

Digital Manufacturing of Ear Prostheses: A Scope Review

Manufatura Digital de Próteses Auriculares: Uma Revisão de Escopo

Fabricación Digital de Prótesis Auriculares: Una Revisión de Alcance

RESUMO

O artigo apresenta uma revisão de escopo das metodologias, tecnologias e resultados associados ao uso da manufatura digital na produção de próteses auriculares, destacando seu impacto transformador na reabilitação auditiva, bem como os desafios atuais e as perspectivas para o desenvolvimento e a disseminação dessa tecnologia. Para isso, foi conduzida uma revisão de escopo com 44 artigos. Os resultados demonstraram a transição para fluxos digitais de trabalho, com o método direto sendo empregado em 55% dos estudos. Essa abordagem tem permitido a criação de próteses mais precisas, eficientes e de baixo custo, resultando em maior satisfação do paciente. A transição para a produção digital de próteses auriculares é um avanço promissor que tem o potencial de superar os desafios da fabricação convencional. A evolução das tecnologias de escaneamento, impressão 3D, softwares de código aberto e o uso de novos materiais tornarão os processos mais acessíveis e eficientes.

DESCRIPTORES: Prótese Auricular; Manufatura Aditiva; Tecnologias Digitais; Reabilitação.

ABSTRACT

This article presents a review of the scope of methodologies, technologies and results associated with the use of digital manufacturing in the production of ear prostheses, highlighting its transformative impact on auditory rehabilitation, as well as the current challenges and perspectives for the development and dissemination of this technology. For this, a scope review with 44 articles was conducted. The results demonstrated the transition to digital workflows, with the direct method being employed in 55% of the studies. This approach allowed the creation of more precise, efficient and low-cost prostheses, resulting in greater patient satisfaction. The transition to digital ear prosthesis production is a promising breakthrough that has the potential to overcome the challenges of conventional manufacturing. The evolution of scanning and 3D printing, development of open source software and the use of new materials will make processes more accessible and efficient.

DESCRIPTORS: Ear Prosthesis; Additive Manufacturing; Digital Technologies; Rehabilitation.

RESUMEN

Este artículo presenta una revisión del alcance de las metodologías, tecnologías y resultados asociados al uso de la fabricación digital en la producción de prótesis auditivas, destacando su impacto transformador en la rehabilitación auditiva, así como los desafíos actuales y las perspectivas para el desarrollo y la difusión de esta tecnología. Para esto, se llevó a cabo una revisión de alcance con 44 artículos. Los resultados demostraron la transición a flujos de trabajo digitales, con el método directo siendo empleado en el 55% de los estudios. Este enfoque permitió la creación de prótesis más precisas, eficientes y de bajo costo, resultando en una mayor satisfacción del paciente. La transición a la producción digital de prótesis auditivas es un avance prometedor que tiene el potencial para superar los desafíos de la fabricación convencional. La evolución de las tecnologías de escaneo, el desarrollo de software de código abierto y el uso de nuevos materiales harán los procesos más accesibles y eficientes.

DESCRIPTORES: Prótesis Auditiva; Fabricación Aditiva; Tecnologías Digitales; Rehabilitación

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INTRODUCTION

The auricle, or outer ear, is a crucial element for facial aesthetics and for defining an individual's physiognomy. Its anatomical structure reflects characteristics such as age and gender, making it an important component in the composition of the face^(1,2). Understanding the aesthetic patterns of ear shape is therefore essential for successful facial analysis⁽³⁾. The outer ear consists of a prominence of

skin and cartilage, and its main anatomical structures are the helix-antihelix complex, the concha, the lobe, and the tragus^(4,5).

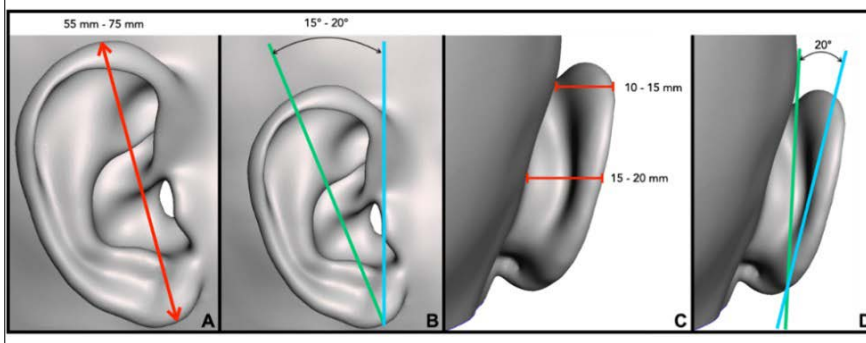
The human ear, a fundamental structure for facial aesthetics and prosthesis design, is formed by specific anatomical proportions and dimensions (Fig. 1). The combination of this information allows for the accurate replication of natural morphology, ensuring functionality and aesthetics in prosthetic and adapted devices⁽⁶⁾.

tient^(11,12).

Surgical reconstruction allows the use of autologous tissues and results in a definitive structure integrated into the body, with less need for maintenance. However, it requires multiple procedures, involves a longer recovery time, and can cause significant scarring due to the removal of the patient's own tissue. Prosthetic rehabilitation provides immediate aesthetic results, is less invasive, and offers greater possibility for personalized adjustments over time, but it presents significant challenges. Among these are the technical difficulties in manufacturing the prosthesis using conventional methods, which can require several complex laboratory steps, a high degree of professional skill, and a long time until the final delivery of the prosthesis. In addition, prostheses require periodic replacement due to material wear, depend on patient adherence to continuous use, and can generate functional and psychological limitations related to the perception of artificiality, as well as the social stigma associated with the use of external devices⁽¹⁴⁾.

