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RESEARCH AND EDUCATION

Effect of tooth preparation design on marginal adaptation of composite resin CAD-CAM onlays

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ABSTRACT

Statement of problem. Although different preparation designs have been proposed for onlays fabricated by computer-aided design and computer-aided manufacturing (CAD-CAM), their effect on marginal adaptation is unclear.

Purpose. The purpose of this in vitro study was to investigate the effect of tooth preparation designs on the marginal and internal adaptation of ceramic-reinforced composite resin CAD-CAM onlays.

Material and methods. A traditional preparation with a heavy chamfer on the functional cusp and a contrabevel on the nonfunctional cusp and a shoulder preparation with equal reduction on all cusps were used for mesial-occlusal-distal (MOD) onlay preparations. Ceramic-reinforced composite resin onlays were designed and milled based on the scanned prepared teeth. A digital silicone replica technique was used to determine marginal discrepancies between preparations and onlay restorations. A total of 100 numeric distances (representations of the fit in each region) were measured in 3 distinct regions: the buccal margin, lingual margin, and internal area. Independent Student *t* tests were used to determine significant differences (α=.05).

Results. Traditional preparation designs resulted in significantly smaller overall discrepancies (50.9 ±0.5 µm and 139.1 ±5.4 µm, P<.001) and smaller marginal discrepancies in the buccal (49.7 ±1.4 µm and 135.8 ±2.2 µm, P<.001) and lingual areas (47.1 ±1.0 µm and 133.4 ±1.1 µm, P<.001).

Conclusions. The marginal adaptation of ceramic-reinforced composite resin CAD-CAM onlays was affected by the preparation design. The traditional preparation design offered better marginal adaptation; therefore, it is recommended in clinical practice. (J Prosthet Dent 2020;124:88-93)

Crowns are widely used to restore missing tooth structure and to increase resistance to occlusal forces.[1] Crown preparation requires reducing all coronal tooth surfaces, which may be too aggressive for teeth with minor structural defects. In these situations, partial coverage restoration such as onlays can provide a more conservative treatment option.[2,3] Onlays can restore the damaged occlusal surface with minimal tooth reduction. With the traditional preparation method, a heavy chamfer margin is prepared on the functional cusps and a contrabevel margin on the nonfunctional cusps. As computer-aided design and computer-aided manufacturing (CAD-CAM) technology has become widely used for onlay fabrication, traditional preparation methods are no longer considered standard. Concerns about digital scanning accuracy in traditionally prepared cusps have been raised, and milling inaccuracies of the intaglio surface and the brittle nature of milled ceramics at margins have led to different preparation methods for CAD-CAM–fabricated onlays.[4-8] The

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Clinical Implications

With the rapid development of CAD-CAM technology, onlays prepared with the traditional method shows better marginal adaptation than those prepared with the shoulder preparation method. A clearly defined finish line is essential and necessary for preparations.

shoulder preparation method[9-11] was introduced to avoid the drawbacks of traditional preparations. During preparation, equal reduction on functional and nonfunctional cusps is performed, which provides a flat surface for easy scanning and milling and is more convenient for the clinician to prepare.[12] This new preparation design has increased in popularity, and acceptable clinical performance has been reported.[13,14]

In the evaluation of prosthesis success, long-term results must be considered. Poor marginal adaptation can result in microleakage, secondary caries, and periodontitis and may eventually lead to clinical failure.[15] According to Holmes et al,[16] marginal adaptation includes horizontal discrepancies, vertical discrepancies, and absolute discrepancies. The absolute discrepancies reflect total misfits at specific points of the margin, which should be carefully measured. Belser et al[17] reported that marginal discrepancies should be less than 50 μm for clinical success, but recent studies of CAD-CAM–fabricated prostheses[18] have found that marginal discrepancies are larger than 50 μm. McLean and Fraunhofer[19] reported that marginal discrepancies smaller than 120 μm were considered clinically acceptable. Nevertheless, it is generally accepted that absolute marginal discrepancies should be as small as possible. While marginal discrepancies are affected by several elements, preparation and finish line designs are essential elements and should be investigated to determine their effects on CAD-CAM onlays.[20]

