

Mechanical Properties of CAD/CAM Frameworks Vs. Conventional Methods (Systematic Review)

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Abstract

Background: The use of cobalt-based alloys, particularly cobalt-chromium, for fabricating metal frameworks in removable partial dentures became widespread from 1930 onward owing to their mechanical and chemical properties. Other materials such as titanium and its alloys, as well as PEEK/PEKK, are also used to fabricate removable partial denture (RPD) frameworks. Their manufacture follows different processes. The aim of this systematic review is to compare the mechanical properties of frameworks produced by conventional methods with those produced by CAD/CAM techniques (SLM, DMLS, DMLM).

Materials and methods: This systematic review was conducted according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 2020 guidelines. It included prospective and retrospective studies, randomized controlled trials, and in vitro studies. The review focused on the mechanical properties of removable partial denture frameworks fabricated by conventional methods or by CAD/CAM. Only studies published between 2015 and 2025 were searched.

Results: The 13 studies selected and analyzed revealed that CAD/CAM produces frameworks with a more homogeneous microstructure and higher hardness (502.86 HV for SLM versus 416.53 HV for casting). However, CAD/CAM-fabricated frameworks may show greater surface roughness and require polishing to achieve a satisfactory clinical fit.

Conclusion: Overall, CAD/CAM appears to offer superior mechanical performance. However, conventional techniques retain an important role in clinical practice. Finally, since all analyzed studies were conducted in vitro, it is useful to supplement these data with longitudinal clinical studies under real intraoral conditions.

Keywords: Removable partial denture – Framework materials – Mechanical properties – Conventional methods – CAD/CAM

1. Introduction

Historically, cobalt-based alloys, and cobalt-chromium alloys in particular, have been the materials most widely used for fabricating the frameworks of conventional removable partial dentures; their use has been

reported since the early 20th century and became widespread from the 1930s onward owing to their mechanical properties and corrosion resistance [3].

These alloys have long represented the reference standard for the study of metal frameworks, which explains why the majority of mechanical comparisons reported in the literature concern cobalt-chromium structures fabricated by different processes [17,21,23].

Titanium was also introduced as a metallic biomaterial in dentistry following advances in manufacturing processes after the Second World War, and it is now recognized for its mechanical performance and biocompatibility, being usable in pure form or as alloys such as Ti-6Al-4V [2,4,5]. Nevertheless, its mechanical behavior likewise remains closely dependent on the shaping process employed, which places its evaluation within the same comparative framework as that applied to cobalt-chromium alloys [2,4].

More recently, high-performance polymeric materials such as polyetheretherketone (PEEK) and polyetherketoneketone (PEKK) have been introduced in the prosthetic field, offering mechanical properties and chemical stability compatible with certain dental applications [7,8].

Their use is described as more recent and still limited, and their mechanical behavior likewise depends on the processing and manufacturing techniques employed, which again underscores the central role of the fabrication process in analyzing framework performance, independent of the material considered [8,10,11].

Most existing studies in the literature have focused on traditional metal alloys. Ours specifically incorporates a comparison with PEEK and PEKK, reflecting the current trend toward “metal-free” dentistry. This inclusion makes it possible to assess whether CAD/CAM techniques (milling vs. printing) offer mechanical properties comparable to metals for these newer materials. It is relevant to ask whether, in patients requiring prosthetic restorations, metal frameworks fabricated by CAD/CAM exhibit better mechanical properties than those obtained by conventional methods.

The central aim of this article is to compare the mechanical properties of frameworks produced using the conventional method versus the digital method. This systematic review could provide a basis for an experimental study of frameworks fabricated from different materials and techniques under intraoral biological conditions.

2. Methodology

This systematic review was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 2020 guidelines [46]. The protocol for this systematic review was registered in the international prospective register of systematic reviews PROSPERO under registration No. CRD420261439142.

2.1 Eligibility criteria

Inclusion criteria

Particular attention was paid to studies published between 2015 and 2025; only studies published in English were included. Prospective and retrospective studies, randomized clinical trials, and in vitro studies were included. The review focused on the mechanical properties of removable partial denture frameworks fabricated by conventional methods or by CAD/CAM.

Studies were selected according to eligibility criteria based on the PICO format (Population, Intervention, Comparison, Outcome), addressing the following research question: In patients requiring prosthetic restorations, do metal frameworks fabricated by CAD/CAM exhibit better mechanical properties than those obtained by conventional methods?

P (Population/Problem): Removable partial denture with a metal framework

I (Intervention): CAD/CAM fabrication, particularly laser fusion

C (Comparison): Conventional fabrication (lost-wax casting)

O (Outcomes): Mechanical properties of metal frameworks

Exclusion criteria

On one hand, systematic reviews, meta-analyses, clinical case studies, animal studies, case reports, letters to the editor, editorials, and conference papers without complete data were excluded.

