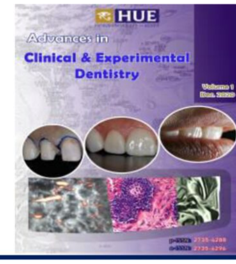
Advances in Clinical and Experimental Dentistry



Assessment of composite leakage using optical coherence tomography: A systematic review

Ebrahim El-Basha [1,2]

Abstract

Background Leakage under dental restorations is problematic because it allows bacterial percolation and can cause a failure of dental restorations. Assessing microleakage and nanoleakage is one of the main topics of research regarding operative dentistry.

Objective This review compares the assessment methods of composite leakage using optical coherence tomography.

Results Optical coherence tomography (OCT) is useful in evaluating the internal adaptation of composite resin restoration and in quantifying resin–dentin interfacial gaps. The sealing performance of resin cementation before and after thermal cycling and monitoring of cariogenic demineralization at the enamel–composite interface was also attempted. OCT is still uncommon in developing countries. Saudi Arabia is the only Arab country that has conducted OCT-based studies.

Advances in Knowledge OCT (swept-source) is an excellent candidate for assessing adhesives, defects at the tooth/self-adhering flowable composite interface cavity, enamel cracks at the adhesive cavosurface margin, the microleakage of resin restorations, and cavity wall adaptation of composite restoration. The most promising area of research for OCT is the measurement of volumetric polymerization shrinkage in relation to internal adaptation in bulk-fill and conventional composites. The sealing performance of resin cement before and after thermal cycling, and monitoring of cariogenic demineralization at the enamel–composite interface was also attempted.

Keywords

Composite Resin, Leakage, Optical Coherence Tomography, Swept-source

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1. Introduction

Advances in restorative dentistry are now synchronized with modifications of resin composite and adhesive formulations. However, polymerization shrinkage of methacrylate-based resin composites during curing may result in contraction stress and a loss of marginal adaptation [1]. Dental adhesives should provide an equally effective bond to both the tooth tissue and composite resin. An inadequate marginal sealing of the restoration can lead to microleakage [2], postoperative sensitivity [3], and debonding [4], which ultimately reduces the longevity of the restoration.

Polymerization shrinkage, the maximum rate of shrinkage, and polymerization shrinkage stress of dental composites of the resin composite can create marginal microgaps at the outer interface of the restoration and interrupt the integrity of internal adaptation between the resin composite and tooth substrate [1]. Marginal microgaps can be identified by an inspection from outside the tooth structure. To find these microgaps inside a tooth, dye and tracer penetration methods have been previously used [2,3]. Because tracers, such as methylene blue, rhodamine, erythrosin and silver nitrate, can infiltrate into teeth, these tracers were used to assess gaps even though restorations must still be cut out [4]. In addition, once the examined teeth are sectioned for the experimental measurement of gaps, the sample is degraded. Even though sacrificing of the experimental sample is plausible, the degree of staining of the dentin layer defines a straightforward measure that predicts the actual microleakage between the cavity and restoration [5].

Marginal adaptation, bond strength, and interaction with the tooth substrate are common methods for assessing the bonding performance of restorative systems [5]. Conventionally, marginal adaptation tests require multiple sectioning of samples, followed by immersion into a staining solution and surface polishing before examination under a light microscope, a scanning electron microscope, or a transmission electron microscope (TEM) [6–8]. These procedures are time-consuming and limited to experimental studies. Measuring microtensile bond strength and interaction with the tooth substrate does not pose as many clinical implications as studies on marginal adaptation [9-11].

Optical coherence tomography (OCT) is a new nondestructive method for producing high-resolution, cross-sectional images of internal biological structures at the micron scale. Based on low-coherence interferometry, OCT was introduced to backscatter signal intensity within the scattering medium. The signal from serial scans can be transformed into an image using specific software [12]. OCT began being used in dental studies to characterize primary and secondary caries, assess gaps between the composite-tooth interface, and evaluate voids and internal defects in dental restorations.

