Laser fluorescence measurements compared to electrical resistance of residual dentine in excavated cavities in vivo

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Abstract

It has been suggested that laser fluorescence close to the dental pulp shows higher values than more distant measurements. The aim of this study was to assess fluorescence on the cavity floor and to correlate these measurements with electrical resistance as a measure of residual dentine thickness. 30 carious lesions were excavated with a bur. The endpoint of caries removal was determined by visual, tactile and auditory means. Fluorescence was measured with the Diagnodent device and with the fluorescence feedback system of a therapeutic Er:YAG laser. Electrical resistance of the residual dentine (PU units) was measured with a proprietary device. Significant differences were observed between the fluorescence systems (p<0.05). For Diagnodent, a decrease of electrical resistance of the residual dentine resulted in an increase of the fluorescence values of 2.99 units/PU (95% CI 2.00,3.97) and an increase of 0.30 units/PU (95% CI 0.19,0.40) for the fluorescence feedback system. For zero electrical resistance, a predicted maximum value of 51.5 units (95% CI 41.3,61.7) was calculated for the Diagnodent and 5.1 units (95% CI 4.1,6.2) for the feedback system. The study indicates that using the suggested detection cut-off with the Diagnodent device may be not suited to assess the endpoint of caries removal close to the dental pulp. Employing the Key Laser III, values up to 6 units might be caused solely by close proximity to the pulp, which should be considered when caries removal by laser is controlled by laser fluorescence feedback.
Infected dentine is usually removed on the basis of its softening and discoloration [McComb, 2000]. Cavity preparation is considered complete when dentine is hard to a sharp probe. Tactile and visual criteria are used by clinicians to assess the endpoint of caries removal. To aid this process detector dyes have been developed [Sato and Fusayama, 1976], but they are non-specific protein dyes that stain the organic matrix of less mineralized dentine, including normal circumpulpal dentine and sound dentine in the area of the enamel-dentine junction [Kidd et al., 1993; McComb, 2000]. This might cause unnecessary tissue removal and result in an increased likelihood of mechanical pulp exposures [Yip et al., 1994; McComb, 2000]. Until now, it is difficult to estimate the endpoint of caries removal because there is a lack of objective clinical markers for the demineralisation process and for the bacterial infiltration in the carious lesion. Even the discoloration of a tooth is not exactly correlated with the level of infection [Banerjee et al., 2000]. Histologically, it is possible to distinguish between an outer unremineralizable and an inner remineralizable layer of carious tissue [Kuboki et al., 1983]. Appreciating the current difficulties to define these layers clinically, the use of laser fluorescence might be helpful. On the basis of investigations that showed stronger fluorescence of carious lesions compared to healthy regions [Sundström et al., 1985; Lussi et al., 2004], a laser fluorescence instrument for caries detection (Diagnodent) was developed. With an excitation wavelength of 655 nm, the total intensity of the resulting fluorescence light correlates with the existence of a carious lesions [Lussi et al., 2004]. The enhanced fluorescence radiation probably results from porphyrins and other chromophores [Koenig et al., 1998; Banerjee et al., 2004]. Laser fluorescence has been shown to be a suitable device for caries diagnosis [Braun et al., 2000; Lussi et al., 2001; Mendes et al., 2004; Shi et al., 2000; Shi et al., 2001] and, for teeth without previous treatment, can be used to facilitate the clinical
decision for either no action, preventive or operative care. Extending the range of this application, it was assumed that the endpoint of caries removal could also be verified by fluorescence measurements [Iwami et al., 2004; Lussi et al., 2000, Lussi et al., 2004].

Some oral microorganisms were reported to produce orange-red fluorophores [Koenig and Schneckenburger, 1994]. Thus, this kind of visible fluorescence in dental hard tissues may be used as a marker for infected dentine as utilised by the fluorescence-aided caries excavation method (FACE) that combines caries detection by fluorescence with caries removal by a rotary instrument [Lennon et al., 2002, 2003].