On the other hand, studies focusing solely on non-metallic materials without a metallic control group, and non-peer-reviewed grey literature (opinions, editorials), were also excluded.

2.2 Information sources

A comprehensive literature search was conducted in the following electronic databases: PubMed/MEDLINE, Cochrane Library, Science Direct, and Google Scholar.

In addition, the reference lists of relevant systematic reviews and meta-analyses identified were manually screened to identify other potentially eligible studies (snowball search). The date of the last search of each source was documented at the time of the search.

2.3 Search strategy

A search of the PubMed, Cochrane Library, Science Direct, and Google Scholar electronic databases was conducted independently by two reviewers. The search terms and keywords are listed in Table 1.

Table 1: List of keywords used for the database search (MeSH terms)

Concepts	English keywords
Removable partial denture metal framework	Removable partial denture; Framework; Cast; Conventional; Laser
Biomaterials	Biomaterial; Material; Alloys; Properties; Mechanical; Biomechanics; Comparison/Comparative

The search was supplemented by a manual review of the references of the included studies and a review of prosthodontic journals to ensure comprehensiveness.

The search strategy was developed for each database using a combination of MeSH (Medical Subject Headings) terms and free-text keywords, adapted to the specific syntax of each platform. Keywords were based on the key concepts of the PICO question. Language filters (English only) and publication-date filters were applied.

This search strategy was adapted for all four databases using the following search strings:

- PubMed: Removable partial denture AND Framework OR Properties OR Mechanical OR Biomechanics OR Alloys OR Material OR Biomaterial OR Cast OR Conventional OR Laser OR Comparison OR Comparative (search conducted on August 2, 2025, yielding 3,176 initial results, then 358 after filters)
- Google Scholar: (“removable partial denture” [Mesh]) AND ((“framework” [Mesh]) OR (“properties” [Mesh]) OR (“mechanical” [Mesh]) OR (“biomechanics” [Mesh]) OR (“biomaterial” [Mesh]) OR (“alloys” [Mesh]) OR (“material” [Mesh]) OR (“cast” [Mesh]) OR (“conventional” [Mesh]) OR (“laser” [Mesh]) OR (“comparison” [Mesh]) OR (“comparative” [Mesh])) (This search string yielded 551 results, then 425 after applying the 2015-2025 filters and excluding citations/patents)

- Cochrane Library: The search was conducted using MeSH terms via the “search” field under “advanced search” for the key concepts. (Query yielding 347 results, then 215 trials after applying the 2015-2025 filters)
- Science Direct: The search was carried out by applying Boolean search strings, then refined using filters. (Search yielding 10,012 initial results, then 788 after filters)

The complete search strategy for each database was documented in an appendix to the final protocol.

2.4 Selection process

The bibliographic search results from all databases were exported to the Zotero reference management software for duplicate removal and citation management. The study selection process took place in two phases, each performed independently by two reviewers:

Initial title and abstract screening phase

Both reviewers screened the titles and abstracts of all identified studies. Each study was classified as “included,” “excluded,” or “uncertain.” Clearly irrelevant studies were excluded at this stage. Studies classified as “uncertain” or “included” proceeded to the next phase.

Final selection phase by full-text reading

In accordance with the eligibility criteria, the full content of the studies selected in the first phase was retrieved and carefully examined by both reviewers. Any misunderstandings or disagreements between reviewers were resolved through discussion and consensus. Where consensus could not be reached, a third reviewer was consulted.

Using a PRISMA flow diagram, the selection process was documented, illustrating the number of studies identified, screened, deemed eligible, and included at each stage. Reasons for excluding studies at the full-text stage were recorded.

2.5 Data collection process

Using a standardized, pre-tested data extraction form, data collection was performed independently. This form included the following information: authors' names, year of publication, study type, materials and fabrication techniques compared, and mechanical properties evaluated.

2.6 Risk-of-bias assessment

The risk of bias of each included study was assessed independently. Since these are in vitro studies, an assessment tool adapted for this purpose was used, namely QUIN (Quality Assessment Tool for In Vitro Studies). This tool comprises 12 specific criteria (often referred to as domains) used to analyze each stage of the study. Each domain was rated as having a “low,” “moderate,” or “high” risk of bias. The results of the risk-of-bias assessment were presented as a summary table for each included study. The implications of the risk of bias for the certainty of the evidence were taken into account when interpreting the results.

2.7 Synthesis methods: decision process

The decision process regarding study eligibility for each synthesis was based on the PICO criteria. After data extraction, the intervention characteristics of each study — fabrication methods compared (conventional, SLM, milling), key manufacturing parameters (e.g., laser power and scanning speed for SLM; machine type for milling), measured mechanical properties (mean values and standard deviations for hardness, yield strength, tensile strength, elongation, elastic modulus, and fatigue resistance), methods used to assess porosity and microstructure, and biocompatibility findings — were tabulated and compared across the groups planned for each synthesis.

