REVIEW ARTICLE

Application of Near-infrared Light Transillumination in Restorative Dentistry: A Review

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Abstract

This paper presents the various applications of near-infrared light transillumination (NILT) in dentistry. Untreated dental caries is considered the most prevalent health condition affecting both children and adults worldwide. Increased awareness and a paradigm shift toward utilization of minimally invasive treatment procedures and nonionizing radiation led to the discovery of newer techniques for screening and early diagnosis of demineralized lesions. Demineralized lesions detected early can be treated with minimally invasive treatment procedures such as the usage of fluoridated dentifrice to encourage remineralization and resin infiltration to arrest caries progression. NILT procedure involves noninvasive, nonionizing radiation and helps in the identification of early demineralized lesions using light transillumination. At near-infrared wavelengths, the enamel appears translucent and helps in visualizing and detecting demineralized lesions when long-wave light transilluminated against the tooth surface. The wavelength in the range of 1310 nm is considered best for the transillumination of lesions. This technique has been proven to be successful in the detection of carious and demineralized lesions. NILT can be used as a screening tool for the early detection of demineralized lesions and can be considered as an adjunct to bitewing radiographs. It can be advantageous in screening pregnant, growing adolescent patients and in cases where multiple follow-ups are needed and ionizing radiation must be avoided.

Keywords: Dental caries, Early diagnosis, Ionizing radiation, Minimally invasive, Near-infrared, Occlusal caries, Transillumination.

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Introduction

Dental caries is a condition characterized by the gradual destruction of the enamel layer of the tooth from acids produced by the action of bacterial acids on dietary carbohydrates.[1] It is a dynamic process involving many cycles of demineralization and remineralization. Unchecked demineralization will lead to cavitation and progression of caries.[2] Dental caries is a common public health problem with high prevalence in school-going children and adults.[3] WHO considered it as a major public health problem and a widespread noncommunicable disease affecting 60–90% of children adults.[4,5] Poor oral hygiene maintenance and lack of health education among the population lead to a higher incidence of caries.[3] Early detection and treatment improve treatment outcomes.[6,7] Remineralization of early lesions can be done by using noninvasive treatment procedures.[8,9] Minimally invasive treatment procedures such as topical fluoride varnish,[10–12] resin infiltration,[13] and occlusal sealants[14] can arrest the progress of carious lesions. Several remineralization techniques have been proved to arrest carious lesions; thus diagnosing early demineralized lesions can intercept the progression of the early lesions.[15,16]

Traditional methods for the detection of dental caries involve a visual-tactile inspection using explorer on the suspected lesion, supported by radiographic examination.[17,18] International Caries Detection and Assessment System (ICDAS) was developed in the year 2002 for visual caries assessment and is a reliable visual method for the detection of dental caries.[19] Radiographs such as bitewing radiographs are used for the inspection of proximal caries and to identify the extent and depth of the lesion.[20,21] Digital radiographs can detect noncavitated lesions better compared to conventional radiographs.[22] A drawback of the radiograph is that at least 30–40% of teeth demineralization is necessary before the lesion is detectable.[23,24] As radiographs detect lesions after reaching a significant level, there is a need for the development of diagnostic methods which detect caries at an early stage. Accurate early diagnosis of presence or absence of lesion is crucial for appropriate care and management of caries by preventive or interceptive therapy.[25,26] Newer alternative techniques include electric conductance measurements,[27,28] ultrasound,[29] fluorescence, transillumination, and optical coherence topography (OCT)[28,30–33] for the detection of caries lesions. Fluorescence and transillumination showed better results.[34]

Quantitative laser fluorescence uses light in the wavelength of 600–700 nm projected onto the caries lesion to produce fluorescence to examine for caries. The fluorescence is due to endogenous fluorophores present in the lesion and appears dark which detects the lesions.[35] DIAGNOdent uses laser diode and fiber-optic probe which uses bacterial porphyrins for detection of lesions.[36] However, it has poor sensitivity for the detection of enamel lesions.[37] Depth-resolved images of lesion severity or demineralization were not possible with fluorescence.[38,39]

