ORIGINAL ARTICLE

The validity of laser fluorescence (LF) and near-infrared reflection (NIRR) in detecting early proximal cavities

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Abstract

Objectives Diagnosing cavitated proximal lesions is important for therapeutic decisions. This clinical study aimed to determine the validity of laser fluorescence (LF) and near-infrared reflection (NIRR) techniques for detecting early proximal cavities.

Materials and methods The study included 43 proximal surfaces in 15 females who had limited radiolucent lesions in their bitewing radiographs. The approximal areas of interest were assessed by DIAGNOdent Pen (LF) and the Proxi interchangeable head of VistaCam iX intraoral camera (NIRR). Finally, orthodontic separators were placed in the contact points to provide enough space between the teeth. The sensitivity, specificity, and accuracy of diagnosing cavitated proximal surfaces were calculated for LF and NIRR against direct visual and tactile examination as the reference standard.

Results On the basis of the reference standard, 34 surfaces (79.1%) were not cavitated, whereas 9 surfaces (20.9%) were cavitated and in need of restoration. The sensitivity, specificity, and accuracy of LF were 44.4%, 61.8%, and 58%, and those of NIRR were 88.9%, 14.7%, and 30%, respectively.

Conclusions The VistaCam iX Proxi was more sensitive and DIAGNOdent Pen was more specific in detection of proximal cavities. However, none of the techniques was accurate enough to be recommended as a sole approach for proximal caries detection.

Clinical relevance LF showed an overall superior diagnostic performance to NIRR for diagnosing proximal cavitation in permanent posterior teeth. Within the limitations of this study, neither VistaCam iX Proxi nor DIAGNOdent Pen could be considered a suitable device for diagnosing proximal cavities.

Keywords Caries · Caries detector · Lasers · Fluorescence · Near-infrared

Introduction

Dental caries is an infected and chronic procedure that initiates from enamel demineralization and progresses to major loss of dental hard tissues, as manifested by the cavity formation. By early caries detection, it is possible to halt and reverse the disease process through taking prophylactic and remineralizing measures. However, the diagnosis of incipient lesions is difficult especially in proximal surfaces, where the presence of adjacent teeth prevents from direct visual and tactile examination. It is estimated that 75% of proximal lesions are located in the interdental contact area and 25% are found beneath that [1]. Bitewing radiography is the most current method of detecting proximal caries, but there are some concerns regarding the exposure of patients to ionizing radiation, and it is not enough precise for detecting the presence or absence of proximal cavities [2, 3]. In fact, the detection accuracy of bitewing radiography increases with the depth of the proximal decay [4, 5]. Several techniques have been developed to help practitioners for diagnosing early stage proximal lesions in the clinical environment; among them are laser fluorescence (LF) and near-infrared reflection (NIRR).

DIAGNOdent Pen (KaVo, Biberach, Germany) is a portable low power laser that employs laser fluorescence technology for quantitative caries diagnosis in the proximal as well as

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the occlusal and smooth surfaces. This diode laser emits the wavelength of 655 nm (red light) at the maximum power of 1 mW to intensify fluorescence in the decayed tooth structure. The bacterial species in carious tissues produce fluorescent markers such as porphyrins as metabolic by-products [6, 7]. The resulting fluorescent light is captured by the device and displayed numerically between 0 and 99, according to the caries progression intensity [8, 9].

The use of near-infrared (NIR) light has received much attention in recent years for the diagnosis of proximal caries in posterior teeth. The Proxi interchangeable head (Dürr Dental, Bietigheim-Bissingen, Germany) was developed as a supplement to the VistaCam iX and the VistaCam iX HD camera systems (Dürr Dental). This diagnostic tool benefits from two infrared LEDs (850 nm wavelength, output power 6 mW, and light spot 7 mm × 9 mm) to illuminate the proximal areas of two adjacent teeth. A semiconductor sensor is mounted between the two LEDs to detect the reflected light. A digital image is then captured and illustrated in a black and white appearance on the monitor using the DBSWIN or VistaSoft imaging programs (Dürr Dental) [5, 10].

