RESUMEN. Introducción: la caries se ha manifestado como una de las enfermedades con mayor prevalencia mundial, pero paradójicamente es una de las más desatendidas. En la actualidad, el tratamiento adecuado y eficaz contra la caries se basa en el diagnóstico temprano y en procedimientos como obturaciones, coronas y tratamiento de conductos. Métodos: esta investigación se centró en examinar el comportamiento de zonas cariadas y no cariadas de piezas dentales vitales (premolares y molares) al someterlas a una longitud de onda de 830 nm en seres humanos mayores de edad que aceptasen una revisión odontológica y que presentaran al menos un caso de caries dental. Underage persons and patients in medical treatment were excluded. After finding a behavior that helped differentiate decayed tissue from healthy areas, the used experimental system was characterized and tested in volunteers. The implemented system contains a fiber optic sensor comprised of a trifurcated fiber and a photodetector to perform optical power measurements. Resultados: este sensor detectó 100% de las muestras de caries dental en superficies oclusales de premolares y molares. Asimismo, exhibió indicios de la capacidad de diagnosticar caries vestibulares. Conclusiones: los resultados mostraron que se puede establecer la presencia de caries en piezas dentales mediante la implementación de un sensor de fibra óptica y luz infrarroja de 830 nm. Palabras clave: caries dental, fibras ópticas, sensores ópticos

ABSTRACT. Introduction: tooth decay has become one of the most prevalent diseases worldwide, but ironically it is one of the most neglected. Currently, adequate and effective caries treatment is based on early diagnosis and procedures such as sealants, crowns, and root canal treatment. Methods: this study examined the behavior of carious and non-carious areas of critical dental units (premolars and molars) subjecting them to a wavelength of 830 nm in adult humans who agreed to a dental examination and had at least one tooth affected by dental caries. Underage persons and patients in medical treatment were excluded. After finding a behavior that helped differentiate decayed tissue from healthy areas, the used experimental system was characterized and tested in volunteers. The implemented system contains a fiber optic sensor comprised of a trifurcated fiber and a photodetector to perform optical power measurements. Results: this sensor detected 100% of dental caries samples on premolar and molar occlusal surfaces. It also showed the ability to diagnose buccal cavities. Conclusions: the results showed that caries can be identified in dental units by means of a fiber optic sensor and infrared light at 830 nm. Key words: dental caries, optical fibers, optical sensors
INTRODUCTION

Caries is a complex process of multifactorial origin affecting dental tissues. This condition causes the destruction of dentine when the dynamic process of demineralization and constant remineralization is altered by the excess production of acids, in combination with other virulence factors of cariogenic microorganisms.1, 2, 3 The first visual manifestation of this disease is an opacity or discoloration of the enamel that, if left untreated, produces cavities and affects other dental tissues.4 Untreated caries can make eating and sleeping difficult, have an impact on children’s growth, and is the main cause of school and work absenteeism.4

Tooth decay is the most widespread chronic disease worldwide, representing a major public health challenge. Current data show that untreated caries in permanent teeth has a global prevalence (averaging all ages) of 40%.5 in Colombia, caries has a prevalence of 55.82% of the population with permanent dentition; however, if early cases are included, this figure increases to 78.97%.6 In consequence, the Ministry of Health and Social Protection of the Government of Colombia recommends developing and promoting different lines of research in oral health based on the country’s realities.6

Despite technological advances, conventional clinical examination remains the most widely used and reliable diagnostic method for dental caries.7, 8 The oral evaluation procedure is based on tactile exploration with tools and the dentist’s visual perception.3 These highly subjective methods can potentially lead to faults in caries detection, including false positives, and cause patient discomfort. Science and engineering have provided dentistry with new diagnostic tools, such as X-rays, the dye method, the electrical conductance method, and a wide range of optical methods: fiber optic transillumination.

INTRODUCCIÓN

La caries es un complejo proceso de origen multifactorial que afecta los tejidos dentales. Esta afección causa la destrucción del esmalte dental cuando el proceso dinámico de desmineralización y remineralización constante se altera por el exceso de producción de los ácidos, en combinación con los otros factores de virulencia de los microorganismos cariogénicos.1, 2, 3 La primera manifestación visual de esta enfermedad es una opacidad o decoloración del esmalte dental que, de no recibir medidas de control, progresa hasta llegar a generar cavidades y efectos en otros tejidos dentales.4 La caries no tratada puede dificultar el comer y el dormir, puede tener impacto en el crecimiento del menor y es la causa principal de absentismo escolar y laboral.4

