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Modern aspects of the use of hardware methods for diagnosing pulp vitality (Part 2. Non-traditional diagnostic methods)

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Abstract

INTRODUCTION. Diagnosis of pulp diseases remains a pressing issue in dentistry, which is determined by their high prevalence and, in some cases, latent course.
AIM. To study new technologies developed for hardware testing of pulp vitality based on modern literature data.
MATERIALS AND METHODS. A systematic search was performed in the electronic databases PubMed, Google Scholar, eLibrary, Google Patents. The search depth was 6 years – from 2019 to 2024.
RESULTS. The search in the electronic library databases initially yielded 793 results. After screening titles and abstracts and removing duplicates, 368 articles were identified, assessed by reading their full text, and analysis of whether the publication criteria were met; 65 articles were included in the systematic review. Based on the results preliminary screening and application of the eligibility criteria, 15 publications were included in the qualitative analysis and 7 publications in the quantitative analysis, 43 publications were used to write the introduction text and in the discussion of the study results. Based on the patent search, 4 patents were included in the analysis. Most of the well-conducted and documented studies were devoted to the pulse oximetry method.
CONCLUSIONS. An analysis of modern literature sources showed that the most common methods for assessing pulp vitality are laser Doppler flowmetry and pulse oximetry. Pulse oximetry is the most accurate diagnostic tool. Alternative diagnostic methods are increasingly being explored for their potential to assess pulp vitality. The most frequently mentioned methods in scientific publications for 2019–2024 are: ultrasound Doppler flowmetry, transillumination, magnetic resonance imaging, speckle imaging, tooth temperature measurements, electroodontometry and plethysmography. However, to date, none of the alternative methods for diagnosing pulp vitality have been integrated into clinical practice, indicating an ongoing challenge in creating a reliable approach to assessing pulp vitality.

Keywords: hardware methods, diagnostics, pulp vitality

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Современные аспекты использования аппаратных методов диагностики витальности пульпы (Часть 2. Нетрадиционные методы диагностики)

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Резюме

ВВЕДЕНИЕ. Одной из актуальных проблем современной стоматологии является применение диагностического арсенала изучения витальности пульпы зубов в тех или иных клинических случаях.
ЦЕЛЬ ИССЛЕДОВАНИЯ. На основании обзора литературных данный изучить инновационные технологии для определения витальности пульпы зубов.

МАТЕРИАЛЫ И МЕТОДЫ. Систематический поиск был выполнен в электронных базах данных PubMed, Google Scholar, eLibrary, Google Patents. Глубина поиска составила 6 лет – с 2019 по 2024 г.
РЕЗУЛЬТАТЫ. Поиск в базах электронных библиотек первоначально дал 793 результата. После удаления дубликатов было идентифицировано 368 статей, на основании соответствия критериям включения публикации выделено 65 статей в систематический обзор. В дальнейшем 15 публикаций были включены в качественный анализ и 7 публикаций в количественный анализ, 43 публикаций были использованы для написания текста введения и при обсуждении результатов исследования.
ВЫВОДЫ. На основании литературных данных можно выделить следующие наиболее распространенные методиками изучения витальности пульпы зубов, к которым можно отнести метод лазерной допплеровской флоуметрии и пульсоксиметрии. Среди нетрадиционных методов диагностики витальности пульпы все чаще исследуются с помощью ультразвуковой допплеровской флоуметрии, трансиллюминации, магнитно-резонансная томографии, спекл-визуализации, измерения температуры зубов, электроодонтометрии и плетизмографии.

Ключевые слова: аппаратные методы, диагностика, витальность пульпы

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INTRODUCTION

In endodontic practice, the assessment of the dental pulp condition is a crucial and necessary diagnostic tool, as diagnosis constitutes an integral part of planning subsequent treatment strategies. The gold standard for determining pulp vitality is its direct evaluation via histological sectioning. However, since the pulp is surrounded by a calcified barrier, such assessment is not feasible prior to the initiation of endodontic treatment.

Given the inability to directly visualize the pulp, indirect methods must be employed to assess its condition by evaluating innervation – for example, pulp sensitivity tests. The most commonly used tests for assessing pulp sensitivity are thermal and electric pulp tests, which stimulate pulpal nerves either through the movement of dentinal fluid induced by temperature fluctuations, resulting in the movement of odontoblastic processes and mechanical stimulation of pulpal nerves, or through the application of an electric current to the tooth, producing electrical stimulation of the pulp nerves [1; 2].

The primary mechanism of the electric pulp test involves initiating ionic changes across the nerve membrane through electrical stimuli, which affect the action potential via rapid depolarization at the nodes of Ranvier in myelinated nerves [3]. Contemporary pulp sensitivity testing methods indirectly evaluate pulp vitality by assessing the neural response, without accounting for vascular circulation, which may result in false-positive responses in teeth that have temporarily or permanently lost sensory function and do not respond to such tests despite the presence of an intact vascular network [4].