Different methods have been used to measure marginal discrepancies between preparations and restorations.[18,21] The direct view (DV)[22] and cross-sectioning (CS) methods[23] can acquire data directly, whereas the silicone replica (SR)[24-26] and microcomputed tomography (μCT) methods[27,28] measure discrepancies indirectly. With the rapid development of computer-aided dentistry, digital methods have been proposed to measure the marginal and internal discrepancies of restorations. Methods such as the triple scan (TS)[29] and 3D superimposition analysis (3DSA)[30] are gaining popularity over traditional techniques. The digital silicone replica approach combines the traditional silicone replica technique with computer-aided concepts. The steps are as follows: scan cast dies by using a laser scanner, create a silicone replica by using light-body polyvinyl siloxane

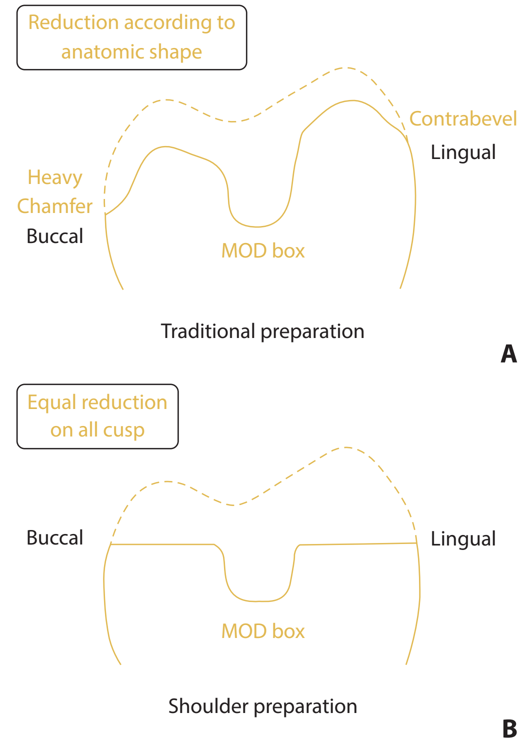

Figure 1. Schematic of preparations. A, Traditional preparation. B, Shoulder preparation.

(PVS) impression material, gently remove the restoration and scan the PVS impression left on the dies, and finally calculate discrepancies by using a 3D comparison software program. This protocol is as efficient and convenient as the traditional silicone replica method and can obtain 3D data of the simulated luting space and overall marginal discrepancies.

By using the digital silicone replica protocol, the present study compared marginal and internal discrepancies between 2 groups of onlay restorations with traditional and shoulder preparation designs. The null hypothesis was that no differences would be found in the detected marginal and overall discrepancies between these 2 groups of onlay restorations.

MATERIAL AND METHODS

Ten standardized typodont right mandibular first molars (A5SAN-500; Nissin Dental Products, Inc) were divided into a traditional preparation group and a shoulder preparation group, with 5 teeth in each group. Onlay preparations were carried out by the same clinician (J.Z.) by using diamond rotary burs (Dia-Burs; Mani) (Fig. 1) in the following sequence. First, all teeth were prepared by standard mesial-occlusal-distal (MOD) box cavity preparation with a depth of 3.0 mm, and mesial/distal finish lines were placed 1.0 mm above the cement-enamel junction (CEJ). After box preparation, all teeth in the traditional preparation group were prepared with a 1.5-