Concerns about ionizing radiation have led to resurgence in the use of transillumination techniques. Fiber-optic transillumination (FOTI) is a laser-based transilluminator that uses visible light and is helpful for the detection of demineralized lesions and carious

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lesions.[40] A modified digital version of FOTI which is referred to as digital fiber-optic transillumination (DFOTI). FOTI and DFOTI use shorter wavelength visible light which increases more scattering in the enamel lead to lesser contrast and thus is difficult to detect lesion.[41]

Near-infrared light transillumination (NILT) is a modification of DFOTI. On examination, the enamel appears transparent to various degrees in the near-infrared range as the light scattering reduces and helps in the diagnosis of demineralized lesions.[42] This paper summarizes the principal applications of NILT in dentistry along with recent advances and prospects.

Near-infrared Light Transillumination

Daniel Fried and Robert Jones in the year 2006 patented NILT for the imaging of dental decay in the wavelength range of 780–1600 nm.[43,44] Commercially available brands are DIAGNOcam (2012, KaVo, Biberach, Germany), Vista-Cam ix (2013, Durr Dental, Bietigheim-Bissingen, Germany), CariVu (2013, Dexis, Alpharetta, USA).[45]

DIAGNO-cam, one of the commercially available devices, entails the following components:

- Two near-infrared (NIR) laser light sources are projected from the buccal and lingual side passing through the gingival tissue, alveolar bone illuminating teeth from the radicular and cervical area.
- Monochromatic 8 bit ¼ inch complementary metal-oxide-semiconductor chip captures a 640 × 480 pixel resolution from the occlusal aspect at a focal distance of 4.5 mm with a 105° angulated wide-angle lens.
- A standard personal computer/laptop with proprietary software (Kavo Integrated Desktop) is used for viewing real-time images.[46]

Operating Principle

Optical properties of the mineralized teeth appear different from the demineralized area as it presents with more pores and interprismatic water which leads to more scattering of the light which records the NIR image. The demineralized lesion appears as darker lesions due to scattering of light rays and sound teeth structure appears as light gray. Shallow and mild demineralization appears less contrast and deeper lesions appear more contrast.[47]

Mechanism

Infrared light from NIR transilluminator passes through gingival tissue, bone and reaches teeth and scatters. The reflected light is captured onto the charged-coupled device sensor present on the occlusal surface. The recorded information is converted into an NIR image using system software.

Considerations While Using in the Oral Cavity

- Thorough scaling should be done to remove plaque, stains, and calculus.
- Tooth surface should be kept dry and devoid of saliva.
- Secondary light sources should be avoided to prevent interference.
- Placement of the scanner should be in the middle and parallel to the occlusal surface.[48]

Pros and Cons

It offers several advantages over conventional detection methods. It utilizes nonionizing radiation and is a nondestructive method. This can be used in young patients with a low risk of caries instead of radiographs to prevent unwanted radiation exposure.[46] Shallow and mild demineralization appears less contrast compared to deeper lesions.

The technique is not without its drawbacks as it can only scan one tooth at a time and this can prove time-consuming. It has low specificity and high sensitivity which may lead to overtreatment. The depth and extent of the lesion in occlusogingival may not be readily apparent and it presents difficulty in screening angulated teeth, root caries, and subgingival caries.

Applications

Caries Detection

NILT is a screening tool used for the detection of incipient caries lesions involving enamel, dentino-enamel junction, and dentinal lesions. This can be used in young patients with a low risk of caries instead of radiographs to prevent unwanted radiation exposure.[49] Shallow and mild demineralization appears less contrast compared to deeper lesions.

Incipient Lesions

Detection of early caries is difficult with visual inspection and radiographs. With the advent of minimally invasive techniques like resin infiltration, fluoride application helps in the remineralization of the demineralized lesion. NILT is the best method available for the detection of early carious lesions.[50] Follow-up study done by Simon showed that 10% of the detected questionable caries needed intervention within 20 months.[51] This study proves the importance of early detection of incipient lesions with NILT to prevent the progression of the lesion.