Over the past 25 years, rehabilitation with ear prostheses has undergone a significant transformation driven by the integration of digital technologies, such as three-dimensional (3D) image acquisition, Computer Aided Design (CAD), and additive manufacturing. The 3D reconstruction of detailed images of the patient's ear enables the creation of digital models capable of accurately reproducing their individual anatomical characteristics. CAD software can be used to refine the models, ensuring proper anatomical fit and aesthetic harmonization. Additive manufacturing enhances the production

Fig. 1. Average anthropometric measurements of the human ear. (A) Ear height (55 mm - 75 mm). (B) Posterior inclination of the ear in relation to the vertical plane (15° to 20°). (C) Distance of the lateral projection of the ear (10-15 mm to the lower part). (D) Angle of separation of the outer edge of the helix in relation to the head (approximately 20°).



Source: Adapted from Ladani, 2021⁽⁶⁾.

The importance of the ear in facial aesthetics is evident. An ear with size, shape, location, and positioning within normal standards tends to go unnoticed. However, any change in its structure causes a significant aesthetic modification⁽⁷⁾. Aesthetic changes in the face can generate negative psychosocial impacts, such as difficulties in interpersonal and social relationships, compromising patients' quality of life⁽⁸⁾. Ear deformities can be caused

by various pathologies, ranging from congenital conditions, such as microtia, to acquired trauma, such as that resulting from car accidents, skin cancer, and burns^(9,10). These congenital or acquired deformities, including partial or complete absence of the ear (anotia/microtia), can be effectively treated through ear reconstruction surgery or prosthetic rehabilitation. The approaches offer distinct advantages and disadvantages, depending on the specific needs and clinical condition of each pa-

process by enabling the direct conversion of digital models into aesthetic prostheses with a high level of precision and realism. This evolution results in a more personalized and efficient approach, with benefits in terms of scalability, production time, and cost-effectiveness⁽¹⁴⁾.

However, despite the obvious advances and benefits, challenges remain related to the standardization of digital protocols, the accessibility of these technologies in clinical contexts, and the scarcity of systematic comparative studies. This article presents a scoping review of the methodologies, technologies, and results associated with the use of digital manufacturing in the production of ear prostheses, highlighting its transformative impact on hearing rehabilitation, as well as the current challenges and prospects for the development and dissemination of this technology. The analysis seeks to identify the challenges that still limit the adoption of these approaches by prosthetic centers and propose strategies to facilitate their dissemination and wider clinical application.

METHOD

This is a scoping review to critically analyze the evolution of digital manufacturing applied to ear prostheses over the last 25 years, identifying the challenges that still restrict its adoption in prosthetic centers and pointing out possible strategies to expand its dissemination and clinical application. The study was conducted in accordance with the Joanna Briggs Institute (JBI) model, as per the JBI Scope Review Manual, and the article was constructed following the PRISMA-SCR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) checklist^(15,16) (Fig. 2.) to identify, select, and analyze the literature on the application of digital technologies in the production of ear prostheses.

Search Strategy

The search for scientific articles was performed in the PubMed, Scopus, and Web of Science databases, limited to the 25-year period from 2000 to 2025, to

cover the most relevant implementations of digital technologies in the field. Keywords were combined using Boolean operators (AND and OR) to maximize the sensitivity of the search. The following combinations of keywords with Boolean operators were used: (“outer ear” OR “auricle”) AND (“prostheses” OR “prosthesis”) AND (“3D printing” OR “additive manufacturing” OR “digital fabrication”).

Eligibility Criteria

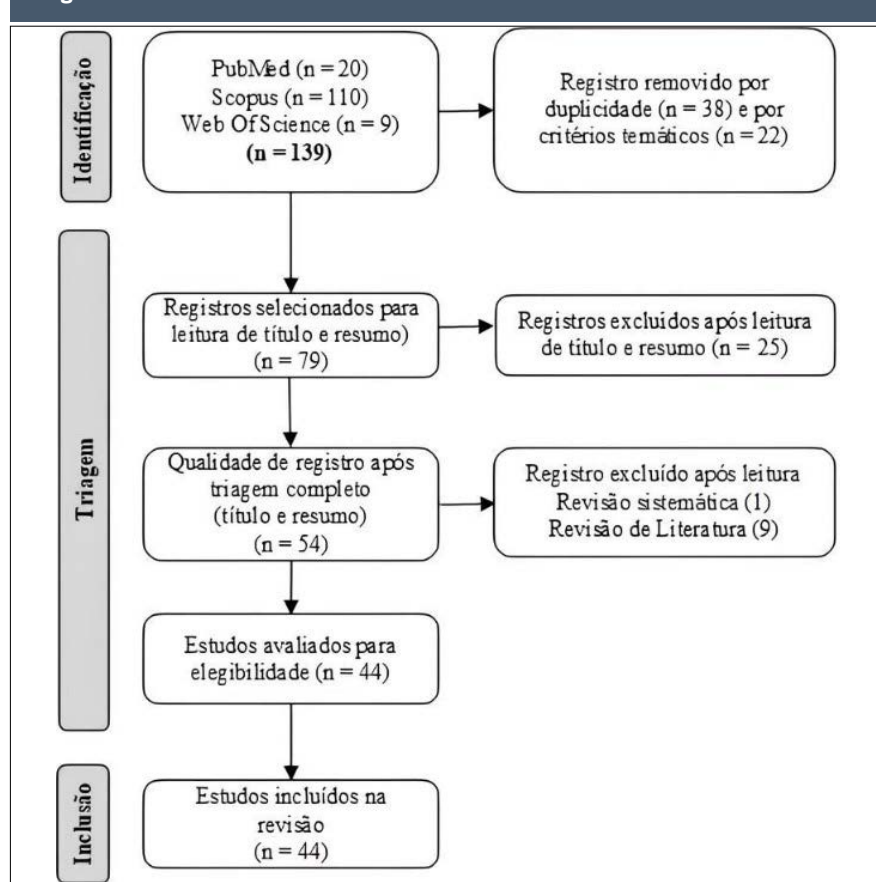
The included articles address the application of additive manufacturing (3D printing), CAD, or CAM in the manufacture of external ear prostheses, including original articles, case studies, clinical trials, and reviews published between 2000 and 2025. Articles that did not specifically address the production of external prostheses, those focused only on surgical