OCT is a noninvasive cross-sectional imaging method that uses low-coherence interferometry. This technique permits visualization of the microstructure of tissues and biomaterials in real-time without requiring tissue sectioning or specimen preparation. A computer can be used to reconstruct a visual image from the obtained backscatter signal as an input [14].

In the OCT image, an interfacial microgap is observed as a bright spot or line with high signal intensity that changes at the interface appears as a white cluster on the image. When light passes through the interface between two medias with different refractive indices, a portion of light is reflected (Fresnel phenomenon), depending on the incidence angle and refractive index. The refractive index of air is 1.0 (n) and a tooth or resin composite is 1.5–1.6 (n) [15-17]. If incomplete adhesion forms a microgap, air or water may exist at the interface. The OCT system shows a higher signal intensity by reflecting light there. If the microgap is filled with another medium, the reflection is weaker than air. Microfocus X-ray computed tomography (micro-CT) is another useful method to evaluate the internal adaptation of restorations [18-20]. Due to the penetrating ability of X-rays, micro-CT evaluates dental hard tissue irrespective of the depth.

Swept-source OCT (SS-OCT) can construct images using ultra-high-speed scanning of the generated near-infrared laser wavelength and by evaluating the superficial dental layers and restorations quickly and precisely. SS-OCT can improve the penetration of images with a 1050 nanometer wavelength to generate an axial resolution of 5.3 µm and a rate of 100,000 scans per second, which equals a two-fold measure of the highest obtained score; this makes it an excellent candidate for studying dental composites, for the early detection of dental caries, and for extension to other uses [16-18]. Micro-CT and SS-OCT can be useful non-destructive methods for the evaluation of internal adaptation. This systematic review investigates the assessment of leakage in dental restoration using OCT

2. Methodology

Search strategy

A systematic review of the published articles regarding OCT was performed using the Cochrane Library, Crossref, PubMed, Science Direct, MEDLINE, Google Scholar, and EMBASE (Ovid). Search keywords and medical subject headings included "optical coherence tomography*," AND "leakage," AND "microleakage," AND "restorations OR resin* OR composite*" AND NOT "retina" AND NOT "cutaneous" AND NOT "cardiac" AND NOT "onco*."

Two hundred and seventy-one articles were found on Scopus, Crossref, PubMed, Science Direct, MEDLINE, Google Scholar, and EMBASE (Ovid). An additional 12 articles were found on the Web of Science. Using Mendeley software, any duplication was initially deleted, which resulted in the deletion of 43 articles. Every submitted article was annotated by the reporting authors and by the authors' affiliations.

Inclusion and exclusion

This systematic review included only medical articles that were published in English and in the dental field. The time of publication ranged from 2005 to 2020. Articles in press that were not assigned a volume were also included. The exclusion criteria included the following: (1) articles that investigate the applications of OCT in other medical domains such as ophthalmology, cardiology, gastroenterology, oncology, and dermatology, (2) manuscripts that report duplication or triplication, (3) studies on ceramic restorations, and (4) studies that do not evaluate leakage under dental composites.