It has been demonstrated that most proximal radiolucencies confined to enamel or outer half of dentin in bitewing radiographs are not cavitated and can be managed by remineralizing measures, thus avoiding invasive restorative therapies [2, 11, 12]. The use of diagnostic tools has been proposed to overcome the limitations of bitewing radiography and identify the cavitated approximal lesions. There are numerous studies on the use of DIAGNOdent Pen for detecting caries at the occlusal, proximal, and smooth surfaces and around restorations [13–19], but information on the use of laser fluorescence for diagnosing cavitated lesions is limited. The Proxi head on the VistaCam iX intraoral camera system has been launched recently, and there is little clinical information on the efficacy of this diagnostic aid in detecting initial lesions in proximal surfaces. Furthermore, no study has yet assessed the benefit of NIRR in diagnosing proximal cavitations. Therefore, this clinical study aimed to investigate the validity (sensitivity, specificity, and accuracy) of DIAGNOdent Pen and VistaCam iX Proxi to detect early proximal cavitation in permanent teeth in relation to direct visual and tactile examination as the reference standard.

Subjects and methods

Sample

The sample of this clinical study consisted of patients who had limited radiolucent lesions in approximal surfaces of posterior teeth in recall bitewing radiographs. The patients were dental students at the School of Dentistry of Mashhad University of Medical Sciences, and the images were taken at the Department of Radiology of the same center, under standardized conditions. The radiographs were assessed by one skilled professional specialized in restorative dentistry under a light box, and those showing radiolucency in inner half of enamel or outer half of dentin were included in the study. In the visual examination, the teeth with radiolucent lesions were in contact with the neighboring teeth. The teeth with obvious marginal ridge discontinuity or cavitated occlusal or smooth surface caries as well as those with proximal restorations were excluded from the sample.

Of the 125 proximal surfaces evaluated in bitewing radiographs, 43 surfaces in 15 female subjects were selected and included in the study. The number of lesions per participant varied from 1 to 4, and the lesions were located in proximal surfaces of premolar or molar teeth in the upper/lower jaws. The case selection and further examinations were performed within 1 week after taking the radiographs. The average age of the participants was 23.5 years (20.2–25.8 years). The study protocol was reviewed and approved by the Ethics Committee of Mashhad University of Medical sciences (IR.mums.sd.REC.1395.136). The aims and procedure of the study were explained thoroughly for each patient, and informed consent was obtained from the participants before the study commencement.

Examination methods

Following case selection, two assessment methods were employed to detect the presence or absence of a cavity in the corresponding approximal surfaces. The detection devices were based on laser fluorescence (LF) and near-infrared reflection (NIRR). Each diagnostic method was applied by an individual investigator who was blinded to the results of previous examinations and was trained and calibrated prior to starting treatment. The final result of LF recordings and NIRR images were analyzed and classified separately as non-cavitated (score 0) versus cavitated (score 1) approximal lesions.

DIAGNOdent Pen examination

The suspected proximal surfaces were cleaned with dental floss and cotton rolls to remove debris and plaque and then air dried. The proximal probe (tip A) of DIAGNOdent Pen (KaVo, Biberach, Germany) was used to examine caries extension in the proximal region. The tip A of this device has a bevel to direct and collect the light at an angle of 100 degrees in order to provide access to the proximal area. The device was calibrated separately before the application on each tooth using a ceramic standard, according to the company's instructions. The probe was then entered beneath the suspected contact area once from the buccal and once from the lingual embrasures. The highest peak value represented by the device

was recorded per contact area. The readings were then interpreted according to the criteria proposed by the manufacturer (0–7, sound tooth surface; 8–15, enamel caries; 16–99, dentin caries). For the present study, the threshold limit was set at 16, and teeth with DIAGNOdent values < 16 were diagnosed to be either sound or showing reversible demineralization (score 0), whereas those with peak values ≥ 16 were considered to be in need of cavity preparation (score 1).

Examination by the Proxi interchangeable head of VistaCam iX intraoral camera

The proximal area of interest was examined by near-infrared reflection (NIRR) using the Proxi interchangeable head of VistaCam iX camera (Dürr Dental, Bietigheim-Bissingen, Germany). The teeth were cleaned and air dried before examination in order to minimize reflections. The Proxi interchangeable head was kept with the corresponding positioning holder over the approximal area, and the images were captured and assessed in DBSWIN software (version 5.9.0).

In this software, structures that have different translucencies are displayed with different brightness as follows:

– Healthy enamel appears dark with high translucence.
– Dentin appears light with low translucence.
– Proximal caries appears light with low translucence.