3. Results

3.1 Study selection (PRISMA diagram)

The initial search identified a total of 14,086 articles (PubMed: 3,176; Cochrane: 347; Science Direct: 10,012; Google Scholar: 551). After applying filters, 1,786 articles were retained. Duplicate removal via Zotero reduced this number to 1,561 articles. After screening titles and abstracts, 70 articles were selected for full-text assessment. Finally, 13 studies were included in this systematic review. The selection process is illustrated by the PRISMA flow diagram below.

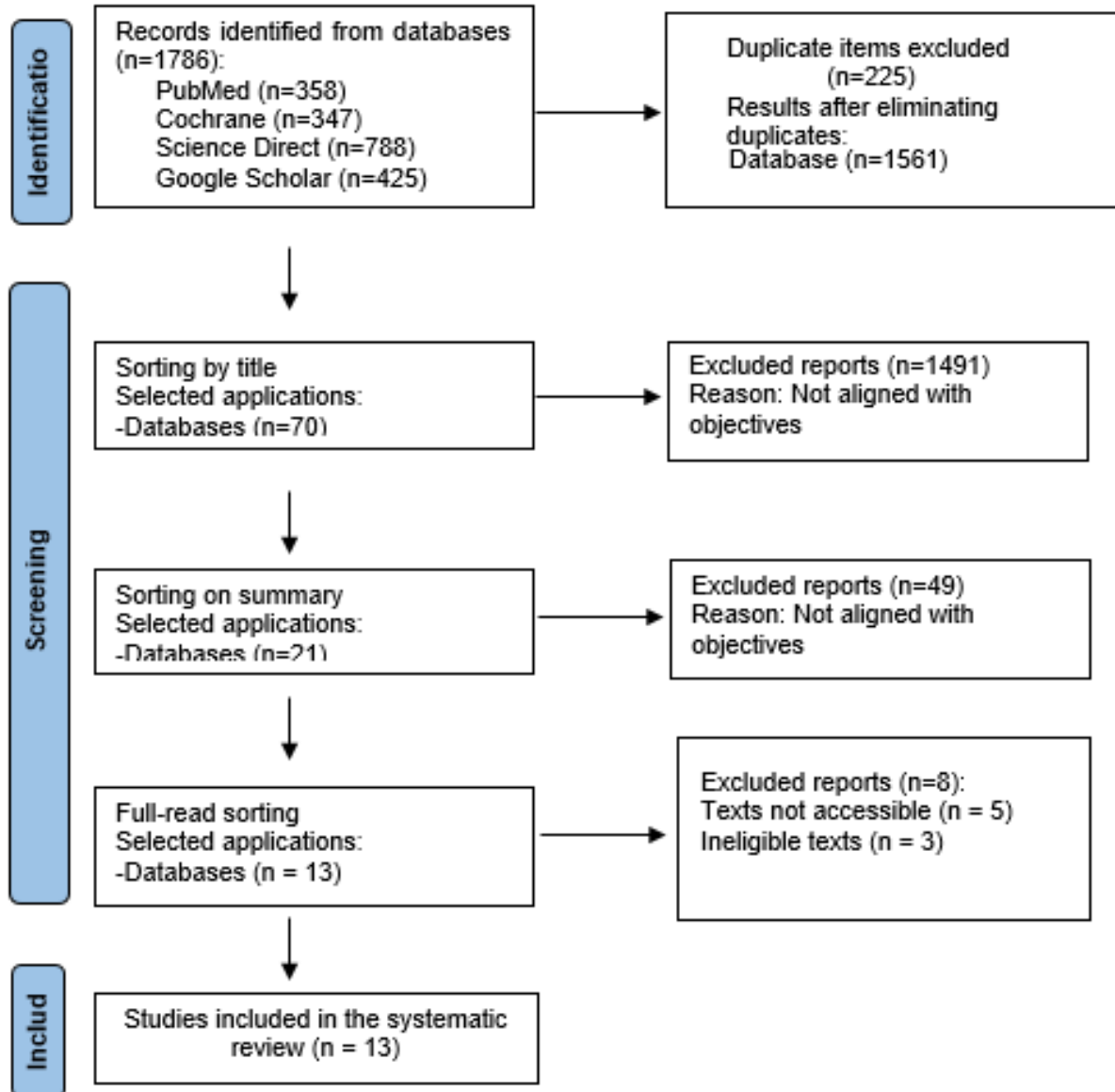


Figure 1: Flow diagram

3.2 Characteristics of included studies

Table 2 presents the main characteristics of the included studies, including authors, year of publication, study type, materials and fabrication techniques compared, and mechanical properties evaluated. The 13 studies retained for this review are summarized in Table 2 below:

Table 2: Main characteristics of the included studies

Ref .	Author(s)	Year	Title	Study type	Materials	Techniques	Mechanical properties evaluated	Results
[19]	Torii et al.	2018	Fitness and retentive force of Co–Cr alloy clasps fabricated with repeated laser sintering and milling	In vitro	Co-Cr	SLM + milling vs. casting	Adaptation, retention force	Clasps fabricated by repeated laser sintering + milling (hybrid) show better adaptation, a smoother surface, and higher, more stable retention forces than cast clasps, especially after heat treatment and insertion cycles.
[27]	Takahashi et al.	2020	Fitness accuracy and retentive forces of additive manufactured titanium clasp	In vitro	Titanium	Additive manufacturing	Fit precision, retention force	AM-fabricated titanium clasps show slightly lower fit accuracy than casting, but clinically acceptable retention forces and better retention stability after 10,000 cycles.