Occlusal Caries

Occlusal caries is often difficult to diagnose with visual inspection and radiograph as deep occlusal fissures undergo staining and are not seen in radiographs. NIR images showed better contrast between sound and demineralized teeth structure. It can easily differentiate demineralized lesions from stains and pigmentations helping in the detection of incipient occlusal caries. NILT when exposed on teeth above the gingival margin diffuses through the dentin and provides backlight illumination for the enamel, allowing for the imaging of occlusal lesions. In primary teeth, NILT should be used along with bitewing radiograph as it is not sensitive enough to diagnose dentinal lesions. NILT shows better sensitivity and specificity in permanent teeth.[47,50]

Proximal Lesions

Proximal lesions are challenging to detect by visual inspection as the proximal areas of a tooth are difficult to view by conventional means. Separating teeth with orthodontic separators to visually examine the area can lead to trauma of the gingiva and discomfort to the patient.[7] Bitewing radiographs can have overlapping of adjacent teeth, hampering accurate diagnosis. NILT has better sensitivity and specificity in the detection of proximal enamel caries in both primary and permanent teeth. More false negatives were observed when detecting dentinal lesions in the primary teeth, especially in first primary molars compared to second primary molars. In the permanent teeth, it showed better accuracy in both enamel and dentinal lesions.[45] NILT can detect dentinal lesions in the proximal cavity and can be used to reduce radiation exposure to the patient.[52]

Secondary Caries

Secondary caries is a late complication of restorations.[53] Conventionally, a combination of visual inspection, tactile inspection, and radiographs is used to screen for secondary caries.[54] Wall caries and secondary caries on the proximal aspect can prove challenging to detect.[55] Radiographs are more sensitive but cannot be used for multiple screening due to the hazards of radiation exposure.[56] NILT differentiates between composite, enamel, dentin, and demineralized lesion and is thus useful for the detection of recurrent caries. It can be used for the detection of secondary caries under proximal restorations like composite and amalgam.[57–59] NILT can be used for screening of wall and outer lesions in both anterior and posterior teeth when a longer wavelength was used.[60] However, NILT cannot differentiate between the demineralized lesions and unknown restorative material.[61]

Cavity Preparation with Laser

Lasers have found a myriad of applications in dentistry, one of them being cavity preparation.[62] With the development of nonionizing radiation methods, a combination of lasers along with nondestructive methods such as fluorescence and NILT can help to selectively remove carious lesions.[63] Real-time NIR imaging can be used for monitoring cavity preparation.[64] NILT, Polarization-Sensitive Optical Coherence Tomography (PS-OCT), and CO_2 laser were used for cavity preparation. NILT was used for detection of the extent of the lesion, PS-OCT for detection of the depth of lesion, and laser for cavity preparation. NILT and PS-OCT are used to scan the tooth to be restored and data are collected to be analyzed as data points. With the available data, treatment planning is done and feed the information to the laser unit. The laser is then used for cavity preparation. Comparison between pre- and postcavity preparation exhibited removal of demineralized lesion and intact sound teeth structure, thus NILT, PS-OCT combined with laser can be used for image-guided selective removal of demineralized lesions using laser ablation.[65]

Differentiation between Teeth and Restoration

Esthetic restorations such as composite are the most preferred restoration in dentistry.[66] Removing old restorative material and replacing it with a newer material can prove to be cumbersome and time-consuming. Removal of teeth colored restorations is a laborious process and risks removal of sound tooth material. NILT used with a longer wavelength can differentiate between teeth structure and composite restoration. Longer wavelengths have better water absorption, and composites being hydrophobic appear with higher contrast in the NIR image. With NILT procedure it can differentiate enamel, dentin, and composite restoration.[67] 1500 nm wavelength is considered as the mean contrast level for the detection of composite and is not impeded by stains present.[68]