reconstruction with autologous or alloplastic materials, as well as conference reports, letters to the editor, editorials, and opinion articles without original data were excluded.

Data Selection and Analysis

In the first stage of study selection, the titles and abstracts of the articles were screened to identify those that met the inclusion criteria. In the second stage, the full texts of the preselected articles were read to confirm eligibility. For each article included, data on authors, year of publication, type of study, technology used, materials, manufacturing methodology, results, and conclusions were extracted. The data were summarized descriptively, and critical analysis of the evidence mapped the challenges to propose dissemination strategies.

Fig. 2. PRISMA flowchart of article selection.



Source: Prepared by the author.

RESULTS

The literature analysis resulted in the compilation of 44 unique articles, which were thoroughly examined to identify the methodologies and processes of prosthetic ear manufacturing using digital manufacturing technologies (Table 1).

Table 1. Methodologies and processes for prosthetic ear fabrication using digital manufacturing.

n°	Authors	Year	Method	Image Acquisition	Process*
1	Chee Kai, et al. ⁽¹⁷⁾	2000	Direct	3D Scanner (Laser)	SLA / SLS / FFF / LOM
2	Gebhardt ⁽¹⁸⁾	2000	Direct	DICOM images (CT) and 3D reconstruction	-
3	Sykes, et al. ⁽¹⁹⁾	2004	Indirect	3D scanner (optical)	MJT
4	Jiao, et al. ⁽²⁰⁾	2004	Direct	DICOM images (CT) and 3D reconstruction	LOM
5	Ciocca e Scotti ⁽²¹⁾	2004	Indirect	3D scanner (laser)	-
6	Chandra, et al. ⁽²²⁾	2005	Direct	3D Scanner (Laser)	MJT
7	Mardini et al. ⁽²³⁾	2005	Indirect	3D scanner (laser)	SLA
8	Bibb, et al. ⁽²⁴⁾	2006	Direct	3D Scanner (Laser)	MJT
9	Subburaj, et al. ⁽²⁵⁾	2007	Indirect	DICOM images (CT) and 3D reconstruction	-
10	Karayazgan-Saracoglu et al. ⁽²⁶⁾	2009	Indirect	DICOM images (CT) and 3D reconstruction	-
11	Turgut, et al. ⁽²⁷⁾	2009	Indirect	DICOM images (MRI and CT) and 3D reconstruction	SLS
12	Karatas, et al. ⁽²⁸⁾	2011	Direct	DICOM images (CT) and 3D reconstruction	MJT / SLA
13	Liacouras, et al. ⁽²⁹⁾	2011	Direct	3D Scanner (Laser)	-
14	De Crescenzo, et al. ⁽³⁰⁾	2011	Direct	-	-
15	Bai, et al. ⁽³¹⁾	2014	Direct	3D Scanner (Light) / DICOM Images (CT) and 3D Reconstruction	SLS
16	He et al. ⁽³²⁾	2014	Direct	-	FFF
17	Watson e Hatamleh. ⁽³³⁾	2014	Direct	3D Scanner (Laser)	-
18	Artioli et al. ⁽³⁴⁾	2014	Direct	DICOM images (CT) and 3D reconstruction	FFF / SLS
19	Nuseir, et al. ⁽³⁵⁾	2015	Indirect	DICOM images (CT) and 3D reconstruction	-
20	Moretto, et al. ⁽³⁶⁾	2016	Direct	DICOM images (CT) and 3D reconstruction	FFF
21	Mohammed, et al. ⁽³⁷⁾	2017	Direct	DICOM images (CT) and 3D reconstruction	PJ
22	Yadav et al. ⁽³⁸⁾	2017	Direct	DICOM images (CT) and 3D reconstruction	SLS
23	Jamayet et al. ⁽³⁹⁾	2018	Indirect	3D scanner (laser)	PJ
24	Mohammed et al. ⁽⁴⁰⁾	2018	Direct	DICOM images (CT) and 3D reconstruction	PJ
25	Sarkar et al. ⁽⁴¹⁾	2019	Indirect	3D scanner (Light)	FFF
26	Unkovskiy et al. ⁽⁴²⁾	2019	Direct	3D Scanner (Light)	SLS / SLA / FFF
27	Unsal e Turkyilmaz. ⁽⁴³⁾	2019	Indirect	DICOM images (CT) and 3D reconstruction	-
28	Cevik e Kocacikli. ⁽⁴⁴⁾	2020	Direct	3D Scanner (Blue Light)	FFF
29	Cruz et al. ⁽⁴⁵⁾	2020	Direct	3D Scanner (Light)	FFF
30	Manju et al. ⁽⁴⁶⁾	2021	Indirect	DICOM images (CT) and 3D reconstruction)	PJ
31	Bi et al. ⁽⁴⁷⁾	2022	Direct	DICOM images (CT) and 3D reconstruction	-
32	Singh e Bhandari ⁽⁴⁸⁾	2022	Indirect	3D scanner (blue light)	SLA
33	Netshilindi et al. ⁽⁴⁹⁾	2023	Indirect	3D scanner (digital intraoral scanner)	SLA
34	Sharma et al. ⁽⁵⁰⁾	2023	Indirect	3D Scanner (Light)	FFF / SLA
35	Hatamleh et al. ⁽⁵¹⁾	2024	Direct	CT, Cone beam computed tomography (CBCT) from the tabletop scanner	
36	Kasahara et al. ⁽⁵²⁾	2024	Indirect	Scanner (Artec Spider) and (Trios3)	
37	Kim et al. ⁽⁵³⁾	2024	Direct	DICOM images (CT) and 3D reconstruction	FFF
38	Capotorto et al. ⁽⁵⁴⁾	2025	Direct	3D Scanner (Laser)	FFF