However, focussing on an excitation wavelength of 655 nm, the authors of the present study found that laser fluorescence showed higher values in deep cavities than in shallow lesions even though they were completely excavated (unpublished data). A similar observation was made also by other authors [Lussi et al., 2000], but should be further evaluated before general recommendations can be given [Lussi et al., 2004].

The technology of caries detection by laser fluorescence was also realised in an Er:YAG laser for caries treatment. Previous studies have demonstrated the efficacy of caries removal and cavity preparation using an Er:YAG laser [Aoki et al., 1998; Armengol et al., 1999; Hibst and Keller, 1989; Keller and Hibst 1997; Keller et al., 1998]. By combining the technology of caries detection by laser fluorescence with an Er:YAG laser it is expected that the laser can be guided to complete caries excavation: the laser is activated only if a certain threshold level for the fluorescence of the dentine surface is exceeded. Therefore, a diode laser with a wavelength of 655 nm was incorporated into the device. The working principle is similar to caries diagnosis with the Diagnodent system. By adding the diagnostic diode laser to the
therapeutic Er:YAG laser, selective caries removal is supposed to be achieved. Therefore, in the present in vivo study, laser fluorescence of residual dentine on the cavity floor following conventional caries removal was determined. These values were correlated with electrical resistance measurements indicating thickness of the residual dentine to determine any influence of the proximity of the dental pulp on the fluorescence readings.

**Materials and methods**

A total of thirty human premolar and molar teeth in 30 patients with a mean age of 37 (±7) years with carious lesions in dentine were included in this in vivo study. Caries was excavated with a conventional steel round bur at a speed of 700 U/min without water cooling. Both class 1 and class 2 lesions were included in the study, allowing a straight access to the cavity floor to all instruments described below. To ensure accurate measurement procedures, only teeth with a minimum distance of 4 mm between the remaining buccal and oral cavity walls after excavation were included. This distance of 4 mm had to be an inclusion criterion for our study, as otherwise the probe of the Diagnodent fluorescence device (diameter approx. 3 mm) could not reach the cavity floor. The endpoint of complete caries removal of the air dried cavities was determined by visual, tactile (sharp explorer) and auditory means: cavity preparation was considered complete when dentine was hard to a probe, discoloration had been reduced and the probe was capable to induce a sharp sound. The completeness of caries removal was confirmed independently by two experienced investigators.

Depending on the size of the carious lesion, measurements were made at up to three points in each cavity. As every measurement was performed by two investigators, one of them could mark the exact measurement point with the tip of a periodontal
probe. Thus, any kind of staining to mark the areas of interest could be avoided. This tip was replaced by the tip of the laser Diagnodent device or the pilot beam of the Er:YAG laser for measurement. The scale of the periodontal probe was used to ensure a distance of 15 mm when the non-contact handpiece of the Er:YAG laser was employed. Laser fluorescence was measured with the Diagnodent device (KaVo, Biberach, Germany) and subsequently with the fluorescence feedback system of the Key Laser III (KaVo, Biberach, Germany). Both measurement devices give values from 0, representing no fluorescence, to 99 units, representing maximum fluorescence. However, the Diagnodent device and the feedback system of the Key laser III are constructed differently concerning both the optics and the different distances between the exit windows of the diode laser and the dentine surface. A standard calibration of the Diagnodent system was performed prior to each examination, using a ceramic touchstone according to the manufacturer’s instructions. The laser feedback system was similarly calibrated, employing the appropriate ceramic touchstone. Measurements with the Diagnodent device were performed with the probe A in contact mode, for the feedback system the non-contact handpiece (No. 2160, KaVo, Biberach, Germany) was used. The distance of the handpiece to the cavity floor was approximately 15 mm according to the manufacturer’s instructions. Each cavity was documented by digital photographs (Nikon, Duesseldorf, Germany).