NILT with Different Wavelengths

NILT conventionally uses wavelengths in the range of 780–1600 nm. A shorter wavelength leads to more scattering in enamel and dentin resulting in an image with less contrast. A longer wavelength above 750 nm presents with a 20–30-fold reduction of scattering in enamel, leading to an image with higher contrast, helpful in detecting demineralization.[69] A wavelength of 1310 nm is best suited for the screening of carious and interproximal lesions.[70] Greater correlation between enamel and water is measured at 1310 nm, thus the contrast between sound and demineralized is better appreciated.[71] A longer wavelength above 1310 nm coincides with higher water absorption leading to more contrast between sound and demineralized teeth.[51] Increased scattering of light in dentin caries was seen at a longer wavelength.[72]

Visible light or NIR light below 780 nm is not suitable for carious lesions because of increased light scattering and less contrast.[73] Proximal caries is better diagnosed with 1310 nm wavelength.[70] Occlusal lesions are better detected at 1450 nm as the water absorption is better contrast between sound teeth and lesion is seen.[74,75] 1500 nm can be considered as the mean contrast level for the detection of composite.[76]

NILT in Orthodontics

NILT can be used as a diagnostic method for caries detection in the presence of brackets, bands, and wires as individual teeth can be scanned and viewed in the occlusal aspect.[46,77] The presence of brackets and wire components on the teeth leads to alterations in the microbial environment which triggers the balance between demineralization and remineralization and is prone to white spot lesions which eventually develops into caries.[78] White spot lesions are the most common demineralized lesions seen postorthodontic treatment and can be treated if identified in early stages.[79] The high contrast between sound teeth and demineralized lesions in NILT can be used for screening white spot lesions.[80] Early detection can help to treat white spot lesions with minimally invasive procedures like fluoride application and resin infiltration.[81] NILT can be used to monitor the efficacy of fluoride application in preventing demineralizing through the course of treatment and to measure the amount of remineralization post fluoride application.[76]

Detection of Attrition and Cracks

Attrition was detected using NILT that appears as a large demarcated patch with a dark area as the enamel layer was attrited.[57] Enamel cracks or craze lines is one of the most common problems in dentistry. Diagnosis and early detection help to limit further crack propagation.[82] Dentin cracks cannot be identified using radiographs as they are not visible.[83] Cracks are easily visible as teeth become transparent when NILT is used at a longer wavelength of 1310 nm. Severe cracks or fractures can be easily identified with NILT as the light propagation is greatly affected and appears as distinctive sectors in the teeth. NILT at longer wavelength aids in fracture identification, severity, and depth assessment. Optical coherence tomography (OCT) is a three-dimensional imaging technique based on light reflectance used to acquire tomographic imaging of internal structures of teeth. This helps in the detection of lesions involving dentin. A combination of NILT and OCT can be used for the detection of cracks involving dentin as these are difficult to detect using NILT.[84]

Advancements in NILT

NILT with Retinal Image Display (RID)

With a conventional NILT device, the positioning of the intraoral camera is challenging.[46] A head-mounted retinal image display (RID) coupled with a NILT device can overcome the problem. A transparent lens consisting of a super video graphics array with a resolution of 800 × 600 pixels can be worn in front of the operator's eye. A 16.7 million color display with adjustable focus (0.30–10 m) appears as a 40 cm laptop screen when viewed from a 1 m distance. The retinal lens can be connected to any PC through a USB without the need for any proprietary software. The image directly appears on the lens, simplifying and streamlining the procedure to reduce operator errors in intraoral camera positioning.[46]

NILT with High Dynamic Range Imaging (HDRI)

Conventional NILT images can present with speckle effect which appears as granular or blurred images due to over- or underexposure. HDRI combined with NILT can overcome this problem. Multiple images are captured during imaging and combined to a single high dynamic range image, providing uniformly exposed, sharper, and more detailed images.[85] NILT-HDRI can diagnose dentin lesions and showed better contrast compared to visual inspection and bitewing radiograph.[86] A disadvantage of this combination is that the lack of rigid fixation of the scanner in the oral cavity might result in blurring of the image. Rigid mechanical support or the use of image stabilizing software can resolve this.

