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Laser Sintering a Solution for Casting Defects: A Systematic Review and Meta Analysis

Abstract:

Introduction : The available evidence regarding the impact of newer techniques, such as Direct Metal Laser Sintering (DMLS), on casting defects when compared to the conventional lost-wax method for both single-unit and multi-unit prostheses is limited. In addition to this literature on whether it increases the longevity of multiunit bridges was also insufficient.

Purpose : The purpose of this systematic review was to evaluate how does new casting procedures like direct metal laser sintering (DMLS) effect the casting defects as compared to conventional lost was technique and whether it increases the longevity of multiunit bridges.

Material and methods: MEDLINE (PubMed), Cochrane Library, Embase, Web of Science, and Google Scholar databases were electronically searched and manual searches in various prosthodontic and engineering journals was also conducted. Later results for casting defects and marginal adaptation in single and multiunit bridges were statistically analysed to bridge the knowledge gap of its relevant effects. Prisma guidelines were followed for data collection.

Results: There was a statistically significant difference in casting defects incurred by DMLS and lost wax casting. The marginal adaptation was found better in DMLS group as compared to conventional lost wax for both single unit and multiunit coping.

Conclusion: *I*n conclusion, DMLS presents a compelling alternative to traditional lost wax casting. This advanced technique effectively reduces casting defects, improves the mechanical properties of the final product, and ensures a clinically acceptable marginal fit for both single and multi-unit dental prostheses.

Key-words: laser sintering, DMLS, casting defects

Introduction:

Conventional lost wax casting is most widely used manufacturing processes for producing metal-ceramic frameworks due to its simplicity, minimal equipment requirements, and cost-effectiveness. However conventional casting has its own set of limitations including coarse surfaces and presence of internal defects that may cause series of unanticipated problems. Moreover, the casting process itself is relatively complex, involving multiple stages such as wax pattern fabrication, investing, wax elimination, casting, devesting, finishing, and polishing.[1]

Advancements in digital technology and the emergence of CAD/CAM manufacturing have introduced alternative methods like computer numerical control (CNC) milling for producing cobalt-chromium prostheses. CNC milling offers notable advantages, such as reducing the need for multiple patient appointments and bypassing issues associated with impression-taking and casting-induced defects, thereby improving the quality and fit of dental reconstructions.[2]

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Recently, additive manufacturing (AM) technologies—also known as three-dimensional (3D) printing or rapid prototyping—have gained attention as a transformative approach in prosthesis fabrication.[1] Techniques such as selective laser melting (SLM), selective laser sintering (SLS), and fused deposition modeling (FDM) allow for the layer-by-layer construction of 3D objects directly from CAD models. These methods contrast with traditional subtractive manufacturing by offering greater design flexibility, material efficiency, and the ability to produce highly complex geometries in a single production stage.[3]

Selective laser sintering (SLS), in particular, utilizes laser beam of high energy to selectively fuse powdered metal materials, resulting in structures with high density and precision (up to 99.8%). The digital workflow includes CAD modeling, data slicing, powder layering, sintering, and post-processing. SLS has been successfully used in the fabrication of complete metal crowns and frameworks, with clinical evaluations often focusing on marginal fit, occlusal accuracy, and axial adaptation. Poor marginal fit can contribute to plaque accumulation, microleakage, cement degradation, and ultimately lead to secondary caries, pulpal irritation, and periodontal inflammation.[4]

Given these considerations, this systematic review aims to evaluate the effectiveness of new procedures such as direct metal laser sintering (DMLS) in reducing casting-related defects when compared to the conventional lost wax technique. The review also investigates whether DMLS contributes to improved clinical outcomes and greater longevity in both single-unit and multi-unit dental prostheses.

Material and Methods:

Protocol And Registration:

This review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines 2020 statement[5] and has been registered in PROSPERO under the ID CRD42024605136

Review Question :

The research question is to evaluate how does new procedures like direct metal laser sintering (DMLS) effect the casting defects as compared to conventional lost wax technique in multiunit and single unit prosthesis and whether it increases the longevity of multiunit bridges?

According to PICO Criteria :

Population – multiunit and single unit bridges

Intervention – Direct metal laser sintering

Control – Conventional lost wax technique

Outcome – Effect on casting defects and longevity

Search Strategy:

The current systematic review's search was extensive and multidisciplinary in its design[6] (Electronic searches were carried out using the following databases: MEDLINE (PubMed), Cochrane Library, Embase, Web of Science, and Google Scholar.