In order to determine the presence of cavity in the proximal area, the following classification was defined and applied using the manufacturer's information as follows:

Score 0: There is no sign of changes in enamel, or there is a wide bright strip or a wedge-shaped bright appearance within the dark enamel up to the enamel–dentine junction.
Score 1: There is a wide bright strip or a wedge-shaped bright appearance that crossed the enamel–dentine junction and is visible in dentin.

The examples of NIR images are presented in Figs. 1 and 2.

The reference standard

Following the use of diagnostic devices, orthodontic separators (Ortho Technology, Tampa, FL, USA) were placed in the contact area to provide enough space between the teeth for direct visual and tactile examination. At least 48 h later, the separators were removed, and the proximal surfaces were cleaned with dental floss and cotton rolls and examined with a mirror and a dental explorer probe. The explorer was employed for tactile examination and scanned the proximal surface without applying pressure.
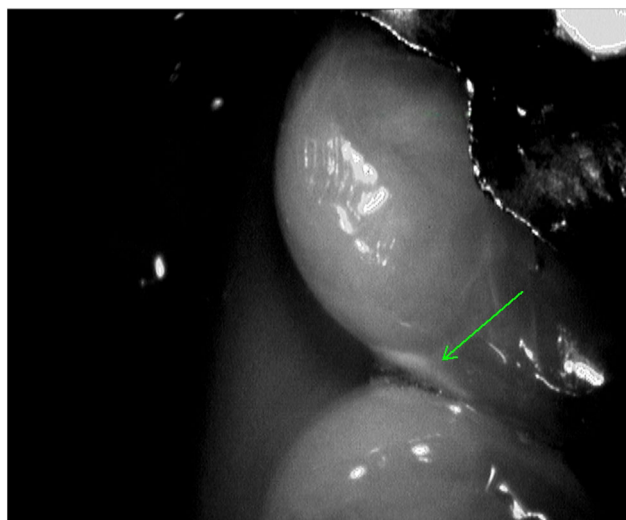

Fig. 1 An example of NIRR images taken with the VistaCam iX Proxi head. The arrow exhibits a wide bright strip within the dark enamel that did not reach the enamel–dentine junction

The examination was carried out by a restorative dentist with more than 15 years of clinical experience, who was not informed of the results of LF and NIRR. The presence or absence of proximal cavity was recorded and classified as follows:

Score 0: The proximal surface is either intact or displays white or brown discoloration, without loss of integrity, classified as non-cavitated caries lesion.
Score 1: The proximal surface is cavitated and shows enamel discontinuity during visual or tactile examination with a dental explorer.
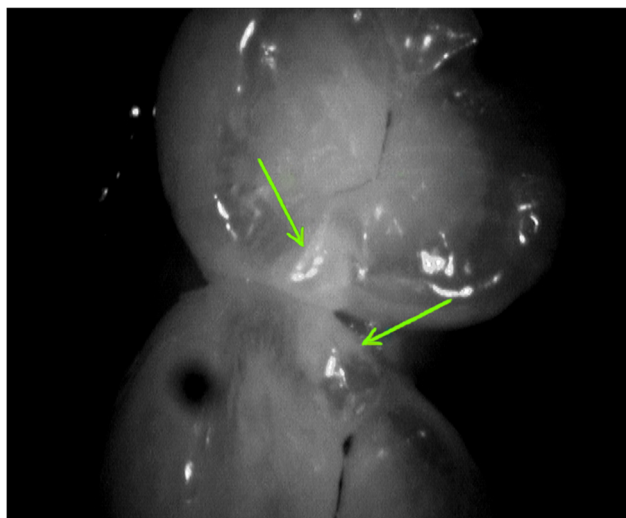

Fig. 2 An example of NIRR images taken with the VistaCam iX Proxi head. The upper arrow indicates a wedge-shaped bright appearance that has extended beyond the enamel–dentine junction and is visible in dentin. The lower arrow shows a wedge-shaped whitish change within the dark enamel up to the enamel–dentine junction

The statistical analysis

The sensitivity, specificity, accuracy, and positive and negative predictive values of diagnosing cavitated proximal surfaces were calculated for DIAGNOdent Pen and the Proxi head of VistaCam iX against the reference standard. The accuracy was defined as the percentage of the correctly classified diagnosis in all samples including cavitated and non-cavitated surfaces. The data analysis was performed with SPSS software (version 16.0; SPCC Inc., Chicago, IL, USA), and $P < 0.05$ was considered statistically significant.