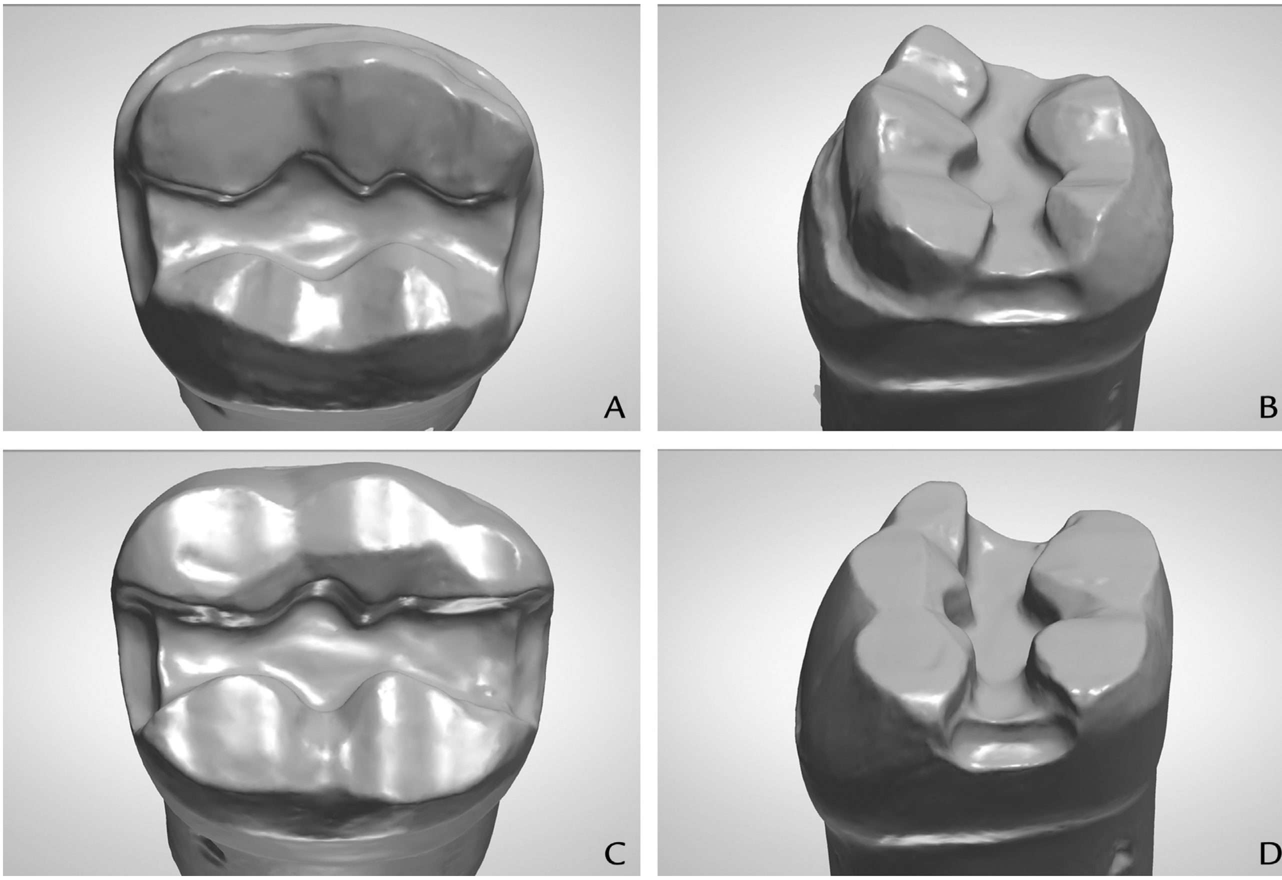

Figure 2. Scanned preparations for onlay fabrication. A, B, Traditional preparation. C, D, Shoulder preparation.

mm occlusal reduction, and a 1.0-mm heavy chamfer was placed on a functional cusp and a 0.5-mm contrabevel on a nonfunctional cusp. For the shoulder preparation group, all teeth were prepared with uniform 2.0-mm cuspal reduction to create a flat platform and remove all of the cusp anatomy. All teeth were rounded and polished to create smooth line and point angles. After preparation, each tooth was scanned by using a 3D laser scanner (TRIOS 2 Color Cart; 3Shape A/S) (Fig. 2). Onlays were designed and fabricated from ceramic-reinforced composite resin blocks (Hyramic; Upcera) by using a subtractive method with 5-axis milling (DWX-51D; Roland). For each preparation, 3 separate onlays were milled to avoid systematic error.

The marginal and internal discrepancies of all onlay restorations were evaluated by the same clinician (Y.Y.) by using the digital silicone replica method.[25] Adjacent teeth were blocked out, and the whole arch was scanned (IScan3D; Imetric) to create dies. Light-body PVS impression material (Honigum Light; DMG) was injected around the preparation and intaglio surface of each restoration, and firm pressure was applied for 150 seconds to allow the material to polymerize completely, according to the manufacturer's instructions. Then, the restoration was removed, leaving a thin PVS layer on the preparation, and the whole arch was scanned once more to create a simulated luting model. All scanned data were exported as standard tessellation language (STL) files and imported into a 3D comparison software program (Geomagic Control X; 3D Systems). After annotation points were created on preparation casts (20 buccal points; 20 lingual points; 60 internal points) (Fig. 3), paired STL files were aligned. Comparisons were made between the annotation points, and marginal and internal discrepancies were measured by calculating deviations from single points on the paired casts. All measurements at marginal annotation points were considered marginal discrepancies, and the mean value of all measurements was defined as the overall discrepancy. Independent Student *t* tests were used to compare marginal and overall discrepancies by using a statistical software program (IBM SPSS Statistics, v25; IBM Corp) (α=.05).