NILT with Deep Learning

In dentistry, deep learning using Convolutional Neural Network has been found in numerous applications ranging from detecting dental caries, diagnosing periodontal bone loss, identifying structures in radiographs, etc., providing a faster, comprehensive evaluation and diagnosis.[87] NILT along with deep learning is a new advancement for automated caries detection and accurate diagnosis of caries.[88] It improves speed, inter-, and intraexaminer reliability and saves chairside time.[89] Generalizability and validity study reveals that deep learning can be used for detecting lesions in NILT images.[90] Data available for deep learning is mainly collected from *in vitro* studies; clinical data should be collected for better validation.

NILT with Intraoral Scanner

There is increased research focused on the application of 3D intraoral scanners for monitoring oral health and in the detection of caries and demineralized lesions.[91] A recent advancement is the TRIOS 4 intraoral scanner mounted with a prototype NIR imaging device which is a combination of an intraoral scanner with NIR transillumination for the detection of carious lesions. It simultaneously records teeth and NIR images which are converted to a 3D model using the software. Visible coherent laser light used in conventional NILT causes speckle effect because of under- and overexposure. This can be prevented as the TRIOS-4 uses visible light (850 nm wavelength) and shows images with an enhanced contrast compared to conventional NILT. It converts a 2D NIR image to a 3D model which helps in better visualization, diagnosis, and facilitates comparison of future images.[92]

Comparison of NILT with Other Approaches

NILT is better at analyzing incipient and early occlusal lesions, compared to a bitewing radiograph, as it does not interfere with the superimposition of adjacent teeth and the ability to identify early demineralization. Bitewing radiographs are better at detecting dentinal lesions and the depth of dentinal lesions involving the pulp. However, they are limited due to the hazards of radiation exposure. NILT can be used as an alternative to radiographs for screening of caries in patients where ionizing radiation is not advised like pregnant and growing patients.[93,94] NILT can be used as a primary screening tool and bitewing can be used to know the depth and extent of the lesion.[95,96] NILT is four times better at detection of lesions reaching the dentino-enamel junction.[49] Unlike radiographs, real-time image identification can be done using NILT which helps in visualizing the position of teeth to be scanned before image capture. Inter- and Intraexaminer reliability was better with NILT compared to bitewing.[97]

Comparison of laser fluorescence and NILT showed that NILT has better specificity for detection of noncavitated proximal lesions and better specificity and sensitivity for detection of proximal and occlusal lesions.[98]

Comparison of visual inspection using ICDAS, radiographic examination, CarieScan PRO, DIAGNOdent, and DIAGNOcam exhibited that DIAGNOcam has better sensitivity and specificity in detection of occlusal and proximal lesions after visual inspection. Accuracy was proved to be best when screened with DIAGNOcam. From this comparison study, we can conclude that the NILT method can be used for the detection of demineralized lesions.[99]

NILT proves better than DFOTI as the latter cannot differentiate between carious lesions and developmental defects. DFOTI uses visible light in a shorter wavelength which scatters more and the contrast between the sound and demineralized lesion is less.[100]

Comparison of NILT and OCT showed similar sensitivity for early caries detection. OCT helps in determining the extent and depth of the lesion which is difficult with NILT. OCT scans the teeth and collects them as 3D data which consumes a lot of space and scans smaller areas compared to NILT. Thus, NILT can be used as a better screening tool when compared to OCT.[51]

Literature available about NILT is mostly limited to *in vitro* studies and very little on *in vivo* studies. More clinical research needs to be done on the application of NILT in the detection of carious lesions and demineralized lesions to validate its usage clinically as a primary screening tool, replacing radiographs.

Furthermore, clinical research on increasing the specificity of NILT imaging is required prior to its widespread usage as a primary screening tool. Data from future clinical studies can be beneficial for machine learning using artificial intelligence for better diagnosis with NILT.

Conclusion

In summary, NILT can be considered as a noninvasive, nondestructive screening tool for early detection of incipient caries, proximal and occlusal caries, secondary caries, white spot lesions, enamels cracks, craze lines, and used for minimally invasive selective cavity preparation. NILT can be considered as an adjunct to radiographs in screening demineralized lesions with an added benefit when screening pregnant women, growing adolescents and patients who need multiple radiographs as it does not use ionizing radiation. NILT is a portable, fast chairside screening method used for screening demineralized lesions.

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