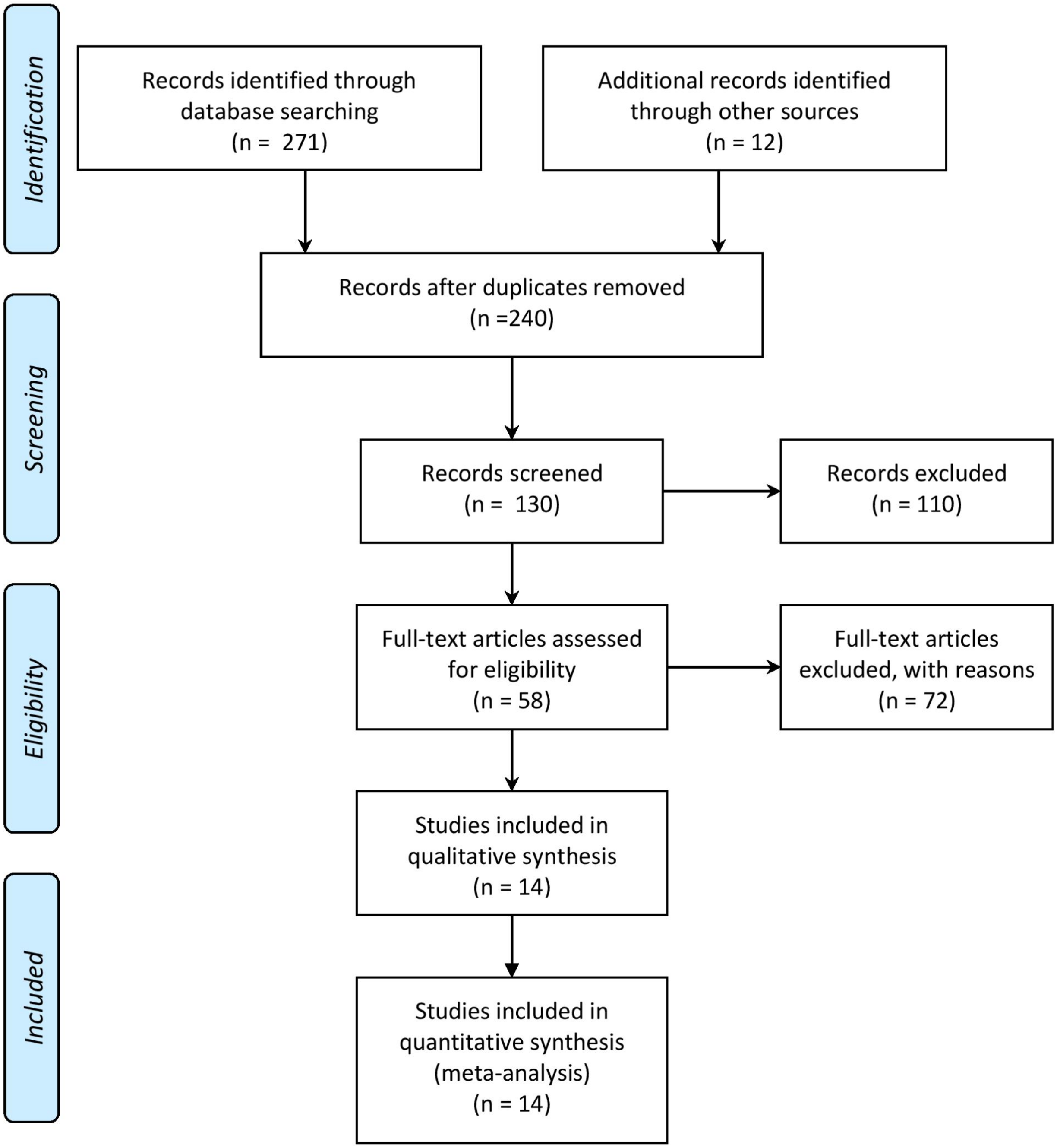

Figure 1. PRISMA flow chart showing the search method

3. Results

Various methods were used to detect microleakage in all types of resin composites. The primary purpose of studying properties of composites was to improve their clinical performance. Table 1 indicates that several prestigious journals highlighted the possible outcomes of using OCT to assess dental biomaterials. Table 2 displays a list of countries in which published dental research articles were conducted.

Table 1. List of journals that published OCT-based dental research articles

Journal	Percentage
Dental Materials	18%
Dental Materials Journal	12%
Journal of Dentistry	10%
Operative Dentistry	7%
Brazilian Oral Research	5%
Clinical Oral Investigations	5%
American Journal of Dentistry	4%
International Ophthalmology	4%
Journal of Adhesive Dentistry	4%
Brazilian Journal of Oral Sciences	2%
International Endodontic Journal	2%
Journal of Prosthodontics	2%
Australian Dental Journal	2%
Dental Research Journal	2%
European Journal of Oral Sciences	2%
Journal of Applied Oral Science	2%
Journal of Dental Research	2%
Journal of Endodontics	2%
Journal of Prosthetic Dentistry	2%
Archives of Oral Biology	1%
Archives of The Balkan Medical Union	1%
Brazilian Dental Journal	1%
British Dental Journal	1%
Caries Research	1%
Current Eye Research	1%
Dentistry Journal	1%
Dentistry Today	1%
Dentomaxillofacial Radiology	1%
European Journal of General Dentistry	1%
European Journal of Paediatric Dentistry	1%
Implant Dentistry	1%
International Dental Journal	1%
International Journal of Oral Science	1%
Journal of Clinical and Experimental Dentistry	1%
Journal of Conservative Dentistry	1%
Journal of Dental Sciences	1%
Open Dentistry Journal	1%

Table 2. List of countries in which the published dental research articles were conducted.