In addition to electronic searches, manual searches were conducted through journals such as the Journal of prosthodontics, Journal of Prosthetic dentistry, British Dental Journal, Journal of Prosthodontic Research, Contemporary Clinical Dentistry, Journal of Advanced Prosthodontics, Journal of Prosthetic and Implant Dentistry, International Journal of Prosthodontics and Restorative Dentistry, The Journal of Indian Prosthodontic Society, and other relevant journals. Furthermore, engineering journals related to additive manufacturing and 3D printing will also be reviewed for relevant reference articles.

A combination of keywords such as laser sintering, DMLS, cast metal, FPD, single coping was used for the search strategy. Boolean operators such as AND, OR, and NOT were utilized together with the search terms[7] The search queries in the database were developed based on PICO questions. Supplementary manual searches were performed by the reviewers by reviewing the sources listed in the bibliography.[8]

Eligibility Criteria:

Inclusion Criteria :

1. Peer reviewed scientific journals from 2010-2024
2. All studies on casting defects published in 2010 - till date
3. In vitro studies, in vivo studies, randomized clinical trials
4. Casting defects in multiunit and single unit prosthesis
5. Direct metal laser sintering and its effect on reduction of casting defects
6. Studies which compared Lost wax technique versus DMLS
7. Studies which compared Lost wax technique versus CAD-CAM versus DMLS
8. Studies which describe characteristics of metal copings fabricated with laser sintering and lost wax technique

Exclusion criteria:

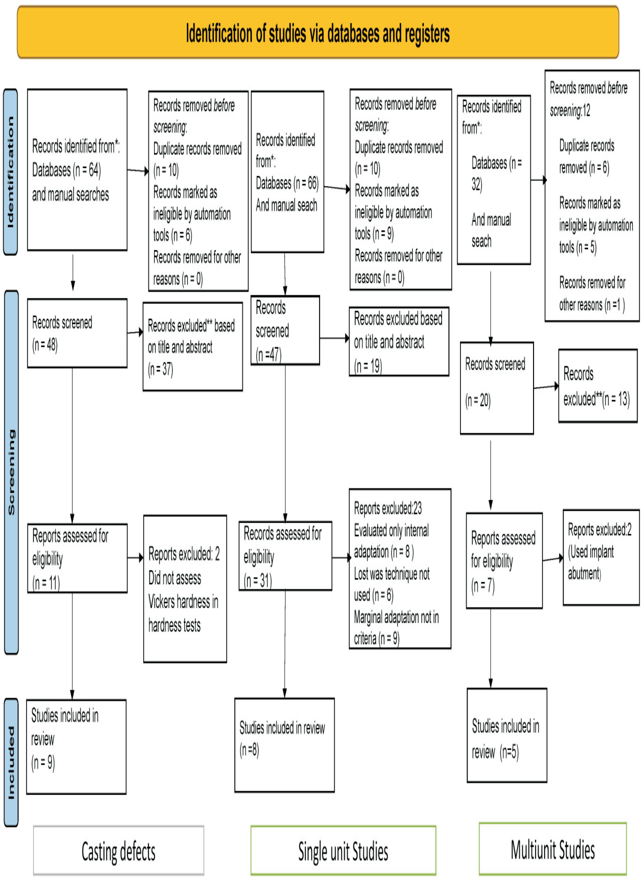
1. Articles with incomplete data were excluded
2. Studies on casting defects before 2010
3. Implant supported prosthesis
4. Traditional casting materials

Data Selection:

The data selection was conducted following a systematic process by two independent reviewers:

1. Title Screening: Titles of identified articles were independently assessed for relevance based on inclusion criteria.
2. Abstract Screening: Studies meeting criteria progresses to full-text review, and doubtful cases were included for further consideration.
3. Full-Text Review: Full texts were assessed separately. Any disagreements were resolved through joint discussion.

