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ReviewPaper: Different Ways to Measure Marginal Fit and Internal Adaptation of Restorations in Dentistry

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ABSTRACT

The purpose of this review article was to summarize the scientific literature investigating all invitro methods that can evaluate both marginal and internal adaptation of direct and indirect restorations. An electronic search of publications from 2000 to March 2022 was made using ScienceDirect, PubMed, and Google Scholar databases. The search included only English-language articles. Therefore, only studies that addressed techniques to measure marginal and internal adaptation in different restorations were selected. Five laboratory methods with different capabilities have been introduced to check the adaptation of dental restorations, including sectioning, Silicon Replica Technique (SRT), Micro-CT, OCT, and triple scan method. In addition, there are factors that may contribute to differences between different methods in measuring adaptation, including 2D, 3D, and absolute adaptation, cost, and feasibility of performing in the oral cavity. SRT and traditional sectioning have the advantage of being simple and inexpensive procedures. Micro-CT, OCT, and triple scan method are costly procedures that necessitate specialized equipment and analysis software which enable both 2D and 3D analysis. Another crucial aspect of the assessment techniques to be applied in clinical trials is the capability to conduct an examination in the oral cavity. sectioning, OCT, and Micro-CT cannot be used to make assessments in the oral cavity, however SRT and triple scan method can. The search for an ideal and standardized device to measure the adaptation of direct and indirect restorations in dentistry is still needed.

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1. Introduction

The clinical success of dental restorations is determined by three main factors including esthetics, fracture strength, and adaptation of the restoration to tooth structure. Marginal and internal fit play a vital role for long-term clinical success both direct and indirect dental restorations using composites, ceramics, and crowns (1).Resin composite restorations are a common choice among clinicians due to rising demand for aesthetics and advancements in adhesive system technology (2). However, a significant problem in clinical practice is shrinkage related to the polymerization of materials. When shrinkage stress exceeds the bond strength of the adhesive interface or the cohesive strength of the tooth, the interfacial quality of the restoration is negatively affected, leading to gap formation, Polymerization shrinkage, which is an intrinsic property of resin composites and is directly related to their composition, appears to be responsible for the poor fit of resin composite restorations. Modifications to the material composition have been made by various manufacturers to reduce the effects of polymerization shrinkage and the internal/marginal gap formation (3).

Furthermore, it has been reported that mechanical properties of resin-based materials can be reduced by defects such as voids, gaps, and bubbles. Although the structural properties of the restorative material may initially be appropriate, defects can reduce the performance of the restorations under fatigue load and decline the durability of the restorative material, leading to fractures and clinical failure. The viscosity of the material, the size of the applicator tip, the entrapment of air inside the bulk of composite resin during the manufacturing process, as well as the incremental technique and other placement techniques can all cause void formation in the material bulk or cavity walls (4, 5).

In the spaces between cavity walls and the restorative material, polymerization shrinkage stress allows fluid movement and bacterial infiltration (6). Microleakage, which is defined as clinically undetectable penetration, can cause pulpal inflammation and necrosis, secondary caries, post-operative hypersensitivity, marginal staining, and post-operative hypersensitivity(2). Microleakage can happen inside the tooth or on its external surface. Hypersensitivity to the cold or pain when chewing can be the result of poor internal adaptation (7).

Indirect restorations are similarly subject to the aforementioned problems. The quality of marginal adaptation and internal adaptation are two elements that influence durability of an indirect restoration. Microleakage, luting cement dissolution, secondary caries, and gingival irritation can all be consequences of poor marginal adaptation.

Poorly adapted restorations are supported by cement, which has an impact on the restoration's lifespan because it is weaker than the tooth structure. Consequently, ceramic restorations like inlay restorations should have a homogenous internal fit. Additionally, a poor internal fit not only can lead to an increase in cement thickness but also change retention, influence occlusion, lessen the restorations' resistance to fracture and compromise the marginal fit. Since inlay/Onlay restorations' margins are subject to mechanical, physical, and thermal stresses, internal and marginal adaptability are especially crucial (8-10) .

Since incorrect interpretation of the marginal and internal fit assessments could lead to incorrect marginal fit values, maintaining patients' long-term health can be challenging. As a result, a Comprehensive technique for assessing the marginal and internal fit of direct and indirect restorations is required. Therefore, the aim of this study was to review in vitro studies in terms of different techniques which can evaluate both marginal and internal adaptation of direct and indirect restorations.

2. Materials and Methods

An electronic search of publications from 2000 to March 2022 was made using ScienceDirect, PubMed, and Google Scholar databases. The search included only English-language articles. Therefore, only studies that addressed techniques to measure marginal and internal adaptation in different restorations were selected.