Country	Percentage
United States	23%
Japan	20%
Brazil	16%
Saudi Arabia	6%
Germany	5%
Italy	4%
South Korea	3%
Belgium	3%
Chile	2%
Turkey	2%
Canada	2%
France	2%
Jordan	2%
Switzerland	2%
United Kingdom	2%
Australia	1%
Austria	1%
Iran	1%
Ireland	1%
Netherlands	1%
Romania	1%

Table 3. Merits and limitations of assessments methods.

Method	Advantage [20]	Disadvantage [20]	Popularity
Dye leakage method	-Used along with no radiation - different dye solutions are available - technique is highly feasible and easily reproducible.	- Some of the dyes can react with dentin such as basic fuchsin. - the particle size of the used dye minimizing reliability - immobility of silver nitrate molecules at a certain point.	15%
Three-dimensional methods	Provides more acceptable precision than 2D	- highly subjective and destructive. - Destroyable samples during sequential grinding and slicing procedures. - slicing can affect the restoration tested and thus alter the results	8%
Micro-computed tomography	- 3D reconstruction can be sectioned in any direction to assess internal geometry and structural parameters. - Maintain 2D section information is; thus, all -Margins are available for visual inspection - Magnification is adjustable to view the interface	- µCT alone is not a substitute for the histological examination of leakage in vitro samples.	10%

Method	Advantage [20]	Disadvantage [20]	Popularity
Radioactive isotopes	- Isotopes can penetrate gaps equal to or larger than 40 nm, which is higher than the minimum detectable range of bacteria-based studies. - Isotopes appear to be better at demonstrating microleakage than dye penetration test	- Radioactive isotopes require the use of radiation, - Obtained autoradiograph does not represent microleakage as a 3D image.	9%
Acetate peel technique	-Acetate films view all teeth layers and microleakage at the interface. - Simple, inexpensive, and fast method for measuring microleakage. -peels are stable and can be preserved for further evaluation	-The peel technique is delicate, which may produce artefacts that can be misinterpreted	11%
Confocal laser scanning microscopy (CLSM)	-Clear indication of leakage limits due to a lens focus that can occur some microns beneath the observed surface. This eliminates the stain spread caused by specimen sectioning and also avoids polishing artefacts that exaggerate dye penetration	Accuracy can be improved.	18%
Scanning electron microscopy	Ability to increase image magnification	- Loss of tooth structure with slicing makes the inspection of the tooth-restoration interface inevitably defective. -The thickness of the cutting blade itself limits the number of sections that can be obtained. -restorations of clinically relevant size and shape may yield very few specimens for observations. - precludes further testing of the specimen and therefore, the possibility to relate leakage to clinical outcome.	24%
Optical coherence tomography	- High spatial resolution - 3-D image reconstruction - measured the microleakage at approximately 401 μm ×148 μm in size. - view interfacial seal at 0.3 to 16 mm. - visualize gaps at the interface, - detect voids or air bubbles of all sizes of composite	- Limited penetration depth and scanning range - Expensive components. -In sufficient scanning range - Low penetration depth -Improper wavelength choice is problematic.	5%

The marginal adaptability of restorations is fundamental for restoring teeth successfully in the long run. Because physical properties of tooth structure and restorative materials are inconsistent, perfect adaptation is always unreachable. Polymerization shrinkage, hydroscopic expansion, light polymerization concepts, thermal cycling, occlusal stresses, and application of an effective bonding agent are all determinants that govern the integrity.