Ref.	Author(s)	Year	Title	Study type	Materials	Techniques	Mechanical properties evaluated	Results
[22]	Mutschler et al.	2020	Retention Forces of Prosthetic Clasps over a Simulated Wearing Period of Six Years	In vitro	Co-Cr	DMLM vs. casting	Long-term retention force	DMLM Co-Cr clasps show a slight increase in retention, while cast clasps show a moderate decrease, with no major clinical difference, after a 6-year simulation.
[29]	El-Baz et al.	2020	Comparative study of Co-Cr and PEEK RPD clasps	In vitro	Co-Cr, PEEK	Casting	Fatigue resistance, deformation, retention	Co-Cr clasps show higher retention, but PEEK shows better fatigue resistance and significantly less deformation after cycling.
[20]	Zhang et al.	2021	Retentive force and fitness accuracy of Co-Cr alloy clasps fabricated with SLM	In vitro	Co-Cr	SLM vs. casting	Fit accuracy, retention force	SLM and cast clasps show similar fit accuracy and initial retention, but SLM clasps retain better residual retention after 7,200 cycles.

Ref.	Author(s)	Year	Title	Study type	Materials	Techniques	Mechanical properties evaluated	Results
[24]	Lee et al.	2022	Microstructure, mechanical properties, and retentive forces of Co-Cr RPD frameworks by SLM	In vitro	Co-Cr	SLM (with/without heat treatment)	Microstructure, mechanical properties, retention force	SLM followed by heat treatment improves microstructure, ductility, mechanical properties and retention forces, exceeding those of SLM alone and of casting.
[17]	Salim et al.	2022	Physicomechanical properties of Co-Cr RPD palatal major connectors by SLM	In vitro	Co-Cr	SLM vs. casting	Microhardness, surface roughness, microstructure	SLM connectors show higher microhardness and a homogeneous microstructure, but less favorable surface fit and roughness than casting.
[30]	Zheng et al.	2022	Fatigue behavior of Co-Cr and PEEK clasp materials	In vitro	Co-Cr, PEEK	Casting, SLM	Fatigue resistance	PEEK shows the best fatigue resistance with no major failure, while cast or laser-

Ref.	Author(s)	Year	Title	Study type	Materials	Techniques	Mechanical properties evaluated	Results
								sintered Co-Cr clasps show similar resistance to one another.
[21]	Rues et al.	2023	Fit and Retention of Co-Cr RPD Frameworks Fabricated with SLM	In vitro	Co-Cr	SLM casting vs.	Adaptation, retention force, reproducibility	SLM frameworks show better reproducibility, retention consistent with recommended clinical values, and lower dispersion of results than casting.
[25]	Stamenković et al.	2023	Comparative Study of Cast vs. 3D-Printed Co-Cr Alloys	In vitro	Co-Cr	DMLS casting vs.	Microstructure, yield strength, tensile strength	Co-Cr alloys fabricated by DMLS show higher yield strength and tensile strength, with slightly lower elongation, than cast alloys.
[31]	Vaddamanu et al.	2023	Retentive Forces and Deformation of PEEK RPD Clasp	In vitro	PEEK	Injection molding	Retention force, deformation	A viable aesthetic alternative: PEEK clasps show slightly lower retention

Ref.	Author(s)	Year	Title	Study type	Materials	Techniques	Mechanical properties evaluated	Results
								than Co-Cr, but significantly less deformation.
[23]	Maalagh-Fard et al.	2024	Comparison between selective laser melted and cast RPD frameworks	In vitro	Co-Cr	SLM casting vs.	Toughness, flexural strength	A potential clinical advantage: SLM Co-Cr frameworks show better toughness, flexural strength and mechanical predictability than casting.
[47]	Husseiny et al.	2025	Comparison of retentive force and deformation of SLM and conventional Co-Cr clasps	In vitro	Co-Cr	SLM casting vs.	Retention force, deformation	Direct digital assembly of SLM Co-Cr clasps showed superior retention and less distortion than conventionally cast, indirectly assembled Co-Cr clasps.