Results

A total of 43 proximal surfaces were included in this study. Nineteen surfaces (44.2%) were distributed in the upper arch and 24 (55.8%) in the lower arch. On the basis of the reference standard used (direct visual and tactile examination), 34 surfaces (79.1%) were not cavitated (score 0), whereas 9 surfaces (20.9%) were categorized as cavitated and in need of restoration (score 1).

Validity estimation

Table 1 presents the distribution of cavitated and non-cavitated proximal surfaces, as diagnosed by DIAGNOdent Pen and direct visual and tactile examination (the reference method). From the 9 surfaces that were diagnosed cavitated with the reference standard, 4 surfaces were also diagnosed cavitated by DIAGNOdent Pen (sensitivity 44.4%; Table 2). Of the 34 non-cavitated surfaces detected by the reference standard, a total of 21 surfaces were found to be non-cavitated by DIAGNOdent Pen (specificity 61.8%; Table 2).

The distribution of cavitated and non-cavitated proximal surfaces as detected by the Proxi head of VistaCam iX and the reference method are presented in Table 1. From the 9 tooth surfaces that were defined as cavitated with the reference method, 8 surfaces were also recorded as cavitated by the

Table 2 The sensitivity, specificity, accuracy, and positive and negative predictive values of DIAGNOdent Pen and VistaCam iX Proxi for detecting proximal cavities

	DIAGNOdent Pen	VistaCam iX Proxi
Sensitivity	44.4%	88.9%
Specificity	61.8%	14.7%
Accuracy	58%	30%
Positive predictive value	23.5%	21.6%
Negative predictive value	80.8%	83.3%

NIRR images. Of the 34 surfaces that were scored non-cavitated with tactile examination, 5 surfaces were also found to be non-cavitated with NIRR images. Therefore, the sensitivity of the VistaCam iX Proxi in diagnosing cavitated proximal lesions was 88.9%, and its specificity was 14.7% (Table 2).

Comparing the two diagnostic devices revealed that the accuracy of LF (58%) was higher than that of the NIRR (30%) for detecting cavitated proximal lesions (Table 2).

The positive and negative predictive values for diagnosing cavitated proximal lesions were 23.5% and 80.8% for DIAGNOdent Pen and 21.6% and 83.3% for VistaCam iX Proxi, respectively (Table 2).

Discussion

This clinical study investigated the validity of laser fluorescence (LF) and near-infrared reflection (NIRR) for detecting early proximal cavities, comparing the results with the findings of direct visual and tactile examination (the reference standard). The sample was selected from cases with questionable proximal lesions in the recall bitewing radiographs. It has been recommended that patients who show no obvious caries and are not at increased risk for caries take posterior bitewing radiographs at intervals of 24 to 36 months to identify caries lesions [20]. The dental students who performed according to

Table 1 The contingency table for the results of DIAGNOdent Pen and VistaCam iX Proxi in detecting proximal cavities

		Reference method		
		Cavitated	Non-cavitated	Total
DIAGNOdent Pen	Cavitated (%)	4 (44.4)	13 (38.2)	17 (39.5)
	Non-cavitated (%)	5 (55.6)	21 (61.8)	26 (60.5)
	Total (%)	9 (100)	34 (100)	43 (100)
VistaCam iX Proxi	Cavitated (%)	8 (88.9)	29 (85.3)	37 (86)
	Non-cavitated (%)	1 (11.1)	5 (14.7)	6 (14)
	Total (%)	9 (100)	34 (100)	43 (100)