The limitations of pulp sensitivity testing have been addressed by the development of pulp vitality testing methods such as pulse oximetry (PO), laser Doppler flowmetry (LDF), and ultrasonic Doppler flowmetry (UDF), which assess pulpal blood flow without relying on patient responses and are considered to provide a more accurate evaluation of pulp status. PO measures oxygen saturation within the pulp chamber using a non-invasive probe with two diodes placed on the tooth, whereas LDF and UDF assess vascular flow within the dental pulp by evaluating the “concentration and velocity of blood cells,” thereby reflecting indicators of pulpal perfusion and vitality [5; 6].

The limitations of pulp sensitivity testing have been addressed through the development of pulp vitality assessment methods. However, laser Doppler flowmetry and pulse oximetry have not yet gained widespread use in routine dental practice, which has prompted increased scientific interest in alternative diagnostic approaches for evaluating pulp vitality.

Among the non-conventional methods currently under investigation are optical diagnostic techniques, ultrasonic Doppler flowmetry, magnetic resonance imaging, terahertz imaging, and dental thermography [7].

MATERIALS AND METHODS

Search Strategy

A systematic electronic search was conducted in the international databases PubMed and Google Scholar, as well as in the Russian scientific electronic library eLibrary. Patent searches were performed using the Google Patents database. The search covered a 6-year period, from 2019 to 2024. Russian literature was defined as studies conducted in Russia and published in Russian scientific journals. The search strategy included the keywords: *Diagnostic*, *Instrumental Methods*, and *Pulp Vitality*. For Russian-language sources, the following terms were used: *Diagnostic*, *Instrumental Methods*, and *Pulp Vitality*.

Inclusion Criteria

1. Articles published in Russian or English between 2019 and 2024.
2. Types of publications: scientific articles–including research and practice-oriented studies–as well as systematic reviews.
3. Full-text availability free of charge on the internet.
4. Relevance to the research topic – instrumental (device-based) methods for the diagnosis of pulp vitality.

Exclusion Criteria

1. Type of publication: conference abstracts, proceedings, and dissertations.
2. Lack of full-text availability online.
3. Absence of analysis regarding the effectiveness of the method.
4. Methods that assess only pulp sensitivity (e.g., thermal tests, electric pulp testing).

A stepwise screening process was employed for the selection of publications. After initial identification, each source underwent title and abstract screening, and duplicates were excluded. Full-text articles were then reviewed for relevance. The bibliographies of all eligible articles were examined to identify additional relevant publications. Each study was assessed for alignment with the research objective based on three criteria: evaluation of the title, abstract, and full text.

Data Extraction

Each included article was analyzed to extract information on bibliometric characteristics, study methodology, and results. The extracted variables included: the type of pulp vitality test or measurement used, patient-related variables (number, age, and sex), number of samples (teeth), type of teeth examined, as well as the technique and device employed for assessing pulp vitality.

RESULTS

Non-Conventional Approaches to Pulp Vitality Diagnosis[1]

In the publications reviewed from 2019 to 2024, the following non-conventional methods for assessing pulp vitality were identified: ultrasonic Doppler flowmetry [9–11], transillumination [12], magnetic resonance imaging [13], speckle imaging [14–16], dental thermography [17; 18], and plethysmography [19].

The studies were grouped according to the type of non-conventional method used. For each method, the diagnostic objective and key findings were summarized. Where available, diagnostic accuracy indicators – such as sensitivity, specificity, positive predictive value, and negative predictive value – were also reported (Table 1).

[1] Traditional Approaches to Assessing Dental Pulp Vitality are discussed in Part 1 of the article [8].

Table 1. Characteristics of the included non-traditional studies

Таблица 1. Характеристика включенных нетрадиционных исследований

Publication, type of research	Sample size and type	Technique	Diagnostic target	Main findings	Accuracy, PPV, NPV
Optical methods					
Dar et al., 2020 [19] Clinical study (on humans)	30 incisors Mx	TLP	Pulpal blood flow	Harmless stimuli caused a reversible decrease in TLP values in human teeth. TLP was able to monitor pulpal blood circulation	Not reported
Knörzer et al., 2019 [20] In vitro (extracted human teeth)	2 mandibular molars (1 for each of the 2 models)	PPG	Simulation of pulpal blood flow	Flow data were detected using light at 625 nm and 940 nm in a model with comparable size and volumetric blood flow rates. Signal interference from the gingiva was observed at 625 nm but not at 940 nm	Not reported
Proulx et al., 2022 [12] In vivo animal model (dog)	45 dogs 45 teeth	TTI	Tooth translucency	Transillumination is less effective than cold and electric tests. In cases without discoloration, transillumination may fail to detect necrotic pulp, resulting in false-negative outcomes. Additionally, discolored teeth with enamel defects or drug-induced stains may produce false-positive results	Sensitivity: 0.59 Specificity: 0.95 PPV: 0.94 NPV: 0.67 Accuracy: 0.76
Xu et al., 2021 [14] In vitro (extracted human teeth connected to an injection pump)	3 teeth	LSI	Simulation of blood flow in the dental pulp	LSCI can detect blood flow in the pulp and is capable of measuring flow velocity. Vertically polarized LSCI demonstrated a wider dynamic detection range compared to non-polarized LSCI (np-LSCI)	The sensitivity of LSCI is sufficient to detect minor changes in blood flow
Chistyakova G.G., 2019 [15] Clinical study (on humans)	141 patients 235 teeth	LSI	Pulpal blood flow	During the analysis and screening of speckle patterns, hemomicrocirculation parameters were optimized, such as spectral power S (relative units) and mean frequency (Hz), which were interpreted as indicators of blood flow level and intensity	Not reported
Chistyakova G.G., 2020 [16] Clinical study (on humans)	190 patients 210 teeth	LSI	Pulpal blood flow	As blood flow intensity decreases, electroodontometry values increase, and the pulp's electrical excitability threshold decreases	Not reported