Author, Year	Assessment method	What they assess?	Ref
Bakhsh et al. (2011)	OCT+ microtensile bond strength	Current adhesives in class I cavity	1
Makishi et al. (2011)	OCT(swept-source)+ µCT	Non-destructive evaluation of an internal adaptation of composites	2
Bakhsh et al. (2013)	OCT	Composite Adaptation to Pulpal Chamber Floor	3
Turkistani et al. (2015)	OCT+ confocal microscopy	Non-invasive quantification of resin–dentin interfacial gaps	4
Turkistani A et al. (2014)	OCT	Sealing performance of resin cements with thermal cycling	5
Han et al. (2016)	OCT(swept-source)	Influence of polymerization shrinkage and stress	6
Zhou et al. (2016)	OCT(swept-source)	Bacterial demineralization around composite restorations	13
Makishi et al. (2015)	OCT	Contemporary available adhesives in class I cavity	14
Sampaio et al. (2019)	OCT+ µCT	Volumetric polymerization shrinkage and its comparison to internal adaptation in bulk fill and conventional composites	18
Tabata et al. (2017)	OCT(swept-source)	enamel cracks at adhesive cavosurface margin	19
Park et al. (2015)	OCT(swept-source)	Defects at tooth/self-adhering flowable composite interface	20
Senawongse et al. (2011)	OCT(swept-source)	Non-destructive assessment of cavity wall adaptation of class V composite restoration	22
Horie et al. (2016)	OCT(swept-source)	Cariogenic demineralization at the enamel–composite interface	24
Kermanshah et al. (2020)	OCT (swept-source)+dye penetration	Comparison of microleakage of Scotchbond™ Universal Adhesive with methacrylate resin in Class V restorations	34

4. Discussion

Several methods are available for determining marginal or interfacial adhesive defects. One commonly used method is to highlight microleakage using an organic dye or silver nitrate as a tracer [34]. The microleakage can then be used to investigate the quality of adhesives on the basis of the marginal gaps or interfacial gaps formed at restorations using them. The disadvantages of microleakage analysis are that it is an invasive semi-quantitative analysis which can be used only in vitro. Additionally, the results of microleakage analysis are recorded from only one to three slices obtained by cross-sectioning, resulting in a limited representation of three-dimensional geometry [20-35]. Furthermore, the effect of artificial aging methods such as water storage and thermocycling on microleakage is minimal [36-40]. Another approach which can be used for qualitative and quantitative assessment is marginal analysis. This method enables monitoring and multiple measurements of marginal integrity when replicas are used, but it cannot cover the entire adhesive area of restorations and does not allow non-destructive internal evaluation of interfaces. Radiography can also provide clinical information about marginal discrepancies or gaps in composite restorations with adhesive luting, but it frequently results in false positive or false negative readings [41]. Micro-computed tomography allows a more detailed display of radiographically detectable interfacial discrepancies. However, it requires long measurement times and can cause deformation of specimens due to over-drying during scanning resulting in false-positive data [42]. Additionally, it can only be used in vitro because of high and long-term X-ray exposure. In contrast to these established methods, OCT enables quantitative and qualitative 1D–3D measurements with high resolution (up to a few micrometers). Furthermore, repeated measurements of the same specimens are possible, giving increased statistical power and extensive evaluation. The suitability of OCT for detecting adhesive defects is based on the large differences in refractive indices characteristically found in the gap area, the light through the interface between 2 media undergoes partial reflection and refraction according to the refractive index of the media crossed [1-14]. OCT imaging can analyze to a depth of about 2–3 mm, so it was necessary to cut samples after the post endodontic restoration to clearly visualize the cavity floor interface. Furthermore, better-quality images are obtained with OCT imaging when the light beam is perpendicular to the interface.

The ability to increase image magnification is an advantage of SEM over micro-CT. Conversely, in micro-CT, magnification depends upon the distance between the specimen and the x-ray source and therefore upon the specimen size: The smaller the distance, the larger the magnification and the greater the detail of the image. On the other hand, micro-CT has the benefit of obtaining an uninterrupted inspection of the interface that enables detection of the deepest leakage point. As a matter of fact, in the present study, for half of the teeth, scanning all the micro-CT cross-sections led to a higher leakage score than that determined from the assessment of three sections or of SEM specimens

SEM allowed leakage evaluation only in the plane of sectioning and with the inevitable loss of information at the site of cutting. Conversely, micro-CT enabled a 3D mapping of the tooth-restoration interface and detection of the deepest leakage level. It was plausibly due to the hit-or-miss characteristic of the section method that for five of 10 tested teeth, a higher leakage score was determined from the observation of all the micro-CT scans than when only three-tooth sections were viewed either with micro-CT or under SEM.