Integrative Review

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39	İnal et al. ⁽⁵⁵⁾	2025	Indirect	3D scanner (intraoral)	FFF
40	İnal et al. ⁽⁵⁶⁾	2025	Indirect	Smartphone application (Polycam)	SLA
41	Kaul et al. ⁽⁵⁷⁾	2025	Indirect	Smartphone application (EM3D and 3D Scanner.	-
42	Gadallah et al. ⁽⁵⁸⁾	2025	Indirect	Intraoral Scanners	-
44	Nightingale et al. ⁽⁵⁹⁾	2025	Indirect	Photogrammetry iPhone and Android, and 3D scanner	-

* FFF: Fused Filament Fabrication; LOM:

Laminated Object Manufacturing; MJT: MultiJet Modeling; PJ: Polyjet. MRI: Magnetic Resonance Imaging; Computed Tomography; SLA: Stereolithography; SLS: Selective Laser Sintering.

The literature on prosthetic ear rehabilitation through additive manufacturing can be categorized into two workflows: The indirect method, which uses addi-

tive manufacturing to produce a physical model of the mold that will be used in conventional prosthesis manufacturing, and the direct method, which employs the technology to manufacture the final prosthesis or a component of it, eliminating the molding and manual sculpting steps. The indirect method was employed

in 20 of the 44 studies (45%), focusing on reducing manual steps, optimizing time, and seeking more accessible and efficient solutions for acquiring the ear image. The direct method, the dominant approach, was explored in 24 of the 44 articles (55%) (Table 2).

Table 2. Application of direct and indirect additive manufacturing methods for ear prostheses, detailing the digital generation of contralateral anatomy without the use of physical molding.

Indirect Method		
Year	Authors	Main findings
2004	Sykes, et al. ⁽¹⁹⁾	Statistical comparisons between a conventionally produced mold and one produced by additive manufacturing.
	Ciocca e Scotti ⁽²¹⁾	The application of the indirect method is only feasible if the scanning and CAD systems are low cost.
2005	Mardini et al. ⁽²³⁾	The indirect method did not require the patient to undergo scanning, reducing acquisition errors and visits to the office.
2007	Subburaj, et al. ⁽²⁵⁾	Feasibility of a semi-automated methodology using CAD and additive manufacturing to develop an ear prosthesis.
2009	Karayazgan-Saracoglu et al. ⁽²⁶⁾	Feasibility of a semi-automated approach using CAD and additive manufacturing.
	Turgut, et al. ⁽²⁷⁾	Reproducibility in 10 cases of unilateral ear absence.
2015	Nuseir, et al. ⁽³⁵⁾	The use of 3D modeling and additive manufacturing simplified production, reducing time and improving the texture and structure of the results.
2018	Jamayet et al. ⁽³⁹⁾	New indirect methodology, eliminating CT scans, which reduced time, cost, and improved accuracy.
2019	Sarkar et al. ⁽⁴¹⁾	Indirect method using Polyjet technology; highlighted economic challenges but acknowledged the potential for cost reduction.
	Unsal e Turkyilmaz ⁽⁴³⁾	Analysis of patient satisfaction in a clinical case of an auricular prosthesis produced by additive manufacturing, reporting satisfaction with the result.
2021	Manju et al. ⁽⁴⁶⁾	The process ensured exceptional realism and precise adaptation, requiring three times fewer hours compared to the conventional method.
2022	Singh e Bhandari ⁽⁴⁸⁾	The indirect method simplified the process of producing ear prostheses, eliminating time-consuming steps.
2023	Netshilindi et al. ⁽⁴⁹⁾	The first report of the use of an intraoral 3D scanner in the indirect method resulted in greater precision, improved efficiency, and a less invasive approach.
	Sharma et al. Sharma et al. ⁽⁵⁰⁾	Confirmed that, despite the initial costs, the indirect method approach significantly reduced the need for patient appointments and chair time.
2024	Kasahara et al. ⁽⁵²⁾	Compared optical scanners with conventional impression-taking, concluding that digital methods caused less deformation and are clinically acceptable.
2025	İnal et al. ⁽⁵⁵⁾	Presented a semi-digital workflow for replacing implant-retained prostheses, using an intraoral scanner and 3D printing to optimize the process.
	İnal et al. ⁽⁵⁶⁾	Validated a low-cost technique for acquiring ear images using a smartphone app, proving that it is an affordable and comfortable alternative.
	Kaul et al. ⁽⁵⁷⁾	Mobile applications are a viable alternative to 3D scanners, with good accuracy and superior performance in terms of time and cost.
	Gadallah et al. ⁽⁵⁸⁾	Evaluated different intraoral scanners, demonstrating that the accuracy for ear scanning varied significantly between models.
	Nightingale et al. ⁽⁵⁹⁾	Validated a photogrammetry method using smartphones that is accurate and repeatable, regardless of the cell phone model, reinforcing the flexibility and potential for democratization of the technology.