Table 2 (ending) / Таблица 2 (окончание)

Publication, type of research	Sample size and type	Technique	Diagnostic target	Main findings	Accuracy, PPV, NPV
Ultrasound Doppler flowmetry					
Kim et al., 2023 [9] In vivo animal model (dog)	9 dogs, 36 right and left maxillary anterior teeth	UDF	Pulpal blood flow	When using UDF, gingival blood flow affects the measurement of pulpal blood flow. Therefore, the gingiva must be isolated from the tooth being evaluated	Not reported
Magnetic resonance imaging					
Juerchott et al., 2022 [13] Clinical study (on humans)	70 individuals, 1585 teeth	MRI	Pulpal blood flow	Teeth with healthy pulp can be visualized, and pulpal tissue can be quantitatively assessed using dMRI with a specific set of parameters. This may serve as a useful diagnostic tool for identifying various pulp diseases in future patient studies	Not reported (the entire pulp is considered intact)
Tooth temperature measurement					
Ajith Kamath, Nasim, 2020 [17] Clinical study (on humans)	75 individuals	ITMI	Tooth surface temperature	There were no significant differences in baseline temperature between vital and non-vital teeth. Vital teeth may exhibit better surface heating compared to non-vital ones	Accuracy of 97.34%
Mendes et al., 2020 [18] Clinical study (on humans)	58 individuals 126 maxillary anterior teeth (including 33 pairs of vital – non-vital maxillary central incisors)	ITMI	Thermograms and tooth temperature	When using an infrared thermograph, teeth with different pulpal conditions exhibited different temperatures	The measurement error of the overall temperature is ±2%

Note: Mx – maxillary; NPV –Negative predictive value; PPV – Positive predictive value; TLP – Transmitted light plethysmography; PPG – Photoplethysmography; TTI – tooth transillumination; LSCI – Laser speckle contrast imaging; LSI – Laser speckle imaging; UDF – Ultrasound Doppler flowmetry; MRI –Magnetic resonance imaging; ITMI – Infrared thermographic imaging
Примечание: Mx – верхняя челюсть; NPV – отрицательная прогностическая ценность; PPV – положительная прогностическая ценность; TLP – световая плетизмография; PPG – фотоплетизмография; TTI – трансиллюминация зуба; LSCI – Лазерная спекл-контрастная визуализация; LSI – лазерная спекл-визуализация; UDF – ультразвуковая допплеровская флоуметрия; MRI – магнитно-резонансная томография; ITM – инфракрасная термографическая визуализация

Table 2. Devices / systems used in studies to assess pulp vitality
Таблица 2. Устройства / системы, используемые в исследованиях для оценки витальности пульпы

System /device (publication)	Purpose / Aim
Photoplethysmography	
The light source is a light-emitting diode (LED) with a wavelength of 525 nm. The transmitted light is delivered in pulses [19]	Pulp blood flow
The light source consists of light-emitting diodes (LEDs) with wavelengths of 625 nm and 940 nm [20]	
Laser speckle imaging	
Polarized Laser Speckle Contrast Imaging (LSCI) systems include vertically polarized LSCI (vp-LSCI) and non-polarized LSCI (np-LSCI) configurations. In vp-LSCI systems, the laser light is vertically polarized [14]	Pulp blood flow
Laser speckle-optical device "Specklemeter" [15; 16]	
Transillumination	
Intense narrow beam of light [12]	Light passing through a tooth
Ultrasound Doppler flowmetry	
Ultrasonic Doppler device and 20 MHz probe [9]	Pulp blood flow
Continuous-wave dental Doppler ultrasound system (DDUS) using 22 MHz ultrasonic probes. The DDUS comprises a dual-element transducer, a two-channel probe system (one for transmission and one for reception), and a laptop	Pulp blood flow
Magnetic resonance imaging	
A 3-Tesla system using a 16-channel coil with intravenous administration of gadolinium contrast [13]	Condition of the pulp tissue
Tooth temperature measurement	
Infrared thermometer with laser targeting [17]	Tooth temperature
FLIR E60 thermal imaging camera [18]	

Table 2 summarizes information on the non-conventional devices and systems described in publications from 2019 to 2024 that were used for the assessment of pulp vitality.

