed White resin. Yet the anatomical detail is very high, processing time to remove supports along vascular structures was 2 h. In addition, in some regions, such as the intraconal orbital spaces, it was not possible to remove supports (red arrow).

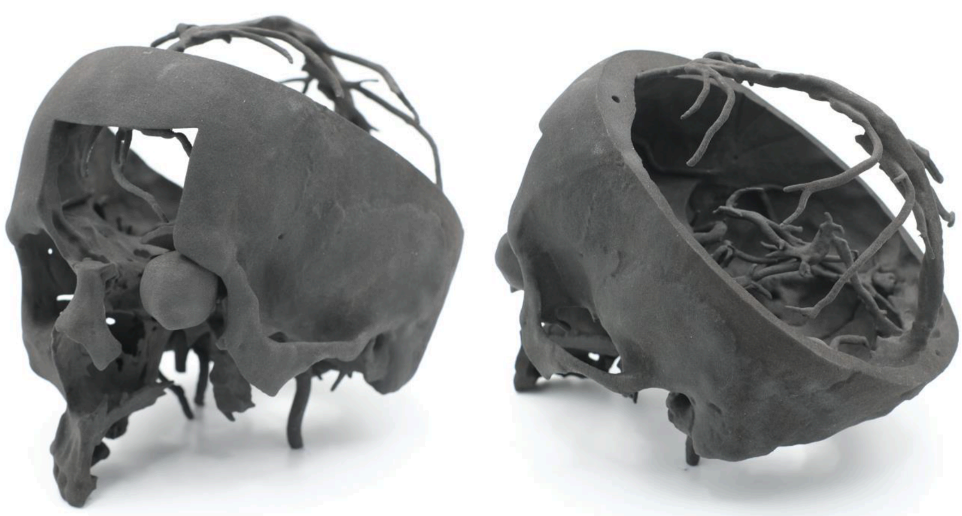

Fig. 5. complex craniofacial resection model printed using a Fuse 1+ with Nylon 12 powder. Anatomical detail was very high along all surfaces, including cavities and undercuts.

Table 1
comparison between anatomical CMF models printer either using SLA (Formlabs Form 3BL) and SLS (Formlabs Fuse 1+).

	Samples printed using SLA (Formlabs Form 3BL)				Samples printed using SLS (Formlabs Fuse 1+)		
	# 1	# 2	# 3		# 1	# 2	# 3
printing time (h)	24	27	32	printing time (h)	18	19	23
wash time (min)	10	10	10	cooling time (h)	9	9	11
cure time (min)	60	60	60	packing density (%)	16	20	18
support removal time (min)	20	25	35	postprocessing time (h)	4	4,5	5
resin used (mL)	450	380	530	powder used (kg)	4.7	3.8	5.5

Results of cost analysis indicate for SLS an average Total Build Material Cost of €100.95; a Total Machine Cost of €30.47, and a Total Production Cost of €131.42. Concerning SLA Technology, Total Build Material Cost was of €148.87; Total Machine Cost of €13.22 and a Total Production Cost: €162.09.

This analysis reveals that while SLS technology involves lower material costs per part compared to SLA, the latter accounts for reduced machine operation expenses. The inclusion of maintenance significantly impacts the overall cost structure for SLS. On the other hand, SLA's cost structure is influenced by resin tank replacements but benefits from lower machine operation expenses.

4. Discussion

SLS represented a consistent advance in 3D printing and is currently one of the preferred technologies in the industry to manufacture anatomical models and surgical guides. Recent technological advances allow to optimize mechanical components, with a significant reduction in size of machines and a substantial decrease in costs. For instance, while the Fuse 1+ has a starting price of approximately 30.000$, industrial SLS machines with initial configuration may start from 100.000 $. The immediate implication is that such evolutions enabled to democratize access to SLS technology, making it available to PoC 3D labs, which are today well widespread in modern hospitals.

Despite this increase in SLS technology in modern labs, scientific evidence about the use of these printers for CMF applications is lacking. Results of our scoping review emphasize that no reports of surgical use of such machines are available for CMF, that is surely one of the fields in which 3D printing is the most widespread.