Direct Method		
Year	Authors	Main findings
2000	Chee Kai, et al. ⁽¹⁷⁾	First report on the direct method, demonstrating the production of ear prostheses using four additive manufacturing technologies (SLA, SLS, FFF, and LOM).
	Gebhardt ⁽¹⁸⁾	Explored the clinical implications of the manufacturing procedure, confirming its applicability.
2004	Jiao, et al. ⁽²⁰⁾	The integration of Additive Manufacturing and Computer-Aided Design (CAD) simplified the production process, increasing efficiency.
2005	Chandra, et al. ⁽²²⁾	Demonstrated the transition from artisanal to engineering-based manufacturing using low-cost laser scanners and receiving positive feedback from doctors and patients.
2006	Bibb, et al. ⁽²⁴⁾	Validated the efficiency of the direct method for magnetic retention prostheses.
2011	Karatas, et al. ⁽²⁸⁾	Affirmed the ability of the approach to generate prostheses with greater realism and facial symmetry, with reduced processing time.
	Liouras, et al. ⁽²⁹⁾	Viability of the direct method to reduce initial steps in the conventional manufacturing process.
	De Crescenzo, et al. ⁽³⁰⁾	Provided results that concluded that the direct method reduced time and costs by eliminating three manufacturing steps compared to the conventional process.
2014	Bai, et al. ⁽³¹⁾	The direct method increased the precision and accuracy of ear prostheses, optimizing manual efforts and minimizing production time.
	He et al. ⁽³²⁾	Validated an economical and user-friendly approach to the production of silicone ear prostheses.
	Watson e Hatamleh ⁽³³⁾	Improved the final prosthesis using a color spectrometer that accurately reproduced digital and physical skin tones.
	Artioli et al. ⁽³⁴⁾	Highlighted the ability of SLS technology to produce a superior quality mold for prostheses, but acknowledged economic disparities.
2016	Nuseir, et al. ⁽³⁵⁾	Open source software to optimize 3D reconstruction from CT images of the ear, facilitating digital modeling of molds.
2017	Moretto, et al. ⁽³⁶⁾	3D design and multi-material printing have been shown to have the potential to create realistic ear prosthesis models, making them suitable for clinical applications.
	Mohammed, et al. ⁽³⁷⁾	Illustrated that CAD/CAM additive manufacturing and selective laser sintering technology replicated accurate ear prostheses, reducing treatment time.
2018	Mohammed et al. ⁽⁴⁰⁾	3D modeling and printing produced superior anatomical reproduction results, reducing production time and costs by 30-35% compared to traditional methods.
2019	Unkovskiy et al. ⁽⁴²⁾	The investigation revealed that all three additive manufacturing methods (FFF, SLS, and SLA) achieved high dimensional accuracy in the production of ear prostheses.
2020	Cevik e Kocacikli ⁽⁴⁴⁾	Additive manufacturing has the potential to replace conventional procedures such as jar molding and wax sculpting.
	Cruz et al. ⁽⁴⁵⁾	Additive manufacturing offers a cost-effective and high-precision solution for the production of ear prostheses.
2022	Bi et al. ⁽⁴⁷⁾	Additive manufacturing and CAD planning optimize the production of ear prostheses, eliminating time-consuming steps.
2024	Hatamleh et al. ⁽⁵¹⁾	Digital workflow for bilateral ear reconstruction, validating the digital workflow to achieve greater symmetry and precision in implant placement.
	Kim et al. ⁽⁵³⁾	Clinical trial that proved the safety and durability of printed PCL implants, with high patient satisfaction results after one year.
2025	Capotorto et al. ⁽⁵⁴⁾	Created a scaffold with two materials (PCL and TPU) via FFF that mimics the mechanical properties of cartilage and adipose tissue, showing superiority over other materials.

DISCUSSION

This scoping review demonstrated that the transition to auricular rehabilitation through digital workflows is a consolidated trend in the literature, with a notable evolution from a focus on technical feasibility to clinical validation and democratization of access. Analysis of the main data, presented in Tables 1 and 2, allowed us to

identify patterns and gaps that shape the future of digital anaplastology.