Photoplethysmography (PPG) – is a non-invasive optical method widely used to study and monitor pulsations associated with changes in blood volume in peripheral vasculature. It is characterized by low susceptibility to signal contamination from surrounding tissues. This method can be applied to assess pulp vitality, particularly in traumatized teeth, using a custom-fabricated holder.

Light sources used in PPG systems include:

– LEDs with wavelengths of 525, 625, and 940 nm [20];

– a spectrometer placed between a xenon arc lamp and a fiber optic bundle, where the transmitted light is recorded in pulses [19].

The method primarily relies on the intensity of transmitted light, which in some studies has been converted into other metrics, such as voltage and pressure signals [20]. Studies have shown that PPG can monitor pulp blood flow changes in response to harmless stimuli [19].

Knörzer et al. developed a dual-wavelength PPG system (625 and 940 nm) and successfully detected signals originating from the dental pulp without interference from surrounding tissues, demonstrating the feasibility of registering pulsed blood signals. The system revealed enhanced signal strength without requiring extensive noise suppression. At a wavelength of 625 nm, signals from both the pulpal and surrounding tissues could be detected on the tooth surface. However, at 940 nm, only signals from the pulp were recorded, free from surrounding tissue interference. These findings highlight PPG as a promising approach for future pulp vitality testing. Crucially, the ability to clearly distinguish between pulpal and non-pulpal PPG signals remains essential [20].

Transillumination (TTI). Transillumination is a diagnostic method in which visible light is directed onto a tooth, and a digital camera captures the resulting bright transmitted illumination of the dental tissues. The light source is positioned behind the tooth, and the pulp's vitality influences its translucency. A vital pulp permits light transmission, resulting in a well-transilluminated tooth, whereas a necrotic pulp appears dark and dim [12].

However, this technique may be unreliable for detecting pulp necrosis in teeth without visible discoloration, potentially leading to false-negative results [12]. Additionally, false-positive outcomes may occur in cases where tooth discoloration is caused by factors unrelated to pulp vitality [12].

Speckle imaging (LSI). LSI is based on the coherent interference of light, which generates a speckle pattern – a mix of bright and dark spots. These speckles exhibit random temporal fluctuations caused by changes in blood flow direction and particle position, allowing the measurement of blood flow velocity through frequency analysis of these fluctuations. LSI enables differentiation between necrotic and vital pulp and facilitates the evaluation of pulpal blood supply. This non-invasive technique does not require the use of holders [14].

LSI is sufficiently sensitive to detect minor changes in blood flow and is a simple, non-invasive, relatively low-cost method that can be readily integrated into dental practice. It allows the measurement of blood flow velocity across a wide range. However, accurate assessment of pulpal circulation using speckle patterns remains challenging due to the limited penetration of light through enamel and dentin [14].

Laser Speckle Contrast Imaging (LSCI) captures a single exposure of the laser speckle pattern projected onto the tissue of interest and analyzes the resulting pattern to provide information on blood flow, including velocity, vessel diameter, and blood volume [1]. Multi-Exposure Contrast Imaging (MECI) is an enhanced extension of LSCI, offering improved resolution and sensitivity [2].

Xu et al. enhanced the detection of stimulus-induced blood flow in extracted teeth by integrating optical polarization technology with laser speckle contrast imaging (LSCI), introducing a promising tool for pulp vitality assessment in clinical settings, particularly in cases of dental trauma [14]. The results demonstrated that a vertically polarized LSCI system (vp-LSCI) could detect a broader dynamic range of pulpal blood flow contrast – 1.5 to 2 times greater – compared to non-polarized LSCI (np-LSCI). A temporal contrast algorithm was able to detect small flow velocity changes of 0.03–0.07 mm/s, with a detection index 5–10 times higher than that of a spatial contrast algorithm. The vp-LSCI system, combined with temporal contrast analysis, significantly enhances the ability of speckle-based techniques to detect pulpal blood flow, enabling the detection of a wider flow velocity range and finer hemodynamic variations [14].

G.G. Chistyakova evaluated microcirculatory parameters in dental pulp vessels using the laser speckle optical device *Speklometr* (State Registration No. Мт-7.1504-0108) in accordance with a methodology approved by the Ministry of Health of the Republic of Belarus (Instruction No. 099 0619 dated June 28, 2019) [16; 21]. During the analysis and screening of speckle patterns, key hemo-microcirculatory parameters – such as spectral power *S* (relative units) and mean frequency (Hz) – were optimized and interpreted as indicators of blood flow level and intensity. It was found that decreased blood flow intensity corresponded with increased electroodontometric values and a reduced threshold for pulp excitability [16].