Prisma flow chart
(Figure 1)



Data Extraction:

Two reviewers independently extracted pertinent information from the included articles and captured for each study: Author name, year of publication, journal name and porosity, vicker hardness value and mean marginal adaptation in groups CAST and DMLS documented their findings on a standardized data extraction form. (Table 1-2)

TABLE I - Data extraction sheet of casting defect porosity and Vickers hardness test values for lost wax and DMLS groups

Author	Journal	Year	Porosity		Vickers Hardness test	
			LWT	DMLS	LWT	DMLS
YS !l Jabbari et al [9\	Dent Mater	2014	Present	Absent	320(12)	371(17)
Ana R Lapcevic et al [10]	Rapid Prototyping journal	2014	Present	Absent	373.76	439.84
Maria Kassapidou et al[11]	J Prosthet Dent	2023	Present	Absent	301(17)	564(62)
Youssef Al Jabbari et al[12]	J Prosthet Dent	2024	Present	Few		
Marit Oilo et al [13\	J Prosthet Dent	2018	Present	!bsent	264(11)	466(13)
Youssef S Al Jabbari et al [14\	J Prosthodont Res	2019	Present	!bsent		
Xian - Zhen Xin et al [15\	Cell Biochem Biophys	2013			384.8(15.56) 458.3(5.8)	
Yun-Jung Choi et al [2\	The J of Korean !cad of Prostho	2014			455.8(37.08) 413.1(8.77)	
Yanan Zhou et al [1\	J Prosthet Dent.	2018			323.7(27.2) 475.3(10.2)	

*LWT: lost wax technique, †DMLS: Direct metal laser sintering

TABLE II - Data extraction sheet of mean marginal gap in multiunit bridges and single unit copings of lost wax and DMLS groups

!UTHOR	JOURN!L	YE!R	RESTOR!TION	TOOTH	ME!N M!RGIN!L G!P	
					DMLS	LWT
Kim baek kim et al[16]	Dent Mater	2013	Multiunit	Premolar Molar	113.3(47.9) 112.0 (52.2)	78.9(14) 80.0(19)
!nders Örtorpa et al [17\	Dent Mater	2013	Multiunit	Premolar Molar	69 99	166 121
Giorgio Pompa et al [18\	Biomed Res International	2015	Multiunit	Premolar Molar	51.87 (19.57) 47.58(15.8) 66.8 (26.4)	67.9 (17.9)
Dahl BE et al [19\	Eur J Oral Sci.	2017	Multiunit	Premolar Molar	74 (23) 81(33)	87 (63) 87(53)
!hmed !ffy et al [20\	J Prosthet Dent	2018	Multiunit	Premolar Molar	31.0 (15.4) 34.3 (23.9)	93.8(46.1) 87.0(38.5)
Dan Xu et aL[21\	J Prosthet Dent	2014	Singleunit	Premolar	102(40.5) 170.19(66.1)	
Hao-Sheng Chang et al [22\	J Dent Sci.	2019	Singleunit	Molar	116(92)	76(61)
Bhushan Satsh Gaikwad et al [23\	J Indian Prosthodont Soc	2018	Singleunit	Stainless steel master die	24.6 (11.68)	39.53(16.5)
Manoj Kumar Sunder et al [24\	J Prosthodont Res	2014	Singleunit	Premolar	56.2(11.07) 66.2(12.7)	
Ki-Baek Kim et al [25\	J !dv Prosthodont	2013	Singleunit	Molar	75.0(9.9)	62.3(14.3)
Ece tamac et al [26	J Prosthet Dent.	2014	Singleunit	Molar	96.23(26.94)	75.92(21.0)
Ki-Baek Kim et al [27 \	J Prosthet Dent.	2014	Singleunit	Molar	47.3(8.6)	64.1(14.2)
Eswaran Bhaskaran et al [28\	J Indian Prosthodont Soc	2013	Singleunit		10.52	45.36

*LWT: lost wax technique, †DMLS: Direct metal laser sintering

Investigation of Publication Bias :

A begg's funnel plot was employed to evaluate the likelihood of publication bias.[29].Egger's regression test and Begg's rankcorrelation test was used to assss publication bias.