this guideline and took periodic bitewing radiographs at the period of this experiment were selected and further assessed for possible inclusion in the study. The present outcomes revealed that the sensitivity of NIRR was greater than that of LF for diagnosing early proximal cavities (88.9% for NIRR versus 44.4% for LF), but its specificity was lower due to its high rate of false positives (14.7% for NIRR versus 61.8% for LF). Altogether, DIAGNOdent Pen showed a greater accuracy (58%) when compared with the Proxi head of VistaCam iX (30%), implying that the diagnostic performance of LF was superior to NIRR for detecting proximal cavities. It appears that the VistaCam iX Proxi has advantages for early diagnosis of proximal lesions because of its high sensitivity. The suspicious proximal surfaces can be examined by NIRR technology when bitewing radiography is not available or cannot be taken due to x-ray exposure. However, the decision concerning preventive care versus operative intervention for the initial lesions cannot be achieved by this device, because the high rate of false positives when using NIRR may result in unnecessary cavity preparations. On the other hand, DIAGNOdent Pen was more suitable for detecting proximal surfaces that are not cavitated and can be improved by remineralizing therapies. The relatively good specificity of DIAGNOdent Pen in this study implies that if the proximal surface was diagnosed non-cavitated by LF, it is more probable that it does not need invasive treatment, but regular check-ups should be performed to determine when a restorative intervention is required.

In the present study, the cutoff threshold of 16 was selected for DIAGNOdent Pen to differentiate between cavitated versus non-cavitated proximal lesions. This cutoff limit was selected according to the manufacturer's instructions and was a bit different from that used in some previous investigations [21, 22]. The use of a higher cutoff limit may decrease the chance of false-positive results in detection of proximal cavities, thus leading to higher specificity at the expense of reducing sensitivity. The cutoff limit used in this study may need reevaluation using larger sample sizes in populations with various risks of caries.

When using NIRR, there is no classification for differentiating cavitated from non-cavitated proximal lesions. The NIRR is based on the physical principle that the infrared light passes through the more transparent enamel, whereas it scatters by the micoporosities within the dental caries and the dentin. Therefore, the sound enamel appears dark in the captured image, and caries and dentin appear opaque due to the infrared light reflection. In NIRR images, the enamel lesions are clearly identified as they are bright within the dark enamel, but detecting the extent of dentin lesions is challenging, as both the carious lesions and healthy dentin are seen bright. It should be born in mind that the Proxi head of VistaCAm iX (wavelength 850 nm) performs in a different way from the fluorescence head of this device (wavelength 405 nm), which is used for caries detection at the occlusal and smooth surfaces. The proxi head is not capable to score and differentiate between caries stages, and this may justify its low validity in the present investigation. The images are represented in black and white, and the detachment between different opacities requires some expert and training and may be impossible in some cases. It seems that a refined scale and improvement in image processing by the software program is required for better discrimination of caries extension. The use of higher infrared wavelengths, in the range of 1300–1700 nm, has also been suggested to provide more contrast between sound and carious tooth structure and thus enhance the diagnostic ability [23–25]. At present, NIRR is only suitable for diagnosing enamel lesions in proximal areas. There are also some problems when taking NIRR images, as the tooth should be dry and the device should be perpendicular to the tooth surface to minimize reflection and improve image quality. In a clinical scenario, it is not possible to take ideal images in all cases, and so the validity of NIRR would be further reduced due to the problems in image visualization.

Concerning laser fluorescence, the outcomes of this study corroborate the results of Mepparambath et al. [26] who found that LF was more accurate for detecting sound teeth and dentin caries, compared with enamel lesions in proximal surfaces of primary teeth. In the study of Ozkan and Guzel [27], LF showed the lowest sensitivity among various methods for detection of approximal caries. In contrast to the outcomes of this study, Bozdemir et al. [28] found that LF device was the most sensitive tool for detecting approximal lesions, whereas bitewing radiography was better than other methods for identifying sound surfaces. Several studies concluded that LF performed similar to or even better than bitewing radiography for detecting proximal lesions [21, 26, 29–31]. Menem et al. [31] indicated that the sensitivity, specificity, and accuracy of the laser fluorescence device were 100, 85, and 95 at the cavitation threshold for detecting approximal caries lesions in posterior teeth. Bussaneli et al. [32] found that DIAGNOdent Pen had the highest sensitivity (97.8%) for detecting proximal caries of primary teeth, whereas visual observation had the highest specificity and accuracy. It should be born in mind that the in vitro studies could not thoroughly simulate the proximal contact area and intraoral conditions and thus they usually show higher sensitivity and specificity values. Furthermore, the case selection in this study was different from most previous investigations, as the participants had limited proximal lesions in the preliminary bitewing radiographs.