RESULTS

Overall and marginal discrepancies in the 2 groups are shown in Table 1. Statistical analysis confirmed that preparation design affected marginal, internal, and overall discrepancies (P<.001). The traditional

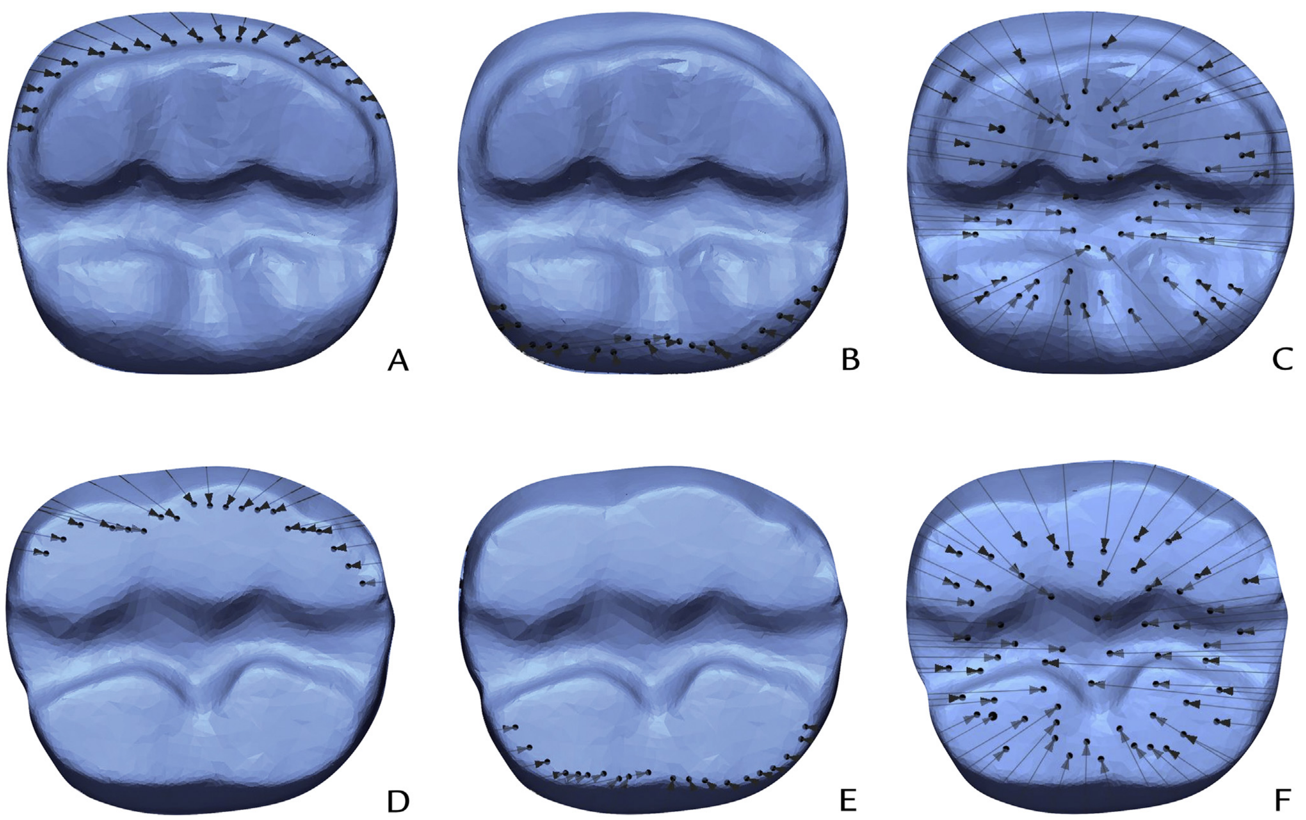

Figure 3. Annotation points on two preparation techniques. A-C, Traditional preparation, D-F, Shoulder preparation (from left to right: buccal, lingual, and internal).