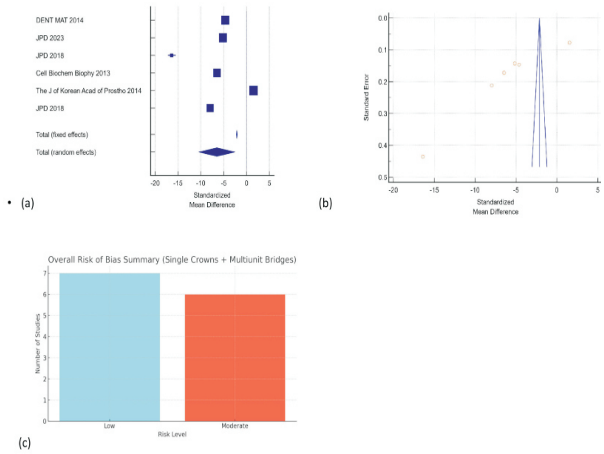
Investigation of Risk of Bias:

The Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Analytical Cross-Sectional Studies was used. Each domain was rated as low, moderate, or high risk based on predefined criteria related to selection bias, measurement reliability, and outcome reporting. Reviewer agreement was reached through consensus

Results:

Synthesis of result:

A total of six studies were included in the meta-analysis to evaluate the standardized mean difference (SMD) between the groups. The forest plot (Figure 2a) demonstrates a consistent trend favoring the DMLS group across most studies. The fixed-effects model calculated a pooled Standardized Mean Difference (SMD) of -2.138 (95% CI: -2.247 to -2.029; p < 0.001), while the random-effects model, accounting for heterogeneity, yielded a more pronounced SMD of -6.498 (95% CI: -10.502 to -2.494; p = 0.001).The width of the confidence intervals in the random-effects model reflects between-study variance, which may be attributed to differences in sample size, methodological approach, and measurement techniques. Despite these variations, the central tendency of most studies still points toward DMLS as the superior technique in minimizing casting defects and achieving improved marginal adaptation.



Funnel plot analysis (Figure 2b) indicated a slight asymmetry, suggestive of potential publication bias. While the Egger's and Begg's tests were not conclusive due to limited study number, the visual skew supports cautious interpretation.

The consistency of statistically significant findings across both models supports the robustness of the observed effect, although the high heterogeneity underscores the importance of context and potential study-level moderators.

TABLE III - Comparison of marginal gaps between LWT and DMLS in various studies. The table shows standard mean deviation (SMD) with standard error (SE), 95% confidence intervals (CI), and statistical significance (p values). Weight percentages represent each study's contribution to the overall effect size under fixed and random effects models.

STUDY	LWT	DMLS	TOTAL	SMD	SE	95%CI	P	Weight(%)	
								Fixed	Random
1) Dent Mater. 2014 YS !I Jabbari et al [9\	320	371	691	-4.643	0.146	-4.931 to - 4.356		14.41	16.69
2) J Prosthet Dent. 2023 Maria Kassapidou et al[11]	301	564	865	-5.145	0.143	-5.426 to - 4.865		15.14	16.69
3) J Prosthet Dent. 2018 Marit Oilo et al [13\	264	466	730	- 16.386	0.436	-17.241 to - 15.530		1.63	16.58
4) Cell Biochem Biophys. 2013Xian - Zhen Xin et al [15\	384	458	842	-6.471	0.172	-6.809 to - 6.134		10.42	16.68
5) J Korean Acad Prosthodont . 2014Yun-Jung Choi et al [2\	455	413	868	1.550	0.077 4	1.398 to 1.702		51.53	16.70
6) J Prosthet Dent. 2018 Yanan Zhou et al [1\	323	475	798	-7.966	0.212	-8.382 to - 7.550		6.87	16.67
Total (fixed effects)	2047	2747	4794	-2.138	0.055 6	-2.247 to - 2.029	<0.00 1	100.0 0	100.00
Total (random effects)	2047	2747	4794	-6.498	2.042	-10.502 to - 2.494	0.001	100.0 0	100.00

Contd*LWT: lost wax technique, †DMLS: Direct metal laser sintering, ‡ SMD: Standard mean deviation, § SE: Standard Error, ¦ CI: Confidence interval.

GRADE Assessment:

A GRADE (Grading of Recommendations, Assessment, Development and Evaluations) approach was used to evaluate the certainty of evidence for the two primary outcomes: casting defects and marginal adaptation.

Marginal Adaptation:

The certainty of evidence was rated as moderate, downgraded for suspected publication bias based on funnel plot asymmetry. Casting Defects: The certainty of evidence was rated as low, due to methodological heterogeneity (differences in study design, measurement tools, and variability in reporting).

These assessments reflect the need for higher-quality, standardized, and clinically oriented studies to confirm the benefits of DMLS observed in controlled environments.

Results of publication bias:

Assessment of publication bias was performed using Egger's regression test and Begg's rankcorrelation test.