La caries dental es la enfermedad crónica más extendida en el mundo y constituye un reto importante en salud pública. Los datos actuales muestran que la caries no tratada en dientes permanentes tiene una prevalencia global (promediando todas las edades) del 40%.5 En Colombia, la caries tiene prevalencia sobre el 55,82% de la población con dentición permanente; sin embargo, al considerar casos incipientes la cifra aumenta al 78,97%.6 En vista de lo anterior, el Ministerio de Salud y Protección Social del Gobierno de Colombia recomienda desarrollar y promover diferentes líneas investigativas en salud bucal a partir de las realidades del contexto del país.6

A pesar de los avances tecnológicos, el examen clínico ortodoxo sigue siendo el método de diagnóstico más utilizado y confiable para la caries dental.7, 8 Este procedimiento de evaluación oral se basa en la exploración táctil con herramientas y en la percepción visual del dentista.3 Probablemente, estas características altamente subjetivas pueden conducir a fallos en la detección de caries, incluso detecciones falsas, y causar malestar en el paciente. Desde luego, la ciencia y la ingeniería han puesto en manos de la odontología nuevas herramientas de diagnóstico como las radiografías, el método de tinte, el método de conductancia eléctrica y una gran variedad de métodos ópticos: transiluminación por fibra óptica.
TOOTH DECAY DETECTION USING A FIBER OPTIC SENSOR

(FOTI), digital imaging fiber optic transillumination (DIFOTI), and light- or laser induced fluorescence. X-rays alone allow the diagnosis of proximal caries but are not a reliable method for occlusal caries detection.\(^8\) Caries-detector dyes help differentiate healthy dentin from decalcified dentin, although several studies have questioned their effectiveness in recent years.\(^9\) Electrical conductance methods are based on the concept that measurements in areas with caries are significantly more sensitive than in caries-free zones, mainly in the differentiation of healthy enamel and carious dentin. They have proven to be more effective than radiographic or transillumination methods in the detection of occlusal caries lesions.\(^10, 11\) But due to the diversity of depths, the mineral content of enamel and the morphology of occlusal surfaces, adequate data interpretations are generally hindered, mistaking areas of healthy enamel with demineralized areas.\(^12, 13\) The optical methods claim that when a tooth is illuminated, the light can be absorbed by the dental organ, or get dispersed. These two processes can be altered by changes in the external/internal structure of the tooth.\(^8\) Transillumination with fiber optics in all its forms is based on the fact that light propagates from a light source to the tooth through optical fibers and must be intense enough to traverse tooth structure. The transillumination method has been recommended to detect proximal and occlusal cavities.\(^14-16\) Acquiring and processing images through fiber optic transillumination to increase sensitivity using software is known as digital imaging fiber optic transillumination.\(^8\)

Light- or laser induced fluorescence is based on the principle that changes induced in the dental structure by the caries process lead to an increase in fluorescence when specific wavelengths are applied.\(^17\) This method has been successfully used in the detection of lesions on flat teeth surfaces but its use in occlusal sides has not been sufficiently demonstrated. However, it seems to be very promising.\(^18\)
Taking into account the state of the art and the recommendation by the Colombian Government, this study sought to examine the behavior of carious and non-carious areas of vital teeth by submitting them to infrared light of 830 nm. It also assesses the effectiveness of this wavelength to diagnose dental caries, with the objective of exploring new perspectives in the creation of more effective detection devices. In finding a behavior to differentiate carious lesions from healthy areas, this study characterized the system used to detect tooth decay. In the suggested system, the infrared light is conducted through a trifurcated optic fiber to reach the teeth, and, thanks to the derived branches, the reflected signal is received and brought to an infrared light sensor.

**METHODS**

The study sample included 167 vital dental units from human beings aged 18 to 60 years who agreed to a dental examination and had at least one dental caries. Underage individuals and patients in medical treatment were excluded. The test population was the administrative staff of Universidad Popular del Cesar.