Although there is currently no SLS 3D printer designed specifically for medical purposes within a PoC 3D lab, there is a number of SLS 3D printers that might orient the choice for an in-house setting based on the following features: printer size, which has direct implications in relation to the spaces available in healthcare institutions, as generally a 3D lab is made of few rooms available and a significantly cumbersome machine may limit other activities; moreover, there is also the need for a cleaning station and powder recycle station; small minimum layer thickness to achieve satisfactory detail and small minimum feature size in X-Y which depends on the spotlight, namely the size of the sculpting laser. Finally, although cost is an important element for the choice, a pricing threshold may vary between centers and countries based on the available resources. For simplification purposes, it may be possible to assume that costs exceeding 100.000$ may be only suitable for an industrial setting. Table 2 presents a collection of currently available SLS models for plastic powder printing and which of them might be indicated for a PoC 3D lab based on the aforementioned assumptions [1].

The limited presence of SLS printers described in literature as part of in-house 3D printing workflows might be due to a variety of reasons: first, PoC SLS printers have been made commercially available only in recent years. Moreover, institutions wishing to start a 3D printing in-house activity tend to opt for simpler machines, including SLA and FDM, which have a very simple learning curve and provide acceptable results. For instance, Msallem et al. compared a variety of 3D printing technologies, both in-house and industrial, and pointed out that the simplest technology (FDM) produced acceptable results for many purposes [5,6]. Similarly, Wang et al. highlighted that desktop 3D printers offered comparable accuracy to professional industrial printers [7]. Subsequently, a newly created in-house 3D lab is likely to adopt SLA and FDM. In addition, not all laboratories have the proper inert gas connections and exhaust systems required for most SLS printers.

Depending on the used material, the inert gas is needed to prevent the powder from burning or combustion when the laser heats it up. The use of inert gas, such as nitrogen, can be economically advantageous for SLS plastic printers. This prevents the powder in the chamber from oxidizing and degrading due to heat [8]. Consequently, the material remains viable for a longer duration, reducing the need to introduce additional powder for subsequent printing sessions. For instance, in the Fuse 1 + 3D printer used in this study, the use of nitrogen is optional.

However, in several centers especially across Europe and the US, 3D labs grew to support multidisciplinary clinical activity and research. In such laboratories, the adoption of SLS enabled clinicians and engineers to access a sophisticated technology which is able to overcome the limitations inherent to SLA and FDM, primarily the need to create supports to avoid the collapse of the model while it is being built. Supports represent the most important limitation of such techniques and significantly prolong the postprocessing time of models printed using SLA and FDM, especially in presence of complex shapes with hollow structures, convoluted geometries and undercuts.

Another important point is the choice of available materials. 3D printers are so interesting for PoC applications because the main uses are cutting or drilling guides or parts for surgical planning. SLA PoC printers offer a wide range of material options, including silicone-like, flexible, transparent, tough, durable, and rigid varieties. Transparent and colorful materials are well suited to produce anatomical replicas, which is possible with SLA printers, but not with SLS printers up to now. The choice of materials for SLS thermoplastic printers is much more limited, mostly polyamide, occasionally polypropylene or thermoplastic polyurethane. However, SLS printed parts generally possess superior mechanical properties.

PA serves as a frequently utilized substance in SLS and holds significant appeal for surgical guides. This is attributed to the material's notable stiffness, enabling precise incisions or drillings, while also allowing for convenient modifications in the operating room. Moreover, the material poses no harm to the patient, and in contrast to SLA prints, there is no residue of uncured outer layers on the final part after use. Also, the sterilizability of printed parts is particularly important. Although polyamide has poorer mechanical properties after sterilization, the parts do not deform, which is extremely important for an accurate fit [8,9].

However, it is worth mentioning that SLS is currently one of the most widespread methods for metal additive manufacturing, whereas commonly used PoC 3D printers, including the Fuse 1+, only allow to print plastic parts using nylon or other polymers. Metal printing requires significantly higher expertise, mostly the presence of a skilled technician, and necessitates of precise safety requirements for the use of metal powder. In addition, metal SLS printers lose the advantage of support-free printing, since the support is required to dissipate heat for most printing applications [10].

Another important element that favors SLS technology from an in-house lab perspective is the fact that SLS enables to recycle unsintered powder, thus economizing the printing process. While for SLA parts a portion of uncured resin is always lost during the washing process, especially for parts with very fine details or lattice structures.

The washing off of resin residues and the short-term dissolution of the surface, as well as the usually finer layer thickness, ensure that SLA parts often have a very fine surface, which is very suitable for display objects. SLS prints tend to have a slightly grainy surface.