Ultrasound Doppler Flowmetry (UDF) is a non-invasive, radiation-free technique that evaluates blood flow by transmitting ultrasonic waves through tissues. UDF operates on the same Doppler principle as laser Doppler flowmetry (LDF) but utilizes ultrasound instead of light. Parameters such as blood flow velocity, pulsatility index, and circulation index are calculated. The technique also allows real-time auditory monitoring of pulsatile sounds [22].

No human clinical studies using UDF for pulp vitality assessment were identified in the reviewed period. However, one animal study (in dogs) and one in vitro study using simulated pulp blood flow in extracted human teeth were published.

A retrospective study in dogs demonstrated that UDF had higher diagnostic effectiveness compared to electric pulp testing (EPT) when assessing pulp vitality in traumatized teeth. It also showed a correlation between pulpal blood flow (PBF) and blood flow in the adjacent gingiva. The study concluded that effective UDF measurement requires isolation of the gingiva from the tooth structure [9].

A laboratory study on extracted human teeth indicated that UDF can detect simulated blood flow below the cemento-enamel junction, but not at the mid-root level [11].

In 2021, a continuous-wave dental Doppler ultrasound system (DDUS) was introduced, employing 22 MHz ultrasound probes. The DDUS comprises a two-element transducer, a dual-channel probe system (one for transmission and one for reception), and a laptop. The probe system performs analog front-end processing, including ultrasound transmission / reception, low-noise amplification (LNA), quadrature demodulation (QDM), low-pass filtering (LPF), and analog-to-digital conversion (ADC). The laptop conducts intermediate-level processing such as decimation, logarithmic compression, interference filtering/noise reduction, and data analysis displayed as a spectrum or spectrogram. To enhance the signal-to-noise ratio (SNR), noise reduction is implemented using Hankel Singular Value Decomposition (SVD). The results are presented in real time as Doppler spectra and spectrograms via a custom-developed graphical user interface (GUI) for the DDUS [10].

The use of Ultrasound Doppler Flowmetry (UDF) in cases of dental trauma presents a promising and potentially more sensitive approach than laser Doppler flowmetry (LDF) [23]. UDF is capable of distinguishing signals originating from the dental pulp and surrounding tissues by analyzing waveform and sound characteristics.

However, the method has several limitations. These include instability in producing consistent results over short observation periods, challenges in accurate probe positioning, potential interference from patient discomfort, and early-stage trauma-induced impairment of pulpal blood supply, which may compromise measurement reliability [23].

Currently, there is no established standard for UDF parameters that distinguish between normal and pathological pulp. Moreover, variables such as probe angle or positioning, probe holder characteristics, and gingival blood flow [9] can significantly influence the recorded values.

Magnetic resonance imaging (MRI). Teeth are difficult to visualize using conventional magnetic resonance imaging (MRI) due to their high mineral content. Moreover, the signal decays rapidly after radiofrequency excitation because of the severely restricted molecular motion of water in densely mineralized tissues. Only with the advent of later technological modifications, such as SWIFT-MRI, have image details emerged that may hold potential value for endodontic research. MRI scanners with a magnetic field strength of 1.5 Tesla have been shown to be insufficient for effective visualization of oral and maxillofacial structures [24].

In response to these limitations, Juerchott et al. conducted a prospective in vivo study aimed at optimizing the assessment of pulpal contrast enhancement (PCE) using dental MRI (dMRI) and at investigating physiological models of PCE. Healthy teeth were examined using 3-Tesla dMRI with a 16-channel coil, and gadolinium contrast agent was administered intravenously before and after scanning. The results demonstrated that PCE in dMRI is a stable intra-individual marker with minimal differences between tooth types, forming an important basis for within-subject comparisons in the evaluation of teeth suspected of endodontic pathology. Furthermore, PCE was shown to be independent of age and sex [13].

The implementation of higher-field MRI systems operating at 3 Tesla has significantly improved dental visualization and is regarded as a promising tool for detecting pulp tissue abnormalities. Nonetheless, further improvement in spatial resolution is essential for enhancing the diagnostic utility of MRI in endodontics [24].

Tooth temperature measurement (TTM). It has been established those vital teeth emit more heat than non-vital teeth. When vital teeth are cooled, a phenomenon known as surface rewarming is observed – these teeth are able to restore their surface temperature over time. Surface rewarming is considered a potential indicator for assessing true pulpal vitality. Vital teeth successfully regained surface heat within a 3-minute period, whereas none of the non-vital teeth reached baseline temperatures within this timeframe. Thus, vital teeth demonstrate faster surface rewarming compared to non-vital teeth. This methodology demonstrated a clinical success rate of 97.34% in diagnosing pulp vitality status [17].

In another study assessing 126 maxillary anterior teeth using the FLIR E60 thermal imaging camera, it was shown that vital and non-vital anterior teeth exhibit distinct temperatures when assessed with infrared thermography [18]. Infrared thermometry with laser guidance may be employed as a routine test for pulp vitality in clinical settings and represents a simple and reliable tool. One of its main advantages is non-invasiveness [17]. However, at this stage, this test appears impractical for routine use as a standalone method of assessing dental vitality.