3.3 Synthesis of findings by mechanical property

Hardness and microstructure: Several studies showed that additive manufacturing techniques such as SLM and DMLS produce finer, more homogeneous microstructures compared with conventional casting,

which often translates into increased hardness and strength [20, 24, 25]. Post-fabrication heat treatment can further improve these properties [24].

Surface roughness: The surface roughness of SLM-fabricated frameworks is a point of discussion. Some studies indicate higher initial roughness for SLM parts, requiring rigorous polishing to reach levels comparable to casting [17]. However, other research suggests that after polishing, roughness can be similar [20].

Retention force: RPD clasps fabricated by CAD/CAM (SLM or milling) demonstrated superior long-term retention stability compared with cast clasps, even after wear-simulation cycles [19, 22, 20, 21, 47]. Additively manufactured titanium also showed clinically acceptable retention forces [27].

Fatigue resistance: PEEK stood out for its excellent fatigue resistance without major failure, making it a promising material for RPD frameworks, although its initial retention force may be lower than that of Co-Cr [29, 30, 31]. SLM-fabricated Co-Cr alloys showed improved toughness and flexural strength compared with casting [23].

Rigidity and deformation: CAD/CAM-fabricated frameworks, particularly those in Co-Cr, showed better rigidity and significantly less deformation after loading cycles, contributing to improved denture stability [29, 31, 47].

3.4 Bias assessment (QUIN)

Table 3 presents the risk-of-bias assessment for each included study, performed using the QUIN tool. Most studies were rated as having a low to moderate risk of bias.

Table 3: Risk-of-bias assessment of the included studies (QUIN Tool)

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Score (%)	Risk
Torii (2018)	2	1	2	2	2	2	1	0	2	2	1	2	79%	Low
Takahashi (2020)	2	1	2	2	2	2	1	0	2	2	1	2	79%	Low
Mutschler (2020)	2	1	2	2	2	2	1	0	2	2	1	2	79%	Low
El-Baz (2020)	2	0	2	2	2	2	0	0	2	2	1	1	67%	Moderate
Zhang (2021)	2	1	2	2	2	2	1	0	2	2	1	2	79%	Low
Lee (2022)	2	1	2	2	2	2	1	0	2	2	1	2	79%	Low
Salim (2022)	2	0	2	2	2	2	0	0	2	2	1	2	71%	Low
Zheng (2022)	2	1	2	2	2	2	1	0	2	2	1	2	79%	Low
Rues (2023)	2	1	2	2	2	2	1	0	2	2	1	2	79%	Low
Stamenković (2023)	2	0	2	2	2	2	0	0	2	2	1	2	71%	Low
Vaddamanu (2023)	2	1	2	2	2	2	1	0	2	2	1	2	79%	Low

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Score (%)	Risk
Maalagh-Fard (2024)	2	1	2	2	2	2	1	0	2	2	1	2	79%	Low
Husseiny (2025)	2	1	2	2	2	2	1	0	2	2	1	2	79%	Low

Legend of criteria (Q1-Q12):

Q1: Study objectives clearly stated

Q2: Sample size calculation

Q3: Details of sample preparation

Q4: Details of intervention/exposure

Q5: Details of outcome measurement

Q6: Standardization of procedures

Q7: Randomization of samples

Q8: Blinding

Q9: Appropriate statistical analysis

Q10: Clear presentation of results

Q11: Discussion of study limitations

Q12: Funding and conflict-of-interest statement

It should be noted that most in vitro dental studies show limitations regarding the statistical justification of sample size (Q2) and the absence of blinding (Q8), aspects that are often difficult to implement in in vitro studies. These factors explain why risk-of-bias scores fall mainly within the “low” to “moderate” categories.

4. Discussion

This systematic review compared the mechanical properties of removable partial denture frameworks fabricated by the conventional method (lost-wax casting) versus CAD/CAM (SLM, DMLM, DMLS, CNC milling, 3D printing). The objective was to determine whether digital processes offer superior, equivalent, or inferior mechanical performance compared with the conventional technique, and to identify areas requiring further research in line with the PRISMA 2020 recommendations.

4.1. Biomaterials and fabrication techniques for removable partial denture frameworks

4.1.1. Biomaterials used for framework fabrication

4.1.1.1. Cobalt-chromium (Co-Cr)

Co-Cr alloys have been used for several decades. Their performance depends on metallurgical integrity (porosity, microcracks, heterogeneities) [1]. Two fabrication routes exist: casting and wrought (plastic deformation) [1]. Cast alloys are common but sensitive to casting quality, whereas wrought alloys offer a more homogeneous microstructure [1]. Co-Cr alloys show excellent resistance to oxidation, wear, and corrosion, together with good biocompatibility [2]. Their use in prosthodontics dates back to the 1930s [3]. Their composition can reach up to 80% cobalt and chromium combined, together with iron, molybdenum, and other elements [3]. However, since 2017 cobalt has been classified as CMR

(carcinogenic, mutagenic, reprotoxic); European regulation (MDR, REACH) restricts its use above 0.1% unless justified. Co-Cr alloys contain 31–63% cobalt, which restricts their future use beyond 2025 without proof of the absence of a suitable alternative [3].