Further surface treatment would be required to achieve a finer finish. However, this is generally not necessary for parts used in CMF surgery.

Although a SLS printer setup is more expensive and complex, compared to SLA or FDM printers, the superior materials properties have big advantages for CMF surgeries. The fact that the used polyamide parts can be autoclave sterilized without any problems is a big benefit in the clinical landscape. As well that the parts are robust, but still modifiable by tools common in the operating room. Learning from other 3D printing concepts, SLS printers will become easier to handle and to acquire in the near future, making them a more common tool for preparing CMF surgeries.

Regarding pricing, there are significant variations among different devices concerning their fabrication capabilities. It is crucial to assess the anticipated printing volume before making a purchase. If an institution only requires a few guides on a weekly basis, a smaller printer would be adequate. Conversely, if production is necessary to cater to all the institutes within the hospital, a larger printer would be more suitable.

5. Conclusions

SLS printers consistently deliver robust parts that are mechanically excellent for surgical guides and easily autoclavable, and the absence of supports simplifies postprocessing, delivering high-quality results for complex anatomical parts, ideal for craniofacial models.

In any case, SLS printing systems require more space, time, and user expertise than a simple SLA printer. Moreover, the boundary between SLS printers suitable for PoC and industrial-scale systems is not entirely defined, and the quantity of 3D printed parts required should be carefully evaluated before acquiring this technology within an in-hospital setting.

Yet, this is a highly promising technology that has made substantial advancements to be brought within hospitals, and its use in CMF surgery will contribute to more reliable anatomical replicas, with superior

Table 2
SLS 3D printers available in the market.