This review of non-conventional methods for pulp vitality assessment aims to present current research trends. However, any conclusions drawn must be interpreted with caution due to the heterogeneity of included studies and the lack of reported accuracy and predictive values in most of them.

Patents on Instrumental Methods for Assessing Pulp Vitality

The results of the patent search identified four patents published during the review period (2019–2024). One patent concerned an electronic device for intraoral scanning [25], two patents described optical methods – a dental diagnostic probe [26] and a fiber-optic device [27] – and one patent focused on an ultrasonic probe [28] (Table 3).

Patent Overview on Instrumental Methods for Assessing Pulp Vitality Jiang X., Fu M., and Yang L. developed a cranio-maxillofacial oral cavity scanning device designed to detect necrotic pulp tissue and residual pulpal matter following operative procedures [25].

Table 3. General information on included patents

Таблица 3. Общая информация о включенных патентах

Publication year	Patent No.	Title
Magnetic resonance imaging		
2021 (G) Jiang et al., 2020 [25]	CN-111528846-B	Oral craniomaxillofacial scanning device and scanning method and electronic device.
Optical		
2023 (G) Ertl et al., 2017 [26]	EP- 3439542- B1	Dental probe
2023 (P) Tang, Schmitt, 2023 [27]	US-2023263398-A1	Apparatus and method for tooth pulp vitality detection
Ultrasound Doppler flowmetry		
2019 (P) Kim, 2018 [28]	KR-20190089430-A	Dental pulpal vitality assessment system including ultrasound probe and method for assessment

T. Ertl, N. Karazivan, and A. Savic proposed a dental diagnostic probe that emits light within the 500–1500 nm range, which passes through part of the pulp. The transmitted signals are captured by a photodiode detector positioned on the opposite side of the tooth. The system enables detection of bacterially induced inflammatory changes in the pulp, even in teeth with crowns or restorations [26].

Tang C.-M. and Schmitt J. developed a fiber-optic device consisting of a handpiece, a rotational axis, and a caliper-like mechanism that emits light onto the tooth and receives interference signals corresponding to pulpal motion [27].

Kim H.-Y. designed an ultrasonic probe that emits ultrasound signals at 15–25 MHz and detects reflected echoes. Signal analysis allows the calculation of blood flow velocity within the pulp [28].

RESULTS

Non-conventional methods for pulp vitality assessment are increasingly being explored for their diagnostic potential. Scientific publications from 2019 to 2024 have referenced a range of such methods, including ultrasound Doppler flowmetry, transillumination, magnetic resonance imaging, speckle imaging, dental thermography, and plethysmography.

Ultrasound Doppler flowmetry has shown a more promising and sensitive approach than laser Doppler flowmetry, particularly in cases of dental trauma. The introduction of high-field 3 Tesla MRI systems has significantly improved imaging capabilities and is now considered a potential tool for detecting pulpal abnormalities. However, further enhancement of spatial resolution is necessary for successful integration into endodontic diagnostics.

The vp-LSCI system, in combination with temporal contrast algorithms, has greatly improved the ability of laser speckle imaging to detect pulpal blood flow, offering greater sensitivity to flow velocity and subtle hemodynamic changes. The transillumination technique is most effective when visible tooth discoloration is present. Photoplethysmography (PPG) shows promise for future pulp vitality testing, though accurate differentiation between pulpal and non-pulpal signals remains a critical requirement. Meanwhile, infrared thermometry, although non-invasive and accessible, currently appears impractical for routine clinical use as a standalone diagnostic method.

To date, none of the non-conventional pulp vitality assessment methods presented in this review have been fully integrated into standard clinical practice, underscoring the persistent challenge of developing a reliable diagnostic approach. While emerging technologies aim to improve diagnostic sensitivity and specificity, further evidence-based studies and the development of clinically applicable, user-friendly equipment are needed to advance their implementation.

LIMITATIONS OF THE STUDY

The primary limitation of this review is the lack of a critical appraisal of the methodological quality of the included studies. This may have resulted in the inclusion of lower-quality research, thereby increasing heterogeneity among the studies. As the current review aims to provide a broad overview of emerging research trends, any conclusions drawn should be interpreted with caution due to the diversity of the included literature.

In several studies, data were limited exclusively to anterior teeth, which restricts the generalizability of the findings to the assessment of pulp vitality in posterior teeth. While sensitivity and specificity are commonly cited indicators of diagnostic validity, positive predictive value (PPV) and negative predictive value (NPV) may better reflect clinical utility. Pulp testing ideally requires clinical validation through histological confirmation, yet such data were absent from most of the included studies. This lack of histological evidence hampers accurate assessment of the diagnostic precision of non-conventional methods.

As a result, questions remain regarding the reliability and clinical relevance of the reviewed technologies, similar to those associated with traditional pulp sensitivity tests. Future studies should encompass both static and dynamic blood flow conditions and investigate a broader spectrum of light frequencies, which are essential for optimizing the efficacy of emerging optical pulp vitality assessment techniques.