This study sought to examine the behavior of carious and non-carious areas by submitting them to infrared light of 830 nm. After finding a behavior that helped differentiate carious lesions from healthy areas, the system was characterized to detect tooth decay. The procedure used an experimental assembly provided with an optic fiber sensor and infrared light with which optical power measurements were acquired from each dental unit. The sampling process was performed on teeth from patients who had previously been diagnosed with cavities by a professional dentist. Each sample was cleaned and dried, trying to maintain that state during measurements, which were performed by a person calibrated in the identification of dental caries and

Teniendo en cuenta el estado del arte y la recomendación del Gobierno colombiano, esta investigación buscó examinar el comportamiento de zonas cariadas y no cariadas de dientes vitales al someterlas a luz infrarroja de 830 nm. Asimismo, estudió la utilidad de dicha longitud de onda para el diagnóstico de caries dental, con el objetivo de investigar nuevas perspectivas para la creación de dispositivos de detección más eficaces. Al encontrar un comportamiento que permitía diferenciar entre zonas cariadas y sanas, en este trabajo se caracterizó el sistema usado con el fin de detectar caries dental. En el sistema planteado, la luz infra roja es guiada a través de una fibra óptica trifurcada para incidir sobre los dientes, y, gracias a las ramas derivadas, la señal reflejada es recogida y llevada a un sensor de luz infrarroja.

**METODOLOGÍA**

La muestra de este estudio fueron 167 piezas dentales vitales de seres humanos entre los 18 y 60 años que aceptasen una revisión odontológica y que presentaran al menos una caries dental. Fueron excluidos menores de edad y personas bajo tratamientos médicos. La población de la prueba fue el personal administrativo de la Universidad Popular del Cesar.

Esta investigación buscó examinar el comportamiento de zonas cariadas y no cariadas al someterlas a luz infrarroja de 830 nm. Tras encontrar un comportamiento que permitía diferenciar entre zonas cariadas y sanas, se caracterizó con el fin de detectar caries dental. El trabajo se basó en un montaje experimental que utiliza un sensor de fibra óptica y luz infrarroja con el cual se adquirieron medidas de potencia óptica reflejada por cada pieza dental. El proceso de toma de muestras se efectuó en dientes de pacientes a los que previamente se les había diagnosticado caries por parte de un odontólogo profesional. Cada muestra fue limpiada y secada, procurando mantener dicho estado durante las mediciones realizadas, que fueron efectuadas por una persona calibrada en la identificación de caries dental.
in the handling of optical fibers. The occlusal and buccal areas of the subjects’ complete denture were preliminarily characterized in order to determine the levels of reflected power of the assembly made for a healthy tooth and a decayed tooth, according to their classification and shape. Once these levels of power were established, the hypothesis was tested in five patients. This study complies with the Declaration of Helsinki\textsuperscript{19} for research on humans and with the terms set forth in Resolution 8430 of the Ministry of Social Protection.\textsuperscript{20}

The experimental assembly is composed of a fiber optic sensor using a Newport/Oriel model 77536 trifurcated fiber which is flexible enough to easily lead infrared light to the teeth. It also consists of a Newport optical table provided with supporting tools to connect an infrared LED (IR LED) with wavelength 830 nm to one of the three branches of the trifurcated fiber. The infrared LED belongs to a Newport Laser Diode-Led Driver Model Nº FK-DRV.\textsuperscript{21, 22} Its two branches are connected by the same method to a Newport Model 1815 Power Meter-C. An 818-SL silicon photodetector was used with a dimmer. The free, unbranched end is used to bring infrared radiation to the teeth as a probe. Figure 1 shows the implemented configuration.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Experimental assembly}
\end{figure}
Once in operation, the assembly brings infrared light through the fiber’s assigned branch to the unbranched end impacting the tooth. At the same time, the radiation reflected by the dental unit is received and transported to the branched ends. The branched ends lead the reflected light to the power meter to establish intensity. In order to obtain results with very significant magnitudes, all the tests and detections were performed with the Newport Laser Diode-Led Driver at maximum power. In this article, averaged values were taken for all variables measurements.

**Optical and electrical characteristics of the implemented optical fiber sensor**

As a fiber optic sensor was implemented, it was necessary to know its operating ranges. The values of the optical power parameters emitted by the IR LED, the power transmitted by the optical fiber, and the current intensity were obtained after selecting the maximum power of the Newport Laser Diode-Led Driver Model Nº FK-DRV as operation current for all tests. Obtaining the values of these variables will help reproduce the output of the assembled device.

![Montaje experimental](image)

**Características ópticas y eléctricas de operación del sensor de fibra óptica implementado**

Dada la implementación de un sensor de fibra óptica, fue necesario conocer los rangos de operación del mismo. Los valores de los parámetros de potencia óptica emitida por el LED IR, potencia trasmitida por la fibra óptica, e intensidad de corriente fueron obtenidos luego de seleccionar la potencia máxima del Newport Laser Diode-Led Driver Model Nº FK-DRV como corriente de operación para todas las pruebas. La adquisición de los valores de estas variables permitirá reproducir el rendimiento del sensor.
this experimental system in future studies or verify the achieved results. The fiber optic sensor operation characteristics can be seen in table 1. Figure 2a shows the process of measuring the power emitted by the IR LED and figure 2b shows the process of acquiring the magnitude of the infrared power transmitted by the sensor.