	Manufac-turer	Material used	Resolution	Layer thickness	Building chamber size	Printer dimensions	Cost	Building speed
Fuse 1+	Formlabs	PA	247 µm	110 µm	165 × 165 × 300 mm	685 x 645 x 1065 mm	min 45k	
Lisa X	Sinterit	PA	not available	75 - 175 µm	130 x 180 x 340 mm	650 x 610 x 1200 mm	24k	14 mm/h
Lisa	Sinterit	PA, TPU	not available	75 - 175 µm	110 x 160 x 145 mm	620 x 400 x 660 mm	14k	3 mm/h
Nils-480	Sinterit	PA, Polypropylen	not available	75 - 175 µm	200 x 200 x 330 mm	1285 x 1250 x 1840 mm	74k	14 mm/h
Lisa Pro	Sinterit	PA, Polypropylen	not available	75 - 175 µm	110 x 160 x 230 mm	690 x 500 x 880 mm	19k	3 mm/h
S2	Sintratec	PA, TPE	145 µm	100µm	needs build chamber (MCU)	1490 x 990 x 600 mm	min 18k	15 mm/h
S3	Sintratec	PA, TPE	145 µm	100µm	needs build chamber (MCU)	1490 x 990 x 600 mm	min 26k	15 mm/h
MCU-220	Sintratec	no laser unit (need S2 or S3)			d220 x 400mm	1100 x 850 x 530 mm	min 11.3k	
MCU-160	Sintratec	no laser unit (need S2 or S3)			d160 x 400mm	1100 x 850 x 530 mm	min 8.9k	
Kit	Sintratec	PA, TPE	not available	100 – 150 µm	90 x 90 x 90 mm	520 x 520 x 360 mm	6k	
SnowWhite 2	Sharebot	PA, TPU	200 µm	50 µm	100 x 100 x 100mm	500 x 610 x 1540 mm	40k	35 mm/h
Gravity	Wematter	PA	not available	100 µm	300 x 300 x 300mm	1700 x 750 x 600 mm	60k - 125k	12 mm/h
eForm	Farsoon	PA, PP	not available	60-300 µm	d250 × 320 mm	1735 × 1205 × 1975 mm	73k	0.8 L/h
Promaker P1000 S	Prodways	PA, TPU, PP	450 µm	60/100/120 µm	300 x 300 x 360 mm	1700 x 1159 x 2008 mm	on request	1.4 L/h
Promaker P1000 X	Prodways	PA, TPU, PP	450 µm	60/100/120 µm	300 x 300 x 360 mm	1700 x 1159 x 2008 mm	on request	2.0 L/h
Formiga P 110 Velocis	EOS	PA, TPU	not available	60/100/120 µm	200 x 250 x 330 mm	1320 x 1067 x 2204 mm	170k	1.2 L/h
Formiga P 110 FDR	EOS	PA	not available	40 µm	200 x 250 x 330 mm	1320 x 1067 x 2204 mm	price on request	0.5 L/h
P 396	EOS	PA, TPU, PP	not available	60/100/120/150/180 µm	340 x 340 x 600 mm	1840 x 1175 x 2100 mm	price on request	3.0 L/h
P 500	EOS	PA	not available	120 µm	500 x 330 x 400 mm	3400 x 2100 x 2100 mm	price on request	6.6 L/h
P 770	EOS	PA	not available	60/100/120/150/180 µm	700 x 380 x 580 mm	2250 x 1550 x 2100 mm	price on request	10.5 L/h
P 810	EOS	high temperature polymers	not available	120 µm	700 x 380 x 380 mm	2500 x 1300 x 2190 mm	price on request	2.7 L/h
SLS 380	3D systems	PA	not available	80 - 150 µm	381 x 330 x 460 mm	1740 x 1230 x 2300 mm	price on request	2.7 L/h
sPro 140	3D systems	PA	not available	80 - 150 µm	550 x 550 x 460 mm	2130 x 1630 x 2410 mm	price on request	3.0 L/h
sPro 230	3D systems	PA	not available	80–150 µm	550 x 550 x 750 mm	2510 x 2080 x 2740 mm	price on request	3.0 L/h
sPro 60 HD-HS	3D systems	PA	not available	80–150 µm	381 x 330 x 460 mm	1750 x 1270 x 2130 mm	price on request	1.8 L/h
EP-C5050	E-Plus-3D	Wax/Sand	not available	80-300 µm	520 x 520 x 500 mm	2000 x 1300 x 2300 mm	price on request	
EP-P420	E-Plus-3D	PA	not available	60-200 µm	420 x 420 x 465 mm	1680 x 1400 x 2470 mm	150k	25 mm/h
EP-C7250	E-Plus-3D	Wax/Sand	not available	80-300 µm	720 x 720 x 500 mm	2000 x 1500 x 2650 mm	price on request	
QLS 820	nexa 3D	PA, PP, PBT	not available	50-200 µm	350 x 350 x 400 mm	2000 x 1400 x 2000 mm	500k	8.0 L/h
QLS 230	nexa 3D	PA	not available	80/100/150/200µm	230 x 230 x 230 mm	1460 x 740 x 1890 mm	price on request	20 mm/h
QLS 236	nexa 3D	PA, TPU, PP	not available	60/80/100/150/200/300 µm	230 x 230 x 250 mm	1480 x 850 x 2040 mm	price on request	22 mm/h
S100	Sindo	PA, TPU, PP	not available	60-180 µm	510 x 510 x 500 mm	2815 x 1590 x 2312 mm	650k	4.7 L/h
S800QL	TPM3D	PA	500 µm	60-200 µm	800 x 800 x 600 mm	>2m	price on request	25mm/h
S600DL	TPM3D	PA	420 µm	60-200 µm	600 x 600 x 800 mm	1650 x 1520 x 2360 mm	price on request	25mm/h
S480	TPM3D	PA	310 µm	60-200 µm	480 x 480 x 600mm	1600 x 1480 x 2220 mm	price on request	25mm/h
S360	TPM3D	PA	250 µm	60-200 µm	360 x 360 x 600mm	1320 x 1280 x 2090 mm	price on request	25mm/h
S320HT	TPM3D	PA	220 µm	60-200 µm	320 x 320 x 380mm	1340 x 1280 x 2150 mm	price on request	25mm/h

Table 2: Green square contains printers that might be suitable for a PoC in-hospital 3D lab based on the assumptions made in Discussion section. Data retrieved from manufacturers' website . AM, additive manufacturing; CMF, cranio-maxillo-facial; CT, computed tomography; FDM, fused deposition modeling; MRI, magnetic resonance imaging; PA, polyamide; PBT, polybutylene terephthalate; PoC, point-of-care; PP, polypropilen; SLA, stereolithography; SLS, selective laser sintering; TPE, thermoplastic elastomere; TPU, thermoplastic polyurethane; 3D, three dimensional.

mechanical properties.

Disclosures

The Authors have no disclosures to declare

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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