FUTURE DIRECTIONS

Further research is necessary to refine non-conventional methods for pulp vitality assessment. Specifically, future investigations should examine their correlation with histological findings. Interdisciplinary collaboration between dental professionals and biomedical engineers will be critical for the development of standardized tooth models for diagnostic testing. Such partnerships will foster innovation, promote effective clinical problem-solving, and bridge the gap between clinical insights and technological advancement. Notably, many of the techniques discussed in this review have been adapted from other medical disciplines, reinforcing the need for comprehensive analysis of the medical, optical, and bioengineering literature to identify promising technologies for pulp testing.

REFERENCES / СПИСОК ЛИТЕРАТУРЫ

1. Xavier M.T., Costa A.L., Ramos J.C., Caramês J., Marques D., Martins J.N.R. Calcium silicate-based cements in restorative dentistry: Vital pulp therapy clinical, radiographic, and histological outcomes on deciduous and permanent dentition – a systematic review and meta-analysis. *Materials*. 2024;17(17):4264. https://doi.org/10.3390/ma17174264
2. Alfaisal Y., Idris G., Peters O.A., Zafar S., Nagendrababu V., Peters C.I. Vital pulp therapy-Factors influencing decision-making for permanent mature teeth with irreversible pulpitis: A systematic review. *Int Endod J*. 2024;57(5):505–519. https://doi.org/10.1111/iej.14036
3. Duncan H.F. Present status and future directions-Vital pulp treatment and pulp preservation strategies. *Int Endod J*. 2022;55(Suppl. 3):497–511. https://doi.org/10.1111/iej.13688
4. Patro S., Meto A., Mohanty A., Chopra V., Miglani S., Das A. et al. Diagnostic accuracy of pulp vitality tests and pulp sensibility tests for assessing pulpal health in permanent teeth: A systematic review and meta-analysis. *Int J Environ Res Public Health*. 2022;19(15):9599. https://doi.org/10.3390/ijerph19159599
5. Alanazi M.H., Barnawi N.I., Almohaimel S.A., Almutairi M.A., Alanezi O.K., Al bassry A.A. et al. Evaluation of dental pulp testing: Simple literature review. *Arch Pharma Pract*. 2019;10(3):37–39. Available at: https://archivepp.com/article/evaluation-of-dental-pulp-testing-simple-literature-review (accessed: 11.03.2025).
6. Almudever-Garcia A., Forner L., Sanz J.L., Llena C., Rodríguez-Lozano F.J., Guerrero-Gironés J., Melo M. Pulse oximetry as a diagnostic tool to determine pulp vitality: A systematic review. *Appl Sci.* 2021;11(6):2747. https://doi.org/10.3390/app11062747
7. Afkhami F., Wright P.P., Chien P.Y., Xu C., Walsh L.J., Peters O.A. Exploring approaches to pulp vitality assessment: A scoping review of nontraditional methods. *Int Endod J*. 2024;57(8):1065–1098. https://doi.org/10.1111/iej.14073
8. Shadrina K.V., Orekhova L.Yu., Goncharov V.D., Vashneva V.Yu., Silina E.S., Kosova E.V., Petrov A.A. Modern aspects of the use of hardware methods for diagnosing pulp vitality (Part 1. Traditional methods). *Endodontics Today*. 2025;23(2):258–270. https://doi.org/10.36377/ET-0084
9. Kim D., Ko H.S., Park S.Y., Ryu S.Y., Park S.H. The effects of gingival blood flow on pulpal blood flow detection using ultrasound Doppler flowmetry: animal study. *Restor Dent Endod*. 2023;48(1):e9. https://doi.org/10.5395/rde.2023.48.e9
10. Park J., Kim Y., Kim J., Song T.-K. Continuous wave dental doppler ultrasound system for measuring pulp blood flow. In: *2021 IEEE Biomedical Circuits and Systems Conference (BioCAS).* Berlin, Germany, 2021, pp. 1–5. https://doi.org/10.1109/BioCAS49922.2021.9644942
11. Yoon M.J., Kim D.H., Jung I.Y., Park S.H. A laboratory study to detect simulated pulpal blood flow in extracted human teeth using ultrasound Doppler flowmetry. *Int Endod J*. 2021;54(2):231–240. https://doi.org/10.1111/iej.13410
12. Proulx C., Dumais Y., Beauchamp G., Steagall P. Reliability of electric pulp test, cold pulp test or tooth transillumination to assess pulpal health in permanent dog teeth. *J Vet Dent*. 2022;39(2):133–141. https://doi.org/10.1177/08987564221076363
13. Juerchott A., Jelinek C., Kronsteiner D., Jende J.M.E., Kurz F.T., Bendszus M. et al. Quantitative assessment of contrast-enhancement patterns of the healthy dental pulp by magnetic resonance imaging: A prospective in vivo study. *Int Endod J*. 2022;55(3):252–262. https://doi.org/10.1111/iej.13662
14. Xu F., Xie C., Zhang Y., Shi G., Shi J., Xu X. et al. Vertically polarized laser speckle contrast imaging to monitor blood flow in pulp. *J Mod Opt*. 2021;68(20):1075–1082. https://doi.org/10.1080/09500340.2021.1973604
15. Chistyakova G.G., Dik S.K. Clinical substantiation of the use of laser speckle-optical diagnostics of microcirculation in the vessels of the tooth pulp. *Dentistry. Aesthetics. Innovations.* 2019;3(3):303–318. (In Russ.).