Evolution of Acquisition Methods and Technologies

A chronological analysis of the literature reveals a significant shift in data acquisition. Initially, the direct method predominated, using laser scanners or computed tomography (CT) image reconstruction^(18,20,22).

Although this approach offered high precision, it depended on large equipment and, in the case of CT, exposed the patient to radiation, which limited its clinical and economic applicability. The indirect method, in turn, was validated with optical scanners⁽¹⁹⁾ on the premise that its viability depended on low-cost systems⁽²¹⁾.

A paradigm shift in data acquisition was observed due to the pro-

gressive elimination of highly complex exams, such as CT, in favor of less invasive and more efficient solutions^(39,49). The use of intraoral scanners^(39, 55) and, more recently, photogrammetry with smartphones^(56,57,59) validate the democratization of acquisition technology. This trend suggests that the main barrier to entry, the cost of the scanner, is being progressively mitigated by affordable devices with acceptable accuracy performance for clinical applications. However, it is crucial to note that accuracy can vary significantly between different scanners, highlighting the need for standardization and validation of protocols⁽⁵⁸⁾.

Additive Manufacturing as a Production Standard

Parallel to the evolution in acquisition, the data indicate a consolidation of additive manufacturing as the primary means of production. Stereolithography (SLA), Fused Filament Fabrication (FFF), and Selective Laser Sintering (SLS) technologies have been the most explored over the years for the production of molds^(23,27) or final prostheses^(32,44). Polyjet (PJ) technology stood out for its ability to produce models with high detail fidelity and realism^(37,39,46). The variety of printing technologies, however, presents a challenge: the choice of manufacturing method directly impacts the cost and mechanical properties of the prosthesis, which requires in-depth technical knowledge on the part of the professional.

The use of 3D printing in both methods (direct and indirect) demonstrates its versatility. In the indirect method, printing a mold or physical model⁽¹⁹⁾ allows the application of traditional prosthetics techniques with a digital workflow. In the direct method, additive manufacturing allows the printing of supports, surgical guides, and even the final prosthesis⁽⁵³⁾, eliminating manual steps and ensuring

greater dimensional accuracy.

Benefits of the digital transition for aesthetic rehabilitation

Analysis of the findings (Table 2) shows that the gains from digital transition go beyond the technical. The reduction in consultations and chair time^(23,50), the elimination of invasive exams such as CT⁽³⁹⁾, and the simplification of time-consuming steps⁽⁴⁸⁾ demonstrate a direct impact on clinical practice and patient experience. Increased satisfaction reinforces the benefit of aesthetic predictability and process optimization⁽⁴³⁾. Technological democratization with low-cost devices suggests that these benefits may become accessible to a larger number of patients, expanding access to high-quality aesthetic rehabilitation.

Challenges and Future Perspectives

Despite advances, the scope review identified important gaps. The main barrier to large-scale adoption remains the high initial cost of equipment and the need for technical training, a limitation that has persisted from early studies⁽²¹⁾ to the most recent ones^(41,50). The future prospects, however, are promising and are already being explored in the literature. The development of new materials, such as the hybrid PCL and TPU scaffold⁽⁵⁴⁾, indicates a direction of research that seeks to mimic not only the aesthetics but also the mechanical and functional properties of tissues. In addition, the validation of digital workflows for bilateral prostheses⁽⁵¹⁾ and the use of smartphone applications⁽⁵⁷⁾ pave the way for research focused on simplifying and scaling the process.

In short, the literature demonstrates a consistent and convergent evolution of methods, with additive manufacturing and 3D scanning consolidating themselves as the backbone of modern ear rehabilitation. The challenge now lies in overcoming

economic and qualification barriers, ensuring that technology, which has already proven its clinical effectiveness, can be democratized and widely adopted, transforming prosthetic care into a more accessible and patient-centered practice.

CONCLUSION

This scoping review has demonstrated that additive manufacturing has established itself as one of the technological pillars of modern prosthetic ear rehabilitation, transforming a traditionally manual process into a digital and predictable workflow. The findings confirm the evolution of two primary methods, direct and indirect, which are establishing themselves as viable and efficient alternatives to conventional techniques. These workflows not only optimize production, reducing time and costs, but also enhance the quality and realism of prostheses, directly impacting patient satisfaction and well-being. Despite persistent barriers, such as the high cost of equipment and the need for specialized training, the growing trend toward technological democratization is driving large-scale adoption. The validation of low-cost solutions, such as smartphone photogrammetry and the development of open-source software, signals a future in which cutting-edge technology will be more accessible, expanding the reach and impact of digital ear rehabilitation. In short, the transition to digital manufacturing represents more than a mere change in technique; it is a move toward democratizing access to high-quality prostheses. The future of digital anaplastology lies in overcoming economic and training gaps while exploring the potential of new biomaterials and advanced customization, solidifying prosthetic rehabilitation as a discipline of engineering, art, and human care.