preparation group shows better results than the shoulder preparation group in terms of overall discrepancy (50.9 ±0.5 μm and 139.1 ±5.4 μm), marginal discrepancy (49.7 ±1.4 μm and 135.8 ±2.2 μm at the buccal margin, 47.1 ±1.0 μm and 133.4 ±1.1 μm at the lingual margin), and internal discrepancy (51.8 ±0.6 μm and 141.5 ±8.1 μm). Representative color maps of overall discrepancy for each group are shown in Figure 4. In the traditional preparation group, most of the areas are green in color, indicating overall discrepancy within ±100 μm. In the shoulder preparation group, areas in yellow and red indicate larger overall discrepancies.

Table 1. Overall and marginal discrepancies (mean ±standard deviation) (μm)

Groups	Overall Discrepancy	Buccal Marginal Discrepancy	Lingual Marginal Discrepancy	Internal Discrepancy
Traditional preparation	50.9 ±0.5^{a}	49.7 ±1.4^{a}	47.1 ±1.0^{a}	51.8 ±0.6^{a}
Shoulder preparation	139.1 ±5.4^{b}	135.8 ±2.2^{b}	133.4 ±1.1^{b}	141.5 ±8.1^{b}

Values indicated by same superscript lowercase letter in each column not significantly different (P>.05).

DISCUSSION

The null hypothesis was rejected, confirming that the marginal design had a significant effect on the marginal, internal, and overall discrepancies of CAD-CAM composite resin onlays and the corresponding preparations. The clinical marginal adaptation of a CAD-CAM onlay is affected by elements that include the accuracy of the digital scan, the identification of the finish line in the software program, the milling machine and material used for the onlay fabrication, and also the clinical evaluation procedure. These factors can cumulatively contribute to the definitive fit of the onlay restoration. The present study indicated that the configuration of the finish line contributed to the marginal discrepancy. Improving the fit of a restoration will decrease microleakage and lower the risk of secondary caries so that the restoration can remain in function for a long period.[15]

A preparation with a shoulder finish line is easier to prepare, scan, and fabricate,[9-11] which could enhance the CAD-CAM restoration procedure. However, the marginal and internal discrepancies of shoulder preparation will be greater than those for a traditional preparation. As no consensus has been reached on maximum acceptable discrepancy, it is safe to say that onlay restorations with smaller marginal and internal discrepancies should improve clinical performance.

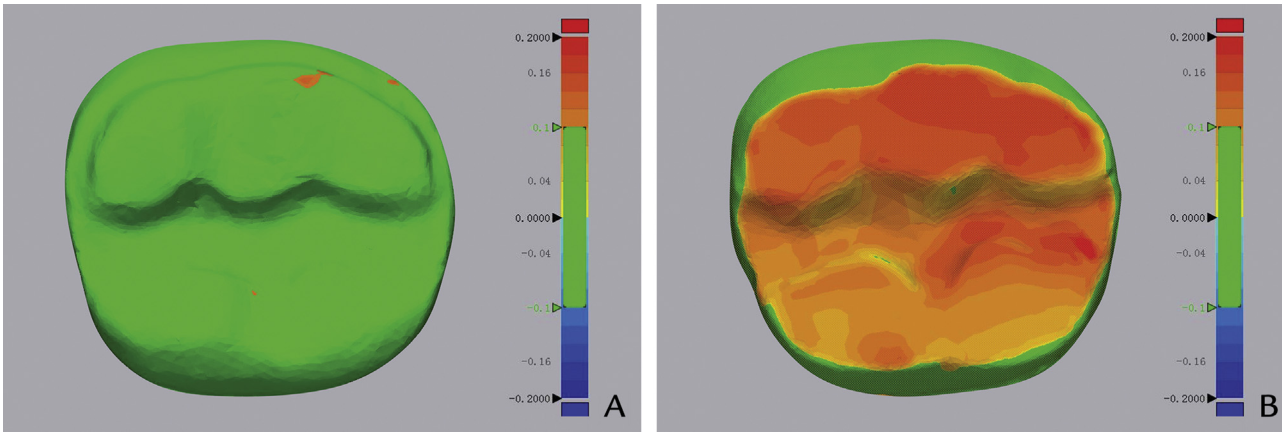

Figure 4. Three-dimensional comparison images for two preparation methods. A, Traditional preparation. B, Shoulder preparation.