- **Egger's test** showed a statistically significant intercept of **-65.2185** (95% CI: -94.4446 to -35.9924;P= 0.0035), indicating potential small-study effects or publication bias.

Similarly, **Begg's test** using Kendall's Tau yielded a value of **-0.8667** with a significant P-value of **0.0146**, further supporting the presence of publication bias.

Results of Risk of Bias of Single Unit and Multiunit Bridge Data:

The combined Risk of Bias Summary and Graph for Single Crowns + Multiunit Bridges studies.

- 7 studies are at Low risk of bias.
- 6 studies are at Moderate risk of bias.
- No studies were rated High risk.[Figure 2©]

Discussion:

Historically, the lost wax technique has remained the cornerstone of dental casting due to its affordability and simplicity[30]. However, the complexity of its multi-step process renders it vulnerable to various errors such as porosity, marginal discrepancies, and internal voids—all of which may compromise the prosthesis fit and longevity[31].These shortcomings often translate into clinical complications including, increased plaque retention, microleakage, secondary caries, and reduced prosthesis durability.[32]

This systematic review aimed to evaluate the effectiveness of newer manufacturing techniques such as Direct Metal Laser Sintering (DMLS), an additive manufacturing process, in reducing casting defects and improving clinical outcomes in both single and multiunit dental prostheses compared to the conventional lost wax technique.

This review included studies primarily focused on cobalt-chromium (Co-Cr) alloys, due to their favorable properties such as high corrosion resistance and reduced allergenicity compared to nickel-chromium alloys.[32]The pooled data analysis revealed a statistically significant reduction in casting-related defects in the DMLS group versus the conventional casting group. Most studies consistently reported the absence or minimal presence ofporosity in the DMLS group, whereas porosity was commonly noted in conventionally cast specimens. According to Theodoros Koutsoukis et al porosity not only weakens structural integrity but also accelerates corrosion via mechanisms like pitting and crevice corrosion.[33]

In terms of mechanical performance, Vickers hardness values were significantly higher in the DMLS group, suggesting a finer microstructure and better surface integrity. The increased hardness can be attributed to the rapid solidification and controlled thermal cycle inherent to laser sintering. Moreover, the SLM technique, a variant of DMLS, theoretically enables a nearly 100% dense microstructure, contingent on optimal process parameters such as scan speed, thickness of layer and laser energy as concluded by Theodoros Koutsoukis et al.[33]

From a clinical standpoint, marginal adaptation is a critical determinant of prosthesis longevityas mentioned byCatherine N. Maundu[34]. The reviewed data suggest that DMLS-fabricated prostheses exhibit enhanced marginal fit compared to those produced using the traditional technique. For both single and multiunit restorations, DMLS yielded mean marginal gap values that were either within or substantially below 120 µm that is considered within clinical norms as suggested by McClean and von Fraunhofer [35]. This is in alignment with findings by Papadiochou, Pissiotis, and others who concluded that laser-sintered restorations provided enhanced fit and functional adaptation[4]. In several studies included in this review, DMLS consistently outperformed CAST in both premolar and molar regions of multiunit frameworks, highlighting its reliability across different spans. The clinical relevance of these findings extends beyond improved initial fit. Studies such as that by Radhakrishnan Prabhu et al. reported a survival rate of 95.5% for laser-sintered metal-ceramic FPDs, compared to 84.3% for cast restorations[36]. Similarly, Kaleli et al. emphasized the superior mechanical resilience of laser-sintered prostheses, particularly for long-span bridges, which are more susceptible to biomechanical failures[37]. While these outcomes suggest a positive trajectory for additive manufacturing, the long-term clinical efficacy and biological impact of DMLS prostheses remain areas requiring further exploration through robust clinical trials.

Despite the compelling findings, this systematic review is not without limitations. A major limitation was the scarcity of high-quality clinical trials directly comparing casting defects in crowns rather than laboratory specimens. Most conclusions were derived from in vitro studies, which may not fully replicate the complexities of the oral environment. Furthermore, the presence of publication bias, as indicated by Egger's and Begg's tests, suggests that studies with positive outcomes may have been more likely to be published, potentially inflating the perceived benefits of DMLS.

Conclusion:

In conclusion, DMLS offers a promising alternative to conventional lost wax casting by minimizing casting defects, enhancing mechanical properties, and achieving clinically acceptable marginal fit in both single and multiunit prostheses. However, future clinical research with long-term follow-up is warranted.

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