Five laboratory methods with different capabilities have been introduced in the literature to evaluate the fitness of dental restorations, including sectioning, Silicon Replica Technique (SRT), Micro-CT, OCT, and triple scan method.

One of the traditional methods that have been used to analyze the internal adaptation caused by polymer shrinkage were dye and tracer penetration methods (11, 12). These methods demand soaking the specimens in various solutions, cutting sections through the restorations, and examining the leakage that has occurred under a light microscope. Tracers that can be utilized for infiltration include methylene blue, rhodamine, erythrosine, and silver nitrate. Although the specimens must be sliced to be studied, these processes are relatively straightforward. Dye samples cannot be reevaluated; they can only be evaluated on the plane on which they were sectioned. After cutting specimens into sections, the resin-dentin interface can also be examined by Scanning Electron Microscopy (SEM). This method has limitations in quantitative evaluation and is particularly technique sensitive (13, 14). Additionally, internal adaptation

before and after thermomechanical loading cannot be compared using conventional techniques, which need sectioning and dye penetration. The other drawback is inability to take measurements inside the oral cavity (7).

The cross-sectional method has also been employed for indirect restorations. With this method, the desired portion of the prosthesis is cut and measured with an optical or electronic microscope after cementation. It has the benefit of permitting precise measurement of the internal and marginal fit of the prosthesis because the actual prosthesis is cut and measured (15, 16). Information on the contents of the related articles is summarized in Table 1.

Table 1. Application of different techniques for measuring adaptation of restorations in recent studies

Article	Type of measurement/ technique	restoration	Result
Stavridakis et al. 2007(11)	Sectioning for internal analysis + SEM polyvinylsiloxane impression material on a polished restoration for marginal analysis + SEM	Different adhesive restorative system in different cavity designs.	In large posterior cavities, the C-factor significantly affects internal and marginal adaptation.
Dionysopoulos et al.2014(12)	Sectioning for internal analysis + SEM internal gap on axial wall	Different restorative techniques in cl V cavity designs.	Following photopolymerization, different restorative techniques behave differently in terms of internal adaptability to dentin.
Rajan et al.2015(16)	Sectioning longitudinally + stereomicroscope analyzing using ImageScope software	zirconia copings fabricated by two CAD/CAM systems	Internal adaptation and marginal fit were demonstrated by both CAD/CAM system copings within an acceptable discrepancy range.
Falahchai et al.2021(21)	SRT	Endocrowns fabricated with zirconia using digital scans and conventional impression	Both the traditional impression technique and the digital scanning technique produced crowns with similar marginal adaptation.
Falahchai et al.2021(23)	SRT	Provisional Restoration Fabricated With Additive, Subtractive, And Conventional Techniques	FDPs fabricated digitally had a superior marginal fit and higher fracture resistance than conventionally fabricated ones.
Sarda et al.2021(41)	SRT	Cobalt Chromium Restorations	Compared with milled wax/lost wax methods, DMLS techniques produced significantly better marginal fit for cobalt-chromium alloy copings
Özal et al.2021(42)	SRT	Restorations fabricated with monolithic zirconia using digital scans	Intraoral scanners generally had lower marginal and internal discrepancies than laboratory scanners
Gautam et al.2021(43)	SRT	Cobalt–Chromium (Co–Cr) Copings	In contrast to conventional cast Co–Cr alloy crowns, the marginal gap for copings made using direct metal laser-sintered crowns was lesser.
Mansour et al.2021(44)	SRT	Ceramometallic restoration (cad wax and press veneering)	Microleakage of ceramometallic restorations is strongly correlated with internal fit.
Son et al.2021(29)	Triple scan	Ceramic crowns fabricated with chairside cad/cam systems	All three chairside CAD/CAM systems produced clinically acceptable prostheses. The marginal gap, which is the most important element in the marginal and internal fit of prostheses, was recorded to be below 100 µm for each all three systems.
Holst et al. 2011(30)	Triple scan	Titanium single crown copings fabricated with CAD/CAM systems	The triple-scan protocol is an effective surface data set registration method for dental applications and removes the restrictions of traditional best-fit registration protocols in the case of cement space or gap
Haak et al. 2021(32)	OCT	Ceramic veneers (IPS InLine Veneer) of two thicknesses in different preparation design	The interfacial bond benefits from a ceramic thickness of at least 0.5 mm and a preparation that does not expose dentine.
Han et al.	OCT & Micro-CT	Different adhesive	Although the measured imperfective margins% in

2016(18)		restorative system in cylindrical cavities	micro-CT differed from those in SS-OCT, there was a fair amount of correlation between the two techniques.
Han et al. 2014(7)	Micro-CT	Different adhesive restorative system in cl I cavities	Following thermomechanical load cycling, the groups using various adhesive systems showed variations in internal adaptation.
Ashiry 2019(36)	Micro-CT	Direct restoration of cl V cavities with and without liner	using Biodentine as liner under cl V cavities exhibited a higher internal adaptation.
Topkara et al. 2021(35)	Micro-CT	Endocrown CEREC Blocs	The amount of Internal and marginal adaptation of endocrowns was different between mandibular and maxillary and molars
Bayrak et al.2020(34)	Micro-CT	Felspathic inlays fabricated by different software programs	marginal and internal fit of inlays designed with different software programs were statistically different.