Table 1. Optical fiber sensor operation features

| Parameter                                | Value  | Unit |
|------------------------------------------|--------|------|
| Operating current                        | 100.3  | mA   |
| Optical power emitted by the IR LED      | 1.814  | mW   |
| Infrared power transmitted by the sensor | 1.386  | mW   |
| Transmitted optical power efficiency     | 76.41% |      |
| Maximum reflected power                  | 228    | µW   |
| Reflected infrared light conduction efficiency | 81.72% |      |

Figure 2. a) Process for measuring the optical power emitted by the IR LED, b) Process for measuring the infrared power transmitted by the optical fiber sensor

Figure 2. (a) Proceso de medición de la potencia óptica emitida por el LED IR, (b) Proceso de medición de la potencia infrarroja transmitida por el sensor de fibra óptica
In order to determine infrared light conduction efficiency, measurements of power reflected by a mirror with and without the sensor were carried out. The reflected power without the sensor between the IR LED and the power meter was 279 µW (this measurement is shown in Figure 3a). When the sensor was added, in the same operating current a reflected power of 228 µW was obtained (the process is illustrated in Figure 3b). Based on these measurements, the reflected infrared light conduction efficiency, which is also referred to in table 1, was calculated.

Finally, after measuring the operation characteristics of the fiber optic sensor, the system was tested in live teeth samples to determine any type of behavior that would help establish the presence of caries.

Con el fin de determinar la eficiencia de conducción de luz infrarroja, se efectuaron mediciones de potencia reflejada por un espejo con y sin el sensor. La potencia reflejada sin el sensor entre el LED IR y el medidor de potencia fue 279 µW (La medición se presenta en la figura 3a). Al añadir el sensor, en la misma corriente de operación se obtuvo una potencia reflejada de 228 µW (el proceso se ilustra en la figura 3b). Con base en estas mediciones, se calculó la eficiencia de conducción de luz infrarroja reflejada, la cual también se encuentra referida en la tabla 1.

Finally, tras la medición de las características de operación del sensor de fibra óptica se procedió a probar el sistema en muestras vivas de dientes, para determinar cualquier tipo de comportamiento que permita establecer la presencia de caries.
RESULTS AND DISCUSSION

Preliminary test on live teeth and characterization of sensor performance

Sampling was performed only in the vestibular, incisal, and occlusal areas of the teeth of a volunteer patient who previously received a dental caries diagnosis by an oral health professional. In attempting to sample the lingual area, the fiber was at risk of suffering a superflexion that could harm the tongue. Therefore, the lingual area was not sampled. The sampling process is shown in figure 4a. In addition, full denture sampling helped determine eigenvalues for common elements in the treatment of oral diseases such as amalgams and resins. Bearing in mind that teeth shape would influence the values of powers to be measured, these were stored by the FDI dental notation, which would allow the analysis per tooth type. To facilitate understanding of this article, the FDI notation is shown in Figure 4b. In comparing the measurements obtained with the oral diagnosis, caries detection thresholds were established on the occlusal, incisal and vestibular surfaces. The reflected power measurements are shown in tables 2 and 3.

RESULTADOS Y DISCUSIÓN

Prueba preliminar en dientes vivos y caracterización del funcionamiento del sensor

La toma de muestras se realizó solamente en las zonas vestibulares, incisales y oclusales de la dentadura de un voluntario que previamente recibió un diagnóstico odontológico de caries dental por un profesional en salud oral. Al intentar muestrear la zona lingual, la fibra quedaba en riesgo de sufrir macroflexiones que podrían dañar la integridad de la misma. Por ello, la zona lingual no fue muestreada. El proceso de muestreo se ilustra en la figura 4a. Además, el muestreo completo de una dentadura ayudó a determinar valores propios para elementos comunes en el tratamiento de enfermedades orales, como amalgamas y resinas. Teniendo en cuenta que la forma de los dientes influiría en los valores de potencias a medir, se almacenaron estos últimos mediante la notación dental FDI, lo cual permitiría el análisis según el tipo de diente. Para facilitar la comprensión del presente artículo, se muestra la notación FDI en la figura 4b. Al comparar las mediciones obtenidas con el diagnóstico oral, se establecieron umbrales de detección de caries en las superficies oclusal, incisal y vestibular. Las medidas de potencia reflejada se muestran en las tablas 2 y 3.