As CAD-CAM technologies and materials have improved and are being developed, the marginal design of a preparation will not introduce significant difference during the step-by-step fabrication process. The drawbacks of traditional onlay preparations have been gradually overcome.[8] As scanners have become faster and more accurate, they can produce a digital scan with great detail and precision for both traditional and shoulder preparations.[6] The fit between the preparation and the intaglio surface of a restoration can also be improved by using advanced 4- or 5-axis milling machines.[7] Dental materials suitable for milling have been developed to keep up with the digital protocol, and ceramic-reinforced composite resins, also known as resin-matrix ceramics,[31] are now recommended for CAD-CAM onlay restorations because they have high flexural strength and modulus of resilience and are less likely to fracture during milling, thereby obtaining better marginal integrity.[32] Another advantage of the ceramic-reinforced composite resin is its low elasticity modulus, which can decrease internal stress on the remaining tooth structure.[33]

In the present study, the chamfer finish line in the traditional preparation resulted in better marginal fit than in the shoulder preparation, which is consistent with other investigations. Shiratsuchi et al[34] reported that finish line design affected the marginal adaptation of electroformed metal copings or metal-ceramic crowns and that heavy chamfer and rounded shoulder preparations had better marginal fit than shoulder preparations. Meanwhile, other advantages of the traditional preparation include the creation of the path of placement. As part of the axial wall is prepared and a heavy chamfer is placed on a functional cusp, the path of placement can be defined. Therefore, a clear and firm stop can be obtained during the evaluation and cementation procedures, which will prevent improper placement of the onlay restoration. Moreover, a heavy chamfer can be easily identified by dental laboratory technicians during fabrication. All these features enhance the marginal fit of the traditional preparations. On the contrary, the flat occlusal surfaces of the shoulder preparation cannot offer a definitive path of placement, which may result in poor marginal adaptation and eventually lead to failure.

Different methods of evaluating marginal and internal discrepancies between restoration and preparation have been used, each with advantages and disadvantages. The direct view and cross-sectioning methods have been widely used because they are straightforward, but the cross-sectioning method requires destruction of the specimens.[21] The profilometry method (P) is a nondestructive method but needs specific equipment to evaluate specimens.[35] Microcomputed tomography has also been used but is complex and requires expensive equipment.[28] The ideal method should be accurate, straightforward, and nondestructive to specimens. The silicone replica (SR) method using light-body PVS impression material to replicate the cementation space has been popular because it avoids these disadvantages and is reliable.[26] However, the thin PVS layer may deform as it is removed from the die, and only a limited number of sections can be examined.[25]

Accurate digital scanning and the development of a 3D comparison software program have made the triple scan (TS) and 3D superimposition (3DSA) analysis methods possible. After superimposition of the original and postcementation digital scans, marginal, internal, and overall discrepancies can be calculated between restoration and preparation with a 3D comparison software program.[29,30] They are fast, straightforward, and nondestructive techniques, and by adding comparison points, discrepancies at different areas can be identified. The accuracy and reproducibility of the TS and 3DSA techniques are determined by the quality of the digital scan and the overlapping of the 3D files. However, as newly proposed techniques, the reproducibility of these methods remains to be verified by other investigators. The digital silicone replica technique used in this study is an integration of the traditional silicone replica method and 3DSA technique. The simulated luting space by PVS can be acquired in 3D data and analyzed digitally, therefore evaluating both marginal and internal discrepancies nondestructively. However, this study does not compare accuracy and reproducibility of the digital silicone replica technique with those of other traditional techniques. As only limited studies have addressed this topic, further research is needed to determine its efficacy both in vitro and in vivo.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. For ceramic-reinforced composite resin CAD-CAM onlays, traditional preparations led to smaller marginal and internal discrepancies between restorations and preparations than the shoulder preparation.
2. The digital silicone replica method can be used to evaluate both marginal and internal discrepancies, but further studies on its accuracy and reproducibility are needed.

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