4.1.1.2. Titanium

Used since the Second World War [5], titanium exists in pure form (CP Ti) or as an alloy such as Ti-6Al-4V [2,4]. The α phase (strong, low ductility) and the β phase (ductile) are combined in Ti-6Al-4V [4]. Aluminum stabilizes the α phase, while vanadium stabilizes the β phase [4,6]. Limitations include ion release, surface wear, and high cost [9]. Despite this, titanium offers excellent biocompatibility and strength [2].

4.1.1.3. PEEK and PEKK

PEEK and PEKK are chemically stable thermoplastic polymers of the PAEK family [7,8]. PEKK was first described in 1962 and PEEK in the 1990s [7,8]. PEKK possesses an additional ketone group, making it more rigid [8,10]. Their tooth-like color, biocompatibility, and use in implantology, fixed/removable prosthodontics, and orthodontics make them promising materials [11]. Their chemical structure is based on an aromatic chain containing ether and ketone linkages [10]. Limitations include high cost, the need for specialized heat treatment, UV sensitivity, and rare adverse reactions [10].

4.1.2. Fabrication techniques

4.1.2.1. Lost-wax casting (conventional)

The conventional technique relies on waxing, placement of sprues, investing, wax elimination, induction casting ($\approx 1370^\circ\text{C}$), recovery, finishing, and polishing [28]

4.1.2.2. Selective Laser Melting (SLM)

SLM comprises several key steps: digital design preparation and slicing into layers [32,33,34]; deposition and spreading of metal powder [32,34,35]; selective laser melting [32,33,36]; management of spatter and laser-material interaction [32,36,37]; rapid solidification leading to fine, anisotropic microstructures [32,34,38]; the development of significant residual stresses [32,33]; and finally powder removal together with thermal and mechanical post-treatments [32,33,34,35].

4.1.2.3. DMLM

DMLM is an alternative designation for SLM (complete melting of the powder), based on the same physical principles [32,33,34].

4.1.2.4. DMLS

DMLS achieves consolidation through sintering (without complete melting), resulting in lower density, and requires a thermal post-sintering treatment [32,33].

4.2. Interpretation of the main findings

4.2.1. Co-Cr: SLM vs. conventional casting

4.2.1.1. Hardness

The extracted data show that SLM produces significantly higher microhardness (502.86 ± 37.9 HV) than conventional casting (416.53 ± 18.5 HV) [17]. This difference is explained by the rapid solidification characteristic of SLM, which generates fine grains and a dense, homogeneous, isotropic microstructure, in contrast to the coarse dendritic structure produced by casting [17,23]. Rues et al. confirm that SLM reaches values >500 HV, exceeding the usual range of 350–450 HV for cast alloys [21]. Clinically, this increased hardness improves the wear and deformation resistance of retentive arms [17,21,23].

4.2.1.2. Surface roughness

Contrary to common assumptions, studies by Rahim et al. and Salim et al. show that after standardized polishing, surface roughness is not significantly different between SLM and casting ($p > 0.2$) [17,18]. Although as-built SLM parts are slightly rougher, this difference remains clinically acceptable after finishing [17]. The internal homogeneity of SLM also reduces subsurface stress concentrations, indirectly improving fatigue resistance [23]. Thus, final roughness depends more on the polishing protocol than on the fabrication process itself [17,18,23].

4.2.1.3. Retention

Initial retention forces vary by process. Torii et al. report that the hybrid process (laser sintering + milling) reaches 16.1 N, versus 12.9 N for casting; after annealing this value rises to 21.5 N [19]. Lee et al. confirm that SLM followed by heat treatment (SLM-H) provides superior retention (≈ 13 N) compared with casting (7–8 N) [24]. In contrast, Zhang et al. find no significant difference between standard SLM (8.51 N) and casting (8.55 N), both values falling within the clinically acceptable range of 5–10 N defined by Rues et al. [20,21]. In summary, standard SLM is equivalent to casting, whereas hybrid or heat-treated processes are superior [19,20,21,24].

4.2.1.4. Fatigue resistance

Fatigue resistance is a key parameter for clinical longevity. Torii et al. show that after 10,000 simulated cycles, the retentive force of cast clasps drops from 13 to 8 N, whereas hybrid-process clasps stabilize at 14–15 N [19]. Zhang et al. report a comparable decrease for both SLM and casting (8.5 $\rightarrow$ 5 N) [20]. According to Rues et al., a loss of 30–35% is typical for Co-Cr alloys subjected to fatigue [21]. Maalagh-Fard et al. provide additional insight: SLM shows better toughness, greater resilience, and a narrower Weibull distribution, reflecting increased mechanical reliability [23]. Thus, casting and standard SLM offer sufficient fatigue resistance, but hybrid and SLM-H processes are superior [19,20,21,23].