![Figure 4. a) sampling process, b) FDI dental notation.](image)

Figura 4. (a) Proceso de muestreo, (b) Notación dental FDI.
**Table 2. Power in the vestibular area**

| Vestibular surface | Type of tooth | Molars | Premolars | Canine | Incisors | Canine | Premolars | Molars |
|--------------------|---------------|--------|-----------|--------|----------|--------|-----------|--------|
| Upper maxillary    | Tooth         | 18     | 17        | 16     | 15       | 14     | 13        | 12     | 11     | 21     | 22     | 23     | 24     | 25     | 26     | 27     | 28     |
|                    | Power (µW)    | 20.8   | 21.3      | 18.3   | 17.8     | 19.5   | 22       | 22     | 18.5   | 20.8   | 19.8   | 18.9   | 19.5   | 20.5   | 19.7   |
| Mandible           | Tooth         | 48     | 47        | 46     | 45       | 44     | 43       | 42     | 41     | 31     | 32     | 33     | 34     | 35     | 36     | 37     | 38     |
|                    | Power (µW)    | 19.4   | 20        | 19.1   | 19       | 21.4   | 22.4     | 21.4   | 21.3   | 21.8   | 21.4   | 19.9   | 18     | 18     | 19     |       |        |

**Tabla 2. Potencia en zona vestibular**

| Incisal and occlusal areas | Type of tooth | Molars | Premolars | Canine | Incisors | Canine | Premolars | Molars |
|----------------------------|---------------|--------|-----------|--------|----------|--------|-----------|--------|
| Upper maxillary            | Tooth         | 18     | 17        | 16     | 15       | 14     | 13        | 12     | 11     | 21     | 22     | 23     | 24     | 25     | 26     | 27     | 28     |
|                            | Power (µW)    | 11.4   | 7.6       | 11.5   | 12       | 10.5   | 8.7       | 8.4    | 9.0    | 8.2    | 10.1   | 12.7   | 12.8   | 11.9   | 8.9    |
| Mandible                   | Tooth         | 48     | 47        | 46     | 45       | 44     | 43       | 42     | 41     | 31     | 32     | 33     | 34     | 35     | 36     | 37     | 38     |
|                            | Power (µW)    | 10.7   | 12.1      | 11     | 11.8     | 6.1    | 6.5       | 7.1    | 6.8    | 7.0    | 7.7    | 13     | 11.5   | 10.2   | 10.2   |

**Table 3. Power in the incisal and occlusal areas**

The dental diagnosis of the patient yielded the following results: caries in the left upper molar 27, an amalgam in the right upper molar 16, a white resin in the lower right molars 36 and 37, and a reconstruction of the left upper incisor 21. Molars 18, 28, 38 and 48 were not present in the patient. Based on this information, the measurements made with the sensor were analyzed.
The obtained measurements showed that the levels of reflected power vary according to the geometry of the dental unit and the existing area for infrared light exposure. Therefore, the analysis of the results was performed per dental areas and according to teeth typeology. The vestibular areas, regardless of tooth type, reflect more uniform levels of infrared power. It should be noted that, because of their size, incisor teeth (dental unit 12, 11, 22, 42, 41, 31 and 32 in Table 2) reflect higher power levels. The same situation was observed in measuring incisal and occlusal areas: the power reflected by the premolars and molars was higher than that reflected by the incisors and canines (see differences in table 3).

The power levels reflected in healthy incisors of incisal areas are lower than those in occlusal areas of premolars and molars. Similarly, in the incisal area, the upper canines reflect higher levels than the lower canines (see teeth 13, 23, 43 and 33 in table 3).

It can be seen (Table 3) that dental unit 27, with caries in its occlusal area, reflected 8.9 µW, while the other healthy bicuspid and molars reflected more than 10 µW. This observation demonstrates that the behavior shown by extracted dental units is also shown in living dental units. This behavior can be used to determine the presence of cavities. In short, caries-related areas reflect less infrared power than healthy areas.

Because of their physical properties (color), amalgams reflect much lower levels than healthy teeth, and they even coincide with caries-specific values (see tooth 16 in Table 3). Resins reflect power levels very close to the levels of healthy areas (see molars 36 and 37 in Table 2 with respect to adjacent healthy molars).