Micro-CT and SS-OCT have their own characteristics as a tool for evaluation. Micro-CT has no limitation for evaluating the restoration in terms of cavity depth. However, SS-OCT has depth limitations. Even though SS-OCT shows very clear images within the penetrating depth of the laser, it cannot be used in deep cavities and fillings. The cavity depth in our experiment was 2mm because the imaging depth of SS-OCT systems had been reported to be in the range of 2–3mm [12]. SS-OCT images were generally clear, and the high-intensity white spots or clusters could easily be identified on the image. In some cases, imprecise spots and indistinct parts were observed. It would be ideal to evaluate the images with a predefined signal intensity threshold for the defect. However, defining a SS-OCT threshold for the micro-gap was complicated because of the influence of the light intensity, scattering, attenuation and transmittance properties of the material [13-,21].

OCT has a limitation to detect the subsurface gaps under the demineralized tissues. Signal intensity and attenuation patterns are both affected by caries. Increased reflectivity from the superficial enamel in the case of lesions resulted in a low backscatter signal from the underlying tissues. Also, light scattering in dentin is an order of magnitude larger than that in enamel because dentin is highly anisotropic and has a different spectral light scattering dependence than enamel. Therefore, tissues below the lesion showed dark areas and DEJ was not clear. Moreover, the fillers in composite resin scatter the light, which affects the intensity of the light reaching a particular depth [45-54].

To overcome the limitation on the use of OCT, sufficient scanning range of OCT, high penetration depth and choosing proper wavelength choice are required [54, 56]. Although 2D and 3D OCT images provided important information about the marginal adaptation of different adhesive systems after 24 hours and 10,000 thermocycles. It appears that an initially good sealing ability and bond strength cannot reliably predict the bonding stability long-term and is highly adhesive-dependent. Further technological development of the resolution and light depth penetration of OCT is necessary to implement this technique for chair-side diagnosis of dentin and long-term monitoring of different restorative materials.

5. Advances in Knowledge

The use of OCT (swept-source) is an excellent candidate for assessing adhesives, defects at tooth/self-adhering flowable composite interface cavity, enamel cracks at adhesive cavosurface margin, microleakage of resin in dental composites, and cavity wall adaptation of class V composite restoration. OCT is also useful in evaluating the internal adaptation of composite resin restoration and quantifying resin–dentin interfacial gaps. The sealing performance of resin cements before and after thermal cycling, and the monitoring of cariogenic demineralization at the enamel–composite interface were also attempted. The most promising area of research for OCT is to measure volumetric polymerization shrinkage and relating it to the internal adaptation in bulk fill and conventional composites.

6. Conclusion

Several methods are available to determine marginal or interfacial adhesive defects. One commonly used method is to highlight microleakage using an organic dye or silver nitrate as a tracer. Any microleakage can then be used to investigate the quality of adhesives on the grounds of marginal or interfacial gaps formed at restorations. The disadvantages of microleakage analysis are that it is an invasive semi-quantitative analysis that can only be used in vitro. Additionally, results of microleakage analysis are recorded only from one to three slices obtained from cross-sectioning, which results in a limited representation of three-dimensional geometry.

Micro-CT and SS-OCT could be useful nondestructive methods for the evaluation of internal adaptation. The measured imperfective margins ratio in micro-CT showed different values of dental materials compared to those of SS-OCT. However, within the past two decades, the use of SS-OCT resulted in more reliable results than all previously introduced methods.

Take-home Messages

1. In-vivo studies would benefit from SS-OCT studies more than any other method

2. For the effective interoperability of OCT-based imaged with computational software and image processing tools, dentists and researchers need to acquire or hone some computational skills to benefit from these techniques and implicate all on daily clinical practice in dentistry.

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