4.2.1.5. Rigidity

The elastic modulus is remarkably stable: 210 GPa for SLM versus 211 GPa for casting [20,21]. In contrast, yield strength differs markedly: 1262 MPa for SLM versus 834 MPa for casting, with SLM-H reaching 1048 MPa [24]. Maalagh-Fard et al. confirm that SLM shows a yield strength 73% higher than casting, with a better capacity to dissipate mechanical energy [23]. Heat treatment improves ductility and promotes ductile rather than brittle fracture [24]. In conclusion, overall rigidity is similar between processes, but SLM and SLM-H resist plastic deformation considerably better [20,21,23,24].

4.2.2. Cast Co-Cr vs. DMLM

The study by Mutschler et al. demonstrates that DMLM produces a dense, homogeneous structure. Mechanical properties are superior to those of casting: ultimate tensile strength 1150 vs. 960 MPa, yield strength 783 vs. 720 MPa, and elongation 8–11% vs. 4% [22]. Notably, after 9,000 cycles (simulating 6 years of use), the retentive force of DMLM clasps increases slightly (+4%), while that of cast clasps decreases (–6%) [22]. DMLM therefore offers better functional stability over time [22].

4.2.3. Cast Co-Cr vs. DMLS

Stamenković et al. show that DMLS provides markedly superior mechanical properties compared with casting: yield strength of 1090–1255 MPa (versus 687 MPa for casting) and tensile strength of up to 1311 MPa (versus 827 MPa for casting) [25]. These improvements result from the fine, homogeneous microstructure produced by laser sintering. However, ductility is reduced (2.7–5.3% versus 8.3%), making the material more brittle [25]. This trade-off between strength and flexibility must be taken into account in prosthetic design [25].

4.2.4. Cast titanium vs. CNC milling vs. 3D printing (AM)

4.2.4.1. Roughness and porosity

Maruo et al. report that cast titanium shows internal porosity of 0.84%, whereas no porosity is detected in CNC-milled parts [26]. Milled surfaces are smoother than cast surfaces [26]. Takahashi et al. observe that 3D printing generates roughness 5 to 10 times higher than casting (Ra 5.49–11.58 μm versus 1.47–1.60 μm), but this roughness remains stable after 10,000 cycles [27]. CNC milling and AM both produce a more homogeneous internal structure without major defects [26,27].

4.2.4.2. Initial retention

Initial retention forces vary considerably: cast CP2, 9.32 N; milled CP2, 4.42 N; milled MDF, 12.45 N [26]. With 3D printing, Ti-6Al-4V reaches 7.17 N (versus 5.99 N for casting) and CPTi reaches 6.30 N (versus 6.10 N for casting) [27]. Thus, digital processes (CNC and AM) provide stable, reproducible retention, but performance strongly depends on the alloy type [26,27].

4.2.4.3. Yield strength

Maruo et al. establish a positive correlation between yield strength and retentive force: cast CP2, 215 MPa; milled CP4, 485–655 MPa; Ti-6Al-4V, >825 MPa; MDF, $\approx$ 950 MPa [26]. Machined or wrought alloys are therefore markedly stronger than cast titanium [26].

4.2.5. Injection-molded PEEK vs. cast Co-Cr

Three studies converge on complementary conclusions [29,30,31]. El-Baz et al. show that after 2,880 cycles (simulating 24 months), the mean retentive force of PEEK is comparable to that of Co-Cr ($p = 0.098$), but PEEK deformation is significantly lower [29]. Zheng et al. report that after 30,000 cycles (simulating 21 years), PEEK shows no failure, whereas cast Co-Cr and SLM Co-Cr fail between 2,861 and 27,155 cycles depending on deflection [30]. Fractographic analyses reveal ductile behavior for PEEK (dense polymer-chain rupture), versus brittle behavior for the metal alloys [30]. Vaddamanu et al. confirm that, despite lower initial retention, PEEK maintains clinically acceptable retention after a simulated six months, with less deformation [31]. In conclusion, injection-molded PEEK offers markedly superior fatigue and deformation resistance compared with Co-Cr, at the cost of slightly lower retention [29,30,31].

4.3. Overall synthesis of the comparisons

Taken together, the extracted data establish a hierarchy of processes for the mechanical properties of Co-Cr frameworks: CAD/CAM processes (SLM, DMLM, DMLS) and their hybrid or heat-treated variants are generally superior or equivalent to conventional casting. The elastic modulus remains invariant, but hardness, yield strength, and fatigue resistance are improved by the rapid solidification and fine microstructure characteristic of additive processes. For titanium, CNC milling and 3D printing reduce porosity and provide stable retention forces. PEEK stands out for its exceptional fatigue resistance, positioning this material as a credible alternative within a “metal-free” approach.