Quantitatively, it is evident that, on the vestibular surface, healthy teeth reflect power levels above 17 µW. On the other hand, the levels measured in healthy incisal surface segments show Las mediciones obtenidas demuestran que los niveles de potencia reflejada varían de acuerdo a la geometría de la pieza dental y al área existente para la exposición a luz infrarroja. Por lo anterior, el análisis de los resultados se realizó por zonas dentales y según la tipología de los dientes. Las zonas vestibulares, sin distinción del tipo de pieza dental, reflejan niveles más uniformes de potencia infrarroja. Es de resaltar que, por su dimensión, los dientes incisivos (piezas dentales 12, 11, 22, 42, 41, 31 y 32 en la tabla 2) reflejan mayor potencia. La misma situación se observó en las mediciones de las zonas incisales y oclusales: la potencia reflejada por los premolares y molares fue superior a la reflejada por incisivos y caninos (ver la diferenciación en la tabla 3).

Puede observarse (Tabla 3) que la pieza dental 27, que presenta caries en su zona oclusal, reflejó 8,9 µW, cuando los demás premolares y molares sanos reflejaron más de 10 µW. Con esta observación se demostró que el comportamiento expuesto por piezas dentales extraídas también se exhibe en piezas dentales vivas. Dicho comportamiento puede ser utilizado para determinar la presencia de caries. En resumen, las zonas con caries reflejan menos potencia infrarroja que las zonas sanas.

Las amalgamas, por sus propiedades físicas (color), reflejan niveles mucho más bajos que los dientes sanos, al punto de coincidir con valores propios de las caries (véase el diente 16 en la tabla 3). Las resinas reflejan niveles de potencia muy cercanos a los niveles de una zona sana (véanse los molares 36 y 37 en la tabla 2 con respecto a molares sanos aledaños).

Cuantitativamente, es evidente que, en la superficie vestibular, los dientes sanos reflejan niveles de potencia superiores a 17 µW. Mientras tanto, en la superficie incisal, los niveles medidos en segmentos sanos ofrecen una...
differences per tooth type: the incisors present powers greater than or equal to 6.5 μW, while the canines reflect powers greater than 6 μW. On the occlusal surface, the bicuspids and caries of the molars reflect powers greater than or equal to 11 μW. Therefore, caries thresholds, as shown in table 4, were determined for the assembled system and used in the additional tests with patients.

**Table 4. Diagnostic thresholds of dental caries**

| Surface               | Thresholds  
|-----------------------|------------|
| Incisal surface       | 0-6.4 μW   |
| Canines               | 0-6 μW     |
| Occlusal surface      | 0-10.9 μW  |

**Caries detection in volunteers**

Given the low number of caries samples in lingual, buccal and interproximal areas, the tests in patients focused mostly on occlusal areas. The verification of the proposed caries diagnostic thresholds was performed in 5 additional patients who had been diagnosed with dental caries by their dentists. The 6 patients, including the volunteer of the preliminary test, offered 167 experimental dental units, of which 11 corresponded to carious teeth diagnosed by the visual-tactile method. The fiber optic sensor detected 100% of caries previously diagnosed by dentists. All the detections made in decayed samples and their respective measurements are displayed in table 5. Healthy teeth reflected power levels higher than the suggested thresholds.

**Detección de caries en voluntarios**

Dado el bajo número de muestras de caries en zonas linguales, vestibulares e interproximales, las pruebas en pacientes se concentraron en su mayor parte en zonas oclusales. La verificación de los umbrales de presencia de caries propuestos se realizó en 5 pacientes adicionales, a quienes su odontólogo de cabecera les había diagnosticado caries dental. Los 6 pacientes, teniendo en cuenta al voluntario de la prueba preliminar, ofrecieron 167 piezas dentales para el experimento, de las cuales 11 correspondían a dientes cariados diagnosticados por el método visual-táctil. El sensor de fibra óptica detectó el 100% de las caries diagnosticadas con anterioridad por odontólogos. Las detecciones en todas las muestras realizadas en piezas cariadas con sus respectivas mediciones se exhiben en la tabla 5. Los dientes sanos reflejaron niveles de potencia superiores a los umbrales planteados.
During the tests, patients expressed discomfort in their teeth under resins in occlusal areas, which were not detected by the dentist or the system. This raises questions—which must be addressed in further studies—regarding the penetration depth of infrared radiation in teeth.