There are limited studies that carry out an objective comparison of different techniques of assessment (15, 17, 18). However, Son et al, performed five internal and marginal fit evaluation methods for fixed prostheses. They found except for the angle region the Silicon Replica Technique (SRT) showed the most approximate value to the cross-sectional method. Based on their findings, it was not found significantly differences between Cross-sectional method and SRT in some points. They both demonstrated the highest values for axial region, and lowest value for margin region. However, other studied methods showed the lower values and did not show statistically significant differences in the axial region (15).

The same process used for cementing a prosthesis is used for the SRT. However, the procedure duplicates the internal and marginal fit for measurement while injecting silicone rather than cement into the prosthetic (15, 19). SRT is a reliable, nondestructive method that has produced discrepancy measurements that are comparable to those of conventional cementation (20). It has been used in numerous studies since it is a reasonably easy and inexpensive technology that enables measurements to be taken right inside the oral cavity. Furthermore, SRT can only conduct assessments utilizing two-dimensional (2D) analysis (15).

This technique entails cutting the silicone duplicate and injecting silicone into the indirect restorations, including inlay, onlay, full crown, endocrown,(21) and interim and provisional restorations.(22, 23). After adjusting the indirect restoration to the study model and filling it with a light-body silicone, a pressure in the range of 10 to 50 N is applied to the restoration using a universal testing machine.(15, 22, 24-27). After the light-body silicone has fully polymerized, the excess is removed, and the restoration is removed leaving a thin film of light-body silicone adhering to the master tooth. Then, a medium or heavy-body silicone with a contrasting color is added to the light-body silicone to support it. The silicone is cut using a razor blade. High-magnification images are recorded with a stereomicroscope or video microscope to calculate the gaps (15).

SRT approach is a well-established and commonly applied technique in fit investigation studies. Nevertheless, SRT comes with inherent errors linked to challenges locating the indirect restoration margin, ripping of the elastomeric film during restoration removal from the preparation, the presence of silicone film flaws, and mistakes in the sectioning planes. Homsy et al. proposed a technique to standardize the load applied for inlay placing on the master preparation, producing replicas free from defects (20). It is thought that the adoption of the cast index probably decreased errors caused by inadequate sectioning process management. In addition, the number of cutting directions and measuring points varies among different studies (28).

The triple scan method is a procedure that involves scanning the inside and outside of the prosthesis, the abutment tooth, and the prosthesis during the try-in stage to collect three-dimensional (3D) data and measure the marginal and internal fit by superimposing the 3D data on analysis software. It is a non-destructive, non-radioactive method that can scan the data and deliver reproducible whenever needed. But because of possible inaccuracy or overlapping of the scanned data, miscalculations might occur (15, 29, 30).

The triple-scan method is performed in the following sequence: The inner side of the prostheses, the abutment teeth themselves (or a model thereof), those prostheses that are properly positioned on the abutment teeth are all scanned first. The spacing between the prosthetic teeth and the abutment teeth is then measured after the triple-scan data are superimposed using a best-fit alignment. This non-invasive technique enables the observation of

numerous cross sections without any restrictions on direction or quantity. Researchers are also able to analyze the 3D space using this method. Additionally, it can check the prosthetics' marginal and internal fit before intraoral installation, which could enhance quality control (29, 30). Park et al. evaluated three different fabrication methods of dental restorations using triple-scan method and SRT and reported that although triple-scan method and SRT and measurements of the occlusal region were significantly different, no significant differences were found for other regions. Therefore, both measurement methods can be used as methods of verifying marginal and internal consistency (17).

OCT was first introduced as a non-invasive cross-sectional imaging approach for biological systems. It allows for real-time viewing of the restoration or tissue without exposing the patient to X-ray radiation. OCT is a measurement technique that employs higher resolution 2D or 3D pictures in optical scattering media using coherent light. Following the projection of a laser source over a surface, the backscattered light is converted into a signal intensity that can be shown as an image. OCT is based on light's coherent characteristics. The interference of light reflections from the reference mirror and backscattered light from the tissue generates the OCT signal. It displays cross-sectional images based on the depth resolution of the optical reflectance property (15, 18).