REFERENCES

1. Khobkhun P, et al. An anthropometric study of the external ear in the Thai population. *J Plast Reconstr Aesthet Surg*. 2022;75(4):1417-23.
2. Tang L, et al. The ideal proportion of the auricle exposure via a morphometric analysis in Asian women. *Aesthet Plast Surg*. 2024;48:2611-7.
3. Lei L, et al. A survey of aesthetic standards of the ear. *J Craniofac Surg*. 2020;31(2):527-9.
4. Lee W, et al. Anthropometric analysis of 3D ear scans of Koreans and Caucasians for ear product design. *Ergonomics*. 2018;61(11):1480-95.
5. Sundar PS, Chowdhury C, Kamarthi S. Evaluation of human ear anatomy and functionality by axiomatic design. *Biomimetics*. 2021;6(2):31.
6. Ladani P. Ear reconstruction. In: Bonanthaya K, et al., editors. *Oral and Maxillofacial Surgery for the Clinician*. Singapore: Springer; 2021. p. 731-45.
7. Klassen AF, et al. An international study to develop the EAR-Q patient-reported outcome measure for children and young adults with EAR conditions. *J Plast Reconstr Aesthet Surg*. 2021;74(9):2341-8.
8. Joukhadar N, et al. Management of congenital auricular anomalies. *Plast Reconstr Surg*. 2020;146(2):205e-16e.
9. Sakae E, Aki F. Estudos das complicações na reconstrução de orelha [dissertação]. São Paulo: Universidade de São Paulo; 2007.
10. Giot JP, Labbe D, Soubeyrand E, Pacini R, Guillou-Jamard MR, Compere JF, et al. Prosthetic reconstruction of the auricle: indications, techniques, and results. *Semin Plast Surg*. 2011;25(4):265-72.
11. Mevio E, et al. Bone-anchored titanium implants in patients with auricular defects: three years and 27 patients' experience. *Int J Otolaryngol*. 2016;2016:9872048.
12. Bhatti SL, et al. Ear abnormalities. *Pediatr Rev*. 2021;42(4):180-8.
13. Viswanathan AK, Chidambaranathan AS. Effective rehabilitation of auricular defects with two different prosthetic materials: case reports. *Tanta Dent J*. 2024;21(1):105-9.
14. Tanveer W, et al. Applications of CAD/CAM technology for craniofacial implants placement and manufacturing of auricular prostheses—systematic review. *J Clin Med*. 2023;12(18):5950.
15. Aromataris E, Lockwood C, Porritt K, Pilla B, Jordan Z. *JBIM manual for evidence synthesis*. JBI; 2024.
16. Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. *Ann Intern Med*. 2018;169:467-73.
17. Chee Kai C, et al. Facial prosthetic model fabrication using rapid prototyping tools. *Integr Manuf Syst*. 2000;11(1):42-53.
18. Gebhardt A. Rapid prototyping based design and manufacturing of facial prostheses. *Phi-dias Report*. 2000;4:4-8.
19. Sykes LM, et al. Applications of rapid prototyping technology in maxillofacial prosthetics. *Int J Prosthodont*. 2004;17(4).
20. Jiao T, et al. Design and fabrication of auricular prostheses by CAD/CAM system. *Int J Prosthodont*. 2004;17(4).
21. Ciocca L, Scotti R. CAD-CAM generated ear cast by means of a laser scanner and rapid prototyping machine. *J Prosthet Dent*. 2004;92(6):591-5.
22. Chandra A, et al. Application of rapid manufacturing techniques in support of maxillofacial treatment: evidence of the requirements of clinical applications. *Proc Inst Mech Eng B J Eng Manuf*. 2005;219(6):469-75.
23. Mardini M, Ercoli C, Graser GN. A technique to produce a mirror-image wax pattern of an ear

using rapid prototyping technology. *J Prosthet Dent.* 2005;94(2):195-8.

24. Bibb R, et al. An investigation of three-dimensional scanning of human body surfaces and its use in the design and manufacture of prostheses. *Proc Inst Mech Eng H J Eng Med.* 2006;214(6):589-94.

25. Subburaj K, et al. Rapid development of auricular prosthesis using CAD and rapid prototyping technologies. *Int J Oral Maxillofac Surg.* 2007;36(10):938-43.

26. Karayazgan-Saracoglu B, Gunay Y, Atay A. Fabrication of an auricular prosthesis using computed tomography and rapid prototyping technique. *J Craniofac Surg.* 2009;20(4):1169-72.

27. Turgut G, et al. Use of rapid prototyping in prosthetic auricular restoration. *J Craniofac Surg.* 2009;20(2):321-5.

28. Karatas MO, et al. Manufacturing implant supported auricular prostheses by rapid prototyping techniques. *Eur J Dent.* 2011;5(4):472-7.

29. Liacouras P, et al. Designing and manufacturing an auricular prosthesis using computed tomography, 3-dimensional photographic imaging, and additive manufacturing: a clinical report. *J Prosthet Dent.* 2011;105(2):78-82.

30. De Crescenzo F, et al. Design and manufacturing of ear prosthesis by means of rapid prototyping technology. *Proc Inst Mech Eng H J Eng Med.* 2011;225(3):296-302.

31. Bai S, et al. Development and application of a rapid rehabilitation system for reconstruction of maxillofacial soft-tissue defects related to war and traumatic injuries. *Mil Med Res.* 2014;1(1):11.

32. He Y, Xue G, Fu J. Fabrication of low cost soft tissue prostheses with the desktop 3D printer. *Sci Rep.* 2014;4:6973.

33. Watson J, Hatamleh MM. Complete integration of technology for improved reproduction of auricular prostheses. *J Prosthet Dent.*

2014;111(5):430-6.