The electrical resistance of the residual dentine underneath each measurement point was determined between an electrode and the crown pulp (Prepometer, Hager and Werken, Duisburg, Germany). Assigning the electrical resistance to a relative value reaching from 1 to 15 units (PU), high values are considered to represent more residual dentine than low values.
For statistical analysis, mean values for laser fluorescence and electrical resistance per tooth were considered, so that the cavity was the statistical unit. Normality of the data was assessed by the Shapiro-Wilk test. As not all values were normally distributed, differences between the values with respect to the diagnostic devices and the calibration procedures were analysed pairwise by means of a non-parametric test (Wilcoxon). The significance level were set at p<0.05. Pearson’s linear correlation coefficients were calculated for the laser fluorescence values and the thickness of residual dentine. Linear regression analysis was performed and 95% confidence intervals were calculated to define differences between the slopes of the lines and the maximum laser fluorescence values given by the y-axis intercept.

Results
Values measured with the two diagnostic systems were significantly different. For the Diagnodent device, the overall median reading was 20.3 units (max: 56, min: 6), while that for the fluorescence feedback system of the Key Laser III was 2.0 units (max: 5, min: 0).

The fluorescence readings of both diagnostic devices were inversely related to the electrical resistance of residual dentine (Fig. 1). For the Diagnodent, the slope of the regression was -2.99 units/PU (95% CI -2.00,-3.97) and for the feedback system it was -0.30 (95% CI -0.19,-0.40). The intercept (predicted maximum fluorescence at zero resistance) was 51.5 units (95% CI 41.3,61.7) for the Diagnodent and 5.1 units (95% CI 4.1,6.2) for the feedback system. Figure 2 shows a representative clinical situation together with the laser fluorescence values measured by the different diagnostic devices.
Discussion

Before feedback-controlled caries excavation with an Er:YAG laser can be recommended clinically, important safety issues need to be addressed: iatrogenic damage to the vital pulp could occur, when circumpulpal dentine shows relative higher fluorescence [Iwami et al., 2004; Lussi et al., 2000, 2004]. A recent study indicated an influence of therapeutic laser irradiation on diagnostic fluorescence readings [Eberhard et al., 2005]. It was hypothesized that the observed increase of fluorescence values could be assigned to dehydration of the dental tissues, because dehydration of enamel was shown to be accompanied by a variation of fluorescence readings [Al-Katheeb et al., 2002; Pretty et al, 2004]. Our unpublished studies demonstrated that these effects were mostly reversible by moistening dental tissues. Moreover, this increase of fluorescence caused by Er:YAG laser irradiation and the increase of fluorescence observed in the present study need not necessarily add up arithmetically. Thus, the exact impact of therapeutic laser irradiation on diagnostic fluorescence readings and the possibility of establishing a threshold value leading to selective caries removal will have to be addressed by further in vivo studies.

In the present study laser fluorescence of dentine on the cavity floor following complete caries removal was related to electrical resistance of the residual dentine, which is an indirect measure of thickness. The device used reliably predicts residual dentine thickness on teeth scheduled for crowning to prevent pulp damage, and in vivo provides clinically relevant information on the thickness of the residual dentine [Gente and Wenz, 1991; Gente, 1995]. The device uses a deflecting electrode which excludes the electrical resistance of the roots [Gente and Wenz, 1991]. However, the device was evaluated using caries-free wisdom teeth in vitro [Gente and Wenz, 1991] or teeth in vivo that were scheduled for extraction [Gente 1995], in which the electrical current is conducted by the aqueous phase of the dentine liquor or open...
dentine tubules. In carious dentine, an additional electrical resistance, not found in sound dentine, and caused by tubule sclerosis, is to be expected. Resistance values are higher in younger patients than in older people [Gente and Wenz, 1991] but this effect should have resulted in a maximum difference of 1-1.5 PU between the teeth in the present study. Moreover, as the depth of the cavities was not correlated with the age of the patients, any inaccuracies because of age occurred at random and should have been of minor impact.