OCT is a non-invasive technique that can be used for a variety of applications, including detecting dental cavities or cracks. A swept-source optical coherence tomography is a form of OCT (SS-OCT). The use of a wavelength-tuned laser as the light source improves picture resolution and scanning speed in SS-OCT.

It is important to highlight that OCT imaging depth is limited to less than 3mm of tissue. The OCT equipment was used to analyze the cavity floor in order to assess internal adaptation. Interfacial micro-gaps are visible as bright spots or lines with high signal intensity on OCT images (31). In the picture, the change in signal intensity near the interface appears as a white cluster. A part of the light is reflected as it passes through the interface between two media with different refractive indices. This is regarded as the Fresnel phenomenon, and it is affected by the incidence angle and refractive index (n) for example, the latter is different between air, composite resin, and water (18,32).

Han et al. performed a comparative study to investigate the internal adaptation of resin composite restorations using two methods and reported SS-OCT and micro-CT methods can be useful for the non-destructive assessment of internal fit. Imperfective margins measured on micro-CT showed different values than SS-OCT values, however, the two methods had a relatively high correlation (18).

Micro-computed tomography (micro-CT) has been utilized more and more recently in restorative and prosthetic dentistry, particularly to evaluate adaptation of restorations. Compared to other methods, the micro-CT approach is considerably more expensive, but it is a non-destructive procedure. Without causing any damage to the sample, this 3D high-resolution imaging equipment delivers extensive information during the assessment of the adaptation between the restoration and tooth (1,10,33-37).

A 90–150 kVA X-ray tube, filter, and collimator, a computer-controlled electric motor, a CCD camera for converting X-ray image data, an image intensifier apparatus, a specimen stand, and a computer are all necessary parts of micro-CT equipment. In vivo and ex vivo scans are the two primary varieties of micro-CT scans. For in vivo scans, an object is positioned on a stationary platform with an X-ray tube and optical X-ray detector rotating around it. In contrast, an object is put on a rotating platform for ex vivo scanning while the X-ray tube and optical X-ray detector are fixed in place. Although rotating object scanners create images with a very high resolution, they are not technically suited for imaging small animals (38,39).

When compared to other techniques, micro-CT has a lot of benefits, but it also has significant limitations. Due to their narrow, monochromatic X-ray and appropriate high flux, these systems have the benefit of making detailed research of X-ray imaging modality easier. The micro-CT has a nondestructive approach in contrast to microscopic approaches; the internal characteristics of the same sample can be checked multiple times, and samples stay intact for additional biological and mechanical testing. The ability to perform several scans and manage the image using specific software is another advantage of micro-CT. The preparation of samples is not a challenge when this method is used instead of more damaging techniques. A more accurate measurement is made possible by overall benefits.

Micro-CT has some drawbacks, including prolonged scanning and reconstruction processing times, expensive costs, and the need for computer knowledge. The size of the image files is huge (around 3 GB). When it comes to storing and retrieving massive numbers of files, data collecting can be a challenge. The radiation dose from a micro-CT scan is sufficient to alter the immune response and other biological processes, which in turn affects the results of experiments. However, it is important to remember that they are typically not deadly. Its usage in clinical settings is restricted by the accompanying high radiation dose (39,40).

According to researchers, non-standardization of the sectional areas because of non-standardization of the system's samples could have an impact on the statistical findings. In indirect restorations, measurements of the same points after they have been standardized may be intriguing and significant (34).

3. Conclusion

Each method for evaluating the adaptation of direct and indirect restorations that was given in this study has benefits and drawbacks. Micro-CT, OCT, and triple scan method are costly procedures that necessitate specialized equipment and analysis software. These three methods enable both 2D and 3D analysis. On the other hand, Silicon Replica Technique (SRT) and traditional sectioning have the advantage of being simple and inexpensive procedures. Another crucial aspect of the assessment techniques to be applied in clinical trials is the capability to conduct an examination in the oral cavity. sectioning, OCT, and Micro-CT cannot be used to make assessments in the oral cavity, however SRT and triple scan method can.

OCT provides the advantage of obtaining a 3D image in real time, but because of its optical properties, no thick or opaque restorations can be used. However, because OCT is a non-radiological approach, it can be developed for use as an intra-oral probe.

Furthermore, the assessment methodologies utilized in various studies may differ based on the laboratory environment and equipment. Furthermore, there is no standard technique for determining the adaptation of dental restorations which necessitates further research in this area.

Ethical Considerations

Compliance with ethical guidelines

Not applicable.

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Authors'contributions

Mehrsima Ghavami-Lahiji: Conceptualization, Methodology, Writing - Review & Editing Mehran Falahchai: Writing - Original Draft, Data Curation, Supervision Abolfazl Habibi Arbastan: Resources, Investigation, Visualization

Conflict of Interests

The authors declare no conflict of interest.

Availability of data and material

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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