**CONCLUSIONS**

This study showed differences between the power levels reflected by carious and non-carious areas, helping establish the presence of dental caries.

| Sample | Location in dental area | Caries type | Sensed optic power (μW) | Upper threshold of dental caries (μW) | Presence of dental caries |
|--------|--------------------------|-------------|-------------------------|---------------------------------------|--------------------------|
| 1      | Buccal                   | Moderate    | 14                      | 17                                    | Positive                 |
| 2      | Buccal                   | Moderate    | 11                      | 17                                    | Positive                 |
| 3      | Occlusal                 | Incipient   | 10                      | 10.9                                  | Positive                 |
| 4      | Occlusal                 | Incipient   | 10.5                    | 10.9                                  | Positive                 |
| 5      | Occlusal                 | Incipient   | 10.2                    | 10.9                                  | Positive                 |
| 6      | Occlusal                 | Moderate    | 7.6                     | 10.9                                  | Positive                 |
| 7      | Occlusal                 | Moderate    | 8                       | 10.9                                  | Positive                 |
| 8      | Occlusal                 | Moderate    | 8                       | 10.9                                  | Positive                 |
| 9      | Occlusal                 | Moderate    | 9                       | 10.9                                  | Positive                 |
| 10     | Occlusal                 | Moderate    | 6                       | 10.9                                  | Positive                 |
| 11     | Occlusal                 | Moderate    | 8                       | 10.9                                  | Positive                 |

**Tabla 5. Detección de caries en los voluntarios.**

| Muestra | Ubicación según zona dental | Tipo de caries | Potencia óptica sensada (μW) | Umbral superior de caries dental (μW) | Presencia de caries dental |
|---------|------------------------------|---------------|------------------------------|---------------------------------------|---------------------------|
| 1       | Vestibular                   | Moderada      | 14                           | 17                                    | Positiva                  |
| 2       | Vestibular                   | Moderada      | 11                           | 17                                    | Positiva                  |
| 3       | Occlusal                     | Incipiente    | 10                           | 10.9                                  | Positiva                  |
| 4       | Occlusal                     | Incipiente    | 10.5                         | 10.9                                  | Positiva                  |
| 5       | Occlusal                     | Incipiente    | 10.2                         | 10.9                                  | Positiva                  |
| 6       | Occlusal                     | Moderada      | 7.6                          | 10.9                                  | Positiva                  |
| 7       | Occlusal                     | Moderada      | 8                            | 10.9                                  | Positiva                  |
| 8       | Occlusal                     | Moderada      | 8                            | 10.9                                  | Positiva                  |
| 9       | Occlusal                     | Moderada      | 9                            | 10.9                                  | Positiva                  |
| 10      | Occlusal                     | Moderada      | 6                            | 10.9                                  | Positiva                  |
| 11      | Occlusal                     | Moderada      | 8                            | 10.9                                  | Positiva                  |

Durante las pruebas, los pacientes refirieron molestias en sus dientes bajo resinas en zonas oclusales, que no fueron detectadas por el odontólogo ni por el sistema. Esto genera dudas, que deben ser estudiadas a posterioridad, con respecto a la profundidad de penetración de la radiación infrarroja en los dientes.

**CONCLUSIONES**

La investigación demostró que existe una diferenciación entre los niveles de potencia reflejados por zonas cariadas y no cariadas, que permite establecer la presencia de caries dental.
of dental caries. Although the oral conditions to which teeth are subjected vary from one individual to another, the system and the suggested diagnostic thresholds of caries meet the desired expectations. The approach used proved to be effective and practical, and might help minimize costs. The implemented sensor detected 100% of caries in the occlusal areas where it was tested. Of course, tests for caries diagnostic thresholds that were not tested because they were not present in patients should be the subject of further studies. In addition, this system needs further studies to find methods to differentiate the reflected powers of amalgams, resins and decayed areas. This will lead to accurate detections, avoiding false positives. In the same way, there are pending questions about the depth of penetration of infrared radiation in teeth and the possible induced infrared fluorescence caused by radiating a carious zone with infrared light with wavelength of 830 nm. These phenomena were not analyzed in this work.

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CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

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de caries dental. A pesar de que las condiciones orales a las que están sometidos los dientes varían de un individuo a otro, el sistema y los umbrales de presencia de caries planteados cumplen las expectativas deseadas. El método planteado ha demostrado ser eficaz, práctico y posee la posibilidad de minimizar costos. El sensor implementado detectó el 100% de las caries en las zonas oclusales donde fue probado. Desde luego, los test para los umbrales de presencia de caries que no fueron puestos a prueba por la inexistencia de pacientes deben ser objeto de estudios posteriores. Además, este sistema todavía necesita más estudios para encontrar métodos de diferenciación entre las potencias reflejadas de amalgamas, resinas y áreas cariadas. Esto conducirá a detecciones precisas y libres de falsos positivos. Del mismo modo, surgen preguntas sobre la profundidad de penetración de la radiación infrarroja en los dientes y la posible fluorescencia infrarroja inducida ocasionada al irradiar una zona cariada con luz infrarroja con longitud de onda de 830 nm. Estos fenómenos no fueron analizados en este trabajo.