Regarding the Proxi head of VistaCAm iX, the outcomes of this study corroborate the in vivo results of Jablonski-Momeni et al. [10] who found that NIR images provide a high contrast between sound enamel and initial lesions. They concluded that radiographs and NIRR yielded comparable results for detection of approximal enamel lesions [10]. In an in vitro study, Tonkaboni et al. [33] reported that the VistaCam iX

Proxi revealed the highest sensitivity for detecting proximal enamel lesions, but radiography was the most sensitive for diagnosing dentin lesions. The outcomes of this study contradict the results of Lederer et al. [5] who evaluated the validity of NIRR and digital bitewing radiography for proximal caries detection with micro-computed tomography (μCT) as the reference standard. They found that the sensitivity of NIRR was 0.13 for enamel caries, and 0.55 for dentin caries, but specificity was high (≥ 0.94) for all caries categories. The authors notified that NIRR was associated with complications related to image quality and artifacts, and thus it could not be recommended as a complementary diagnostic technique for proximal lesion assessment [5].

In the present study, tactile examination of the tooth surfaces after orthodontic separation was considered to be the reference standard, and the validity of other approaches was compared to this method. In most in vitro studies, histological sections and μCT have been employed as the golden standard for determining caries extension [5, 8, 33, 34], but the in vivo condition is different. In a doubtful clinical setting, the only method that can be used as the reference standard is either opening the suspected contact area by an invasive restorative treatment or using orthodontic elastic separators to provide enough space between the teeth and allow for direct visual and tactile examination of the approximal area [2, 35–38]. Although orthodontic separation could not determine the caries extent or severity, but it is more conservative and ethical than opening the lesion. The presence or absence of cavitation is the main factor to decide whether to go through an invasive restorative intervention or take a wait and see policy through remineralizing measures for arresting the lesion. Despite its benefits, orthodontic separation is associated with some problems, since the separators should be retained for 1 to 7 days to provide enough space in the contact area, and they are experienced very painful by most patients.

The present study provides helpful clinical information on the use of two diagnostic devices for proximal caries lesions. The results of clinical studies are valuable because the intraoral conditions such as the presence of tight contacts, dental plaque, and stains could not be simulated in the laboratory experiments. It has been assumed that for caries diagnostic instruments, sensitivity should be at least 75% and specificity should be over 85% [2, 39]. Therefore, none of the devices used in this study could be considered suitable for detection of proximal cavitation. It should be noted that the study was performed on subjects who had radiolucent lesions in preliminary bitewing radiographs. Therefore, the inclusion criteria of this study differed from most of the previous investigations that assessed the diagnostic ability of different modalities including bitewing radiography in proximal areas. Indeed, the devices in the present study were employed in cases that bitewing radiography

would not provide enough diagnostic validity. The important benefit of LF and NIRR is their inherent safety as they emit non-ionizing radiation. These diagnostic aids can be used for monitoring progression or regression of caries at frequent intervals [14, 40] and can be used safely in children and pregnant women. The limitation of this study was the small sample size and the low caries prevalence in the study population, because the sample was selected from the dental students who usually maintain accurate dental care. It is suggested that future studies compare different diagnostic aids for proximal caries detection using larger sample sizes in populations with various degrees of caries susceptibility.

Conclusions

Within the limitations of this study:

1- The Proxi head of VistaCam iX showed a high sensitivity for detecting early proximal cavities in posterior permanent teeth, but it was associated with a high rate of false positives and thus very low specificity. Therefore, NIRR is not suitable to distinguish proximal surfaces that are not cavitated. Altogether, NIRR showed low accuracy for detection of proximal cavities.

2- DIAGNOdent Pen showed an overall lower sensitivity and higher specificity in diagnosing cavitated proximal lesions, implying that it was more useful for the detection of non-cavitated surfaces that could be improved by remineralizing treatments.

3- Laser fluorescence exhibited a relatively higher level of diagnostic accuracy compared to NIRR for detecting proximal cavitation in permanent posterior teeth. However, within the limitations of this study, neither VistaCam iX Proxi nor DIAGNOdent Pen could be considered a suitable device for diagnosing proximal cavities.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The protocol of the study was reviewed and approved by the Ethics committee of Mashhad University of Medical Sciences.

Informed consent The procedure was explained in detail for all the patients, and signed consents were taken before the study commencement.

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