4.4. Limitations of the review and potential biases

In accordance with the PRISMA 2020 recommendations, several limitations must be explicitly reported:

- Methodological heterogeneity: Experimental protocols vary considerably between studies (number of fatigue cycles, clasp geometry, polishing conditions, additive manufacturing parameters). This heterogeneity precludes any meta-analysis and limits direct comparability of absolute values.
- Absence of clinical studies: All included studies are in vitro work. No randomized clinical trial comparing the long-term survival of CAD/CAM versus conventional frameworks was identified. Intraoral conditions (saliva, temperature, complex masticatory forces, biofilm) are not reproduced.

- Risk of publication bias: Studies reporting positive results for new technologies (CAD/CAM) are probably overrepresented. Negative studies, or those showing strict equivalence, may be underrepresented.
- Risk of bias within the included studies: Few studies report blinding of the experimenter during mechanical measurements. Sample standardization is generally good (identical digital models were used), but randomization of measurements is not always explicit.
- Limited generalizability: The results come from academic laboratories with specialized equipment. Transferability to dental offices and community dental laboratories is not guaranteed, particularly given the investment costs of CAD/CAM machinery.

4.5. Comparison with the existing literature and explanation of discrepancies

Our results are consistent with previous literature on the influence of microstructure on the mechanical properties of Co-Cr alloys. However, some discrepancies deserve discussion. For example, Zhang et al. find no difference in initial retention between SLM and casting [20], whereas Lee et al. report a superiority of SLM [24]. This discrepancy may be explained by differences in fabrication parameters (laser power, scanning speed, layer thickness) and finishing protocols. Similarly, contrasting results on roughness can be explained by the use of different roughness parameters (Sa vs. Ra) and by the presence or absence of standardized polishing [17,18,23].

4.6. Implications for clinical practice and future research

For clinical and laboratory practice: The findings of this systematic review indicate that CAD/CAM (SLM, DMLM, CNC milling) constitutes a reliable and often superior alternative to conventional casting for metal frameworks, particularly in terms of reproducibility, hardness, yield strength, and retention stability. Hybrid processes and post-fabrication heat treatments further improve performance. The choice between these techniques must take into account cost, available equipment, and laboratory expertise.

For future research: Randomized clinical trials comparing the long-term survival (5–10 years) of RPDs with CAD/CAM versus conventional frameworks are urgently needed. Such studies should include clinical outcome measures (retention, patient comfort, abutment-tooth wear, biological complications) and cost-effectiveness analyses. In addition, research on optimizing additive manufacturing parameters (laser power, scanning strategy, part orientation) and on standardized post-treatment protocols is required. Finally, in vivo evaluation of PEEK and PEKK under real oral conditions should be pursued.

4.7. Strengths of the review

This systematic review has several methodological strengths. It was conducted according to PRISMA 2020 standards, ensuring transparency and rigor throughout the process. The literature search was comprehensive, covering four major databases (PubMed, Cochrane Library, Science Direct, Google Scholar) over a 10-year period (2015–2025), allowing the identification of the full range of relevant studies on the topic. Article selection was carried out in three successive stages (title screening, then abstract screening, then full-text screening), with rigorous duplicate management via Zotero software, thereby reducing the risk of selection bias. Data extraction was standardized, and the results were synthesized in clear comparative tables, facilitating the interpretation of quantitative data. Furthermore, the inclusion of multiple materials (cobalt-chromium, titanium, PEEK/PEKK) and multiple CAD/CAM processes (SLM, DMLM, DMLS, CNC milling, additive manufacturing) provides a broad, up-to-date, and comparative view of the field, allowing cross-cutting conclusions on the influence of the fabrication process independent of the material used.

5. Conclusion

This systematic review aimed to compare the mechanical properties of removable partial denture frameworks fabricated by conventional casting versus CAD/CAM. The analysis confirms the decisive role of the fabrication process in the mechanical behavior of frameworks.

For cobalt-chromium alloys, CAD/CAM frameworks (particularly SLM) show a more homogeneous microstructure, better reproducibility, and mechanical properties that are often superior to casting, notably better retention stability, increased fatigue resistance, and higher mechanical predictability, particularly after heat treatment. However, CAD/CAM can generate greater surface roughness, requiring rigorous polishing.

For titanium, digital techniques offer acceptable mechanical properties, with good precision and retention stability, but require further standardization.

Polymers such as PEEK, despite lower retention than metals, show excellent fatigue resistance, low deformation, and aesthetic appeal, constituting an alternative for allergic or demanding patients.

CAD/CAM represents a major advance, offering standardization, reproducibility, and promising performance, although the conventional technique retains an important place owing to its accessible cost and established clinical track record. Finally, to confirm these in vitro findings, longitudinal clinical studies under real clinical conditions are needed. The reasoned pairing of material and fabrication process remains important for optimizing denture longevity.

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