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Los autores manifiestan no tener ningún conflicto de intereses.

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REFERENCES / REFERENCIAS

1. Gutiérrez S. Fundamentos de ciencias básicas aplicadas a la odontología. Bogotá: Pontificia Universidad Javeriana; 2006.

2. Summitt J, Robbins J, Schwartz R, Hilton T. Fundamentals of operative dentistry: a contemporary approach. 3 ed. Hanover Park, IL: Quintessence Publishing Co; 2006.

3. Dikmen B. Icdas II criteria (international caries detection and assessment system). J Istanb Univ Fac Dent. 2015; 49(3): 63–72. DOI: https://doi.org/10.17096/jiufd.38691

4. Heymann H, Swift E JR, Ritter A. Sturdevanant's art and science of operative dentistry. St. Louis: Mosby Elsevier; 2006.

5. Federación Dental Internacional (FDI). El desafío de las enfermedades bucodentales: una llamada a la acción global: atlas de salud bucodental. 2 ed. Brighton, RU: Myriad; 2015.

6. Colombia. Ministerio de Salud y Protección Social. IV estudio nacional de salud bucal: situación de salud bucal. Bogotá: Diseñum Tremens; 2014.

7. Ferreira A, Zero DT. Instrumentos diagnósticos para la detección precoz de caries. J Am Dent Assoc. 2007; 2(2): 89-95

8. Carrillo C. Diagnóstico de lesiones incipientes de caries ¿Es este el futuro de la odontología? Rev ADM. 2010; 67(1): 13-20.

9. Cedillo J, Treviño E. Tecnología en el diagnóstico de caries. Rev ADM. 2007; 64(5): 211-214.

10. Ten-Bosch J. Light scattering and related methods in caries diagnosis. En: Stookey G. Early detection of dental caries: proceedings of the 1st. annual Indiana Conference. Indianapolis: Indiana University; 1996. p. 81-90.

11. Kidd E, Fejerskov O. Dental caries, the disease and its clinical management. Oxford, Reino Unido: Blackwell Munsgaard; 2003.

12. Kidd E. Essentials of dental caries. The disease and its management. 3 ed. New York: Oxford University Press Inc; 2005.

13. Henostroza-Haro G. Caries dental: principios y procedimientos para el diagnóstico. Lima: Universidad Peruana Cayetano Heredia; 2007.

14. Parker P, Fan P, O’Brien W, Brooks S. Detection of enamel demineralization with transillumination. Clin Prev Dent. 1987; 3(3): 12-14.

15. Gwinnett J. A comparison of proximal carious lesions as seen by clinical radiography, contact microradiography and light microscopy. J Am Dent Assoc. 1971; (83)5: 1078-1080.

16. Lussi A, Firestone A, Schoenberg A, Hotz P, Stich H. In vivo diagnosis of fissure caries using a new electrical resistance monitor. Caries Res. 1995; 29(2): 81-87. DOI: https://doi.org/10.1159/000262046

17. Hibst R, Gall R. Development of a diode laser-based fluorescence caries detector. Caries Res. 1998; 32(4): 294.

18. De-Josselin-de-Jong E, Sunstrom F, Westerling H, Tranæus S, Ten-Bosch J, Angmar-Månsson B. A new method for in vivo quantification of changes in initial enamel caries with laser fluorescence. Caries Res. 1995; 29(1): 2-7. DOI: https://doi.org/10.1159/000262032

19. Asociación Médica Mundial. Principios éticos para las investigaciones médicas en seres humanos. Declaración de Helsinki. Finlandia: Asociación Médica Mundial; 1964.

20. Colombia. Ministerio de Salud. Resolución 8430 de 1993: por la cual se establecen las normas científicas, técnicas y administrativas para la investigación en salud. Bogotá: Minsalud; 1993.

21. Suarez N, Castellanos R, Vargas R, Mattos L, Torres C. Estimación de pérdidas de potencia en enlaces con fibras ópticas. Revista Colombiana de Física. 2004; 36(2): 353-357

22. Newport Corporation. Projects in fiber optics [Internet]. New York: Newport Corporation; 1986. Available in: https://www.newport.com/medias/sys_master/images/images/h56/hc4/8972899581982/NWP-FO-Projects-TOC.pdf

23. Castejón I, Magán R, García C. Sistema de notación dentaria. Odontol Pediatr. 2001; 9(3): 126-128.