    Чистякова Г.Г., Дик С.К. Клиническое обоснование применения лазерной спекл-оптической диагностики микроциркуляции в сосудах пульпы зуба. *Стоматология. Эстетика. Инновации*. 2019;3(3):303–318.
16. Chistyakova GG. Functional methods for the diagnosis of hemodynamics and neuroreceptor system of tooth pulp. *Dentistry. Aesthetics. Innovations*. 2020;4(1):98–113. (In Russ.) https://doi.org/10.34883/PI.2020.4.1.009
    Чистякова ГГ. Функциональные методы диагностики гемодинамики и нервно-рецепторного аппарата пульпы зуба. *Стоматология. Эстетика. Инновации*. 2020;4(1):98–113. https://doi.org/10.34883/PI.2020.4.1.009
17. Ajith Kamath K., Nasim I. Evaluation of laser guided infrared thermometry as an auxiliary tool for pulp vitality assessment-a clinical study. *International Journal of Pharmaceutical Research*. 2020;12(4):2216–2221. https://doi.org/10.31838/ijpr/2020.12.04.310
18. Mendes S., Mendes J., Moreira A., Clemente M.P., Vasconcelos M. Thermographic assessment of vital and non-vital anterior teeth: A comparative study. *Infrared Phys Technol*. 2020;106:103232. https://doi.org/10.1016/j.infrared.2020.103232
19. Thaw Dar O., Kakino S., Kusano M., Ikeda H., Miyashin M., Okiji T. Transmitted-light plethysmography detects changes in human pulpal blood flow elici-

ted by innocuous tooth cooling and foot heating. *Arch Oral Biol*. 2020;119:104881. https://doi.org/10.1016/j.archoralbio.2020.104881

20. Knörzer S., Hiller K.A., Brandt M., Niklas A., Putzger J., Monkman G.J. et al. Detection of pulsed blood flow through a molar pulp chamber and surrounding tissue in vitro. *Clin Oral Investig*. 2019;23(3):1121–1132. https://doi.org/10.1007/s00784-018-2530-y
21. Chistyakova G.G. Evaluation of microhemodynamic disorders in the dental pulp during replacement therapy for wedge-shaped defects. *Dentistry. Aesthetics. Innovations*. 2019;3(3):327–339. (In Russ.).
Чистякова ГГ. Оценка микрогемодинамических нарушений в пульпе зуба при заместительной терапии клиновидных дефектов. *Стоматология. Эстетика. Инновации*. 2019;3(3):327–339.
22. Cho Y.W., Park S.H. Measurement of pulp blood flow rates in maxillary anterior teeth using ultrasound Doppler flowmetry. *Int Endod J*. 2015;48(12):1175–1180. https://doi.org/10.1111/iej.12422
23. Ahn S.Y., Kim D., Park S.H. Efficacy of ultrasound doppler flowmetry in assessing pulp vitality of traumatized teeth: a propensity score matching analysis. *J Endod*. 2018;44(3):379–383. https://doi.org/10.1016/j.joen.2017.10.004
24. Hilgenfeld T., Saleem M.A., Schwindling F.S., Ludwig U., Hövener J.B., Bock M. et al. High-Resolution Single Tooth MRI With an Inductively Coupled Intraoral Coil-Can MRI Compete With CBCT? *Invest Radiol*. 2022;57(11):720–727. https://doi.org/10.1097/RLI.0000000000000890
25. Jiang X., Fu M., Yang L. *Oral craniomaxillofacial scanning device and scanning method and electronic device*. Patent ID, CN-111528846-B, filed 30 April 2020, published 14 May 2021 and granted, 14 May 2021.
26. Ertl T., Karazivan N., Savic A. *Dental probe*. Patent ID, EP-3439542-B1, filed 07 April 2017, published 12 July 2023 and granted 12 July 2023.
27. Tang C-M., Schmitt J. *Apparatus and method for tooth pulp vitality detection*. Patent ID, US-2023263398-A1, filed 21 April 2023 and published 24 August 2023.
28. Kim H-Y. *Dental pulpal vitality assessment system including ultrasound probe and method for assessment*. Patent ID, KR-20190089430-A, filed 22 January 2018 and published 31 July 2019.

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All the authors made equal contributions to the publication preparation in terms of the idea and design of the article; data collection; critical revision of the article in terms of significant intellectual content and final approval of the version of the article for publication.

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