34. Artioli BO, Maluf NN, Roxo VGL. Produção de um protótipo de prótese de pavilhão auricular [monografia]. São Paulo: Pontifícia Universidade Católica de São Paulo; 2014.

35. Nuseir A, et al. Improved construction of auricular prosthesis by digital technologies. *J Craniofac Surg.* 2015;26(6):e502-5.

36. Moretto E, et al. Elaboração de próteses auriculares individualizadas por meio de manufatura auxiliada por computador. In: *Brazilian Symposium on Computing Applied to Health (SBCAS)*; 2016; Porto Alegre. Porto Alegre: Sociedade Brasileira de Computação; 2016. p. 2461-70. doi:10.5753/sbcas.2016.9892.

37. Mohammed MI, et al. Advanced auricular prosthesis development by 3D modeling and multi-material printing. *KnE Eng.* 2017:37-43.

38. Yadav S, et al. CAD/CAM-assisted auricular prosthesis fabrication for a quick, precise, and more retentive outcome: a clinical report. *J Prosthodont.* 2017;26(7):616-21.

39. Jamayet NB, et al. A fast and improved method of rapid prototyping for ear prosthesis using portable 3D laser scanner. *J Plast Reconstr Aesthet Surg.* 2018;71(6):946-53.

40. Mohammed MI, et al. Augmented patient-specific facial prosthesis production using medical imaging modeling and 3D printing technologies for improved patient outcomes. *Virtual Phys Prototyp.* 2018;13(3):164-76.

41. Sarkar MA, Chahar P, Gowda EM, Prakash P. Rehabilitation of a patient of traumatic anotia using computer aided designing and rapid prototyping. *Int J Contemp Med Res.* 2019;6(1):A18-A21.

42. Unkovskiy A, et al. Additive manufacturing: a comparative analysis of dimensional accuracy and skin texture reproduction of auricular prostheses replicas. *J Prosthodont.* 2019;28(2):e460-8.

43. Unsal GS, Turkyilmaz I. Improved recon-

struction of an implant-retained auricular prosthesis using CAD/CAM technology. *J Dent Sci.* 2019;14(3):328.

44. Cevik P, Kocacikli M. Three-dimensional printing technologies in the fabrication of maxillofacial prosthesis: a case report. *Int J Artif Organs.* 2020;43(5):343-7.

45. Cruz RL, et al. Advancements in soft-tissue prosthetics part A: the art of imitating life. *Front Bioeng Biotechnol.* 2020;8:121.

46. Manju V, et al. Rapid prototyping technology for silicone auricular prosthesis fabrication: a pilot study. *J Head Neck Physicians Surg.* 2021;9(1):35-40.

47. Bi Y, Zhou M, Wei H. Digital workflow for auricular prosthesis fabrication with a negative mold. *J Prosthet Dent.* 2024;131(6):1254-8.

48. Singh K, Bhandari SK. Rehabilitation of a patient with anotia with implant-retained silicone auricular prosthesis using custom fabricated abutments and bar: a case report. *Int J Prosthodont Restor Dent.* 2022;12(1):42-5.

49. Netshilindi N, Asia-Michaels W, Maart R. An innovative digital workflow for the fabrication of a prosthetic ear: a case report. *S Afr Dent J.* 2023;78(2):92-6.

50. Sharma S, et al. Reverse engineering and CAD/CAM application in the design of maxillofacial prosthesis. *Int J Interact Des Manuf (IJIDeM).* 2025;19(2):1179-93.

51. Hatamleh MM, Hatamlah HM, Nuseir A. Use of 3-dimensional imaging and manufacturing for bilateral auricular prostheses: A case series of six patients with congenital auricular defects. *J Prosthet Dent.* 2024;132(5):1076-81.

52. Kasahara T, et al. Accuracy of the Conventional Facial Impression Method and Three-Dimensional Auricular Shape Data Obtained Using Extra-and Intraoral Optical Scanners. *Dent J.* 2024;12(11):354.

53. Kim M, et al. One-year results of ear reconstruction with 3D printed implants. *Yonsei Med J.* 2024;65(8):456-62.

54. Capotorto E, et al. Toward improved auricle reconstruction: The role of FDM 3D printing with PCL and TPU materials. *Biomater Adv.* 2025;169:214175.

55. İnal CB, Ayten UC, Nemli SK. Replacement implant-retained ear prosthesis using a semidigital workflow: A case report. *Int J Prosthodont.* 2025;38(2).

56. İnal CB, Bankoğlu GM, Karakoca NS. Using a smartphone three-dimensional scanning application (Polycam) to three-dimensionally print an ear cast: a technique. *J Prosthet Dent.* 2025;133(3):926-8.

57. Kaul RD, et al. A comparison of the accuracy and feasibility of a low-cost mobile application versus higher-cost handheld 3D scanner for digital ear prosthetics. *ANZ J Surg.* 2025;95(4):719-26.

58. Gadallah MA, Khamis MM, Abdelhamid AM, Ezzelarab S. Evaluation of the use of different intraoral scanners for auricular prosthetic reconstruction. *J Prosthet Dent.* 2025;134(2):513-9. doi:10.1016/j.prosdent.2023.09.028.

59. Nightingale RC, Price GL, Pickering E, Powell SK, Woodruff MA. Comprehensive smartphone-based 3D scanning framework for capturing the external ear. *J Plast Reconstr Aesthet Surg.* 2025;108:26-33.

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