Since laser fluorescence readings for both systems increased as the resistance of the residual dentine decreased, measurements in deep cavities may be influenced by the pulpal tissue as previously suggested [Iwami et al., 2004; Lussi et al., 2000, 2004]. Laser fluorescence values could also be affected by the transmission and scattering properties of the deep dentine, which differ according to the direction of the tubules [Iwami et al., 2003; Vaarkamp et al., 1995], by the higher organic content of dentine near the pulp [Schroeder, 2000] or by predentine [Yonomoto et al., 2006].

Staining on the cavity floor could be observed after excavation, although the intensity or exact diameter of these discolorations were not assessed. Staining might have influenced laser fluorescence values and has to be evaluated in further studies. Braun et al. [2005] demonstrated that laser fluorescence values following standard calibration were approximately 5 units higher than after individual calibration, in which the basic fluorescence of each tooth is deducted from subsequent measurements. A possible impact is therefore entirely predictable and was not shown in the present study.

The fluorescence values obtained by the Er:YAG laser were always approximately ten times lower than those obtained by the Diagnodent. This could be because, as the light transmission window of the laser handpiece is larger than that of the Diagnodent tip, the manufacturer has adjusted the sensitivity of the laser handpiece.
Additionally, this observation can be explained by the different distances between the exit windows of the diode laser and the dentine surface.

In this study the endpoint of complete caries removal of cavities was determined by visual, tactile and auditory means. The hardness and the colour of dentin are presently the main parameters used by clinicians to differentiate between infected and noninfected dentine during excavation [Banerjee et al., 2000; Thylstrup and Fejerskov, 1994; Kidd et al., 1993]. Whereas a significant correlation has been found between dentin hardness and level of bacterial infection, the same is not true of tissue colour [Kidd et al., 1996], so it may be not necessary to continue preparation until the dentine is stain free [Kidd et al., 1996]. Thus, in the present study the residual dentine on the floor of cavities might be already ‘overprepared’ with regard to bacterial infection. However, determining both tissue colour and hardness is highly subjective, so deciding whether excavation is complete or not remains often difficult.

The present study indicates that using the suggested detection cut-off with the Diagnodent device may be not suited to assess the endpoint of caries removal close to the dental pulp, since values higher than 10 could be measured in completely excavated cavities. However, the available studies coincide with the finding that a cut-off value of approximately 10 units is appropriate to indicate a possible dentinal lesion and that values higher than 29 already indicate caries to be excavated [Braun et al. 2000; Lussi et al. 1999, 2001]. In the present study, median values inside the cavities were 20.3 (6-56) with a tendency to increase with lower resistances. Thus, approaching the dental pulp, increasing fluorescence values might lead to unnecessary pulp exposures. Employing the Key Laser III, there is the same tendency for fluorescence to increase with low resistance values. However, these values were never higher than 6 fluorescence units. Eberhard et al. [2005] observed no residual bacteria in cavities excavated with the fluorescence aided Er:YAG laser
when a threshold value of 7 units was used and the fluorescence values of the present study were all lower than this threshold. Thus, we conclude that fluorescence-aided caries removal might be possible with the Key Laser III: the observation of increasing fluorescence with decreasing electrical resistance is not clinically evident, if the threshold value is set higher than 6 [U]. Consequently, a threshold level of 7 [U] might be well suited for the diagnostic feedback system of the Er:YAG laser to assess the endpoint of caries removal without jeopardizing vital structures. In the future, well controlled clinical investigations will have to confirm this threshold value not only in rotary excavated but also in laser irradiated cavities.
References


Figures

Fig. 1: Laser fluorescence measurements with the Diagnodent device (DU) and readings of the laser fluorescence feedback system (FU) with respect to the Prepometer values (PU). A decrease of the electrical resistance of residual dentine resulted in an increase of the fluorescence values.

Fig. 2: Representative individual clinical case. Laser fluorescence values with respect to the different diagnostic devices and the mode of calibration. Prepometer units (PU) represent the electrical resistance of residual dentine.