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**CURRENT APPROACHES ON DENTAL PULP  
VITALITY ASSESSMENT AND PRESERVATION IN  
PRIMARY AND PERMANENT TEETH IN CHILDREN**

**ABSTRACT**

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## Introduction:

Dental caries is still a major health problem today, with very high prevalence among children, all around the globe. Due to various reasons (lack of proper dental education, lack of access to dental care, “silent symptomatology”, etc.), treatment is often initiated when the progression degree has reached a deep, cavitary stage, often with pulp involvement. The primary goal of vital pulp therapy is to maintain the integrity and health of the teeth and their supporting tissues, while maintaining the vitality of the pulp. Recent advances in the field of biomaterials, as well as advances in pulp biology that have improved clinicians' understanding of the biological and reparative processes occurring in the injured dental pulp, have shifted the pulp treatment paradigm from the formocresol era towards approaches aimed at preserving pulp vitality and stimulating the inflamed pulp tissue to heal.

For the success of vital pulp therapy procedures, beside the therapeutic properties of the biomaterial used for pulp stimulation, an accurate diagnosis of the initial pulp condition is an essential requirement, yet it represents a great challenge for paediatric dentists. Diagnostic pulp tests provide information about the pulp status by investigating either the neural component (mechanical and sensibility tests), or the vascular supply (vitality tests). Mechanical and sensibility pulp tests have limited diagnostic value in children, due to inaccuracy of the patient's response related to cooperation issues and understanding of the procedure. Recent studies highlighted the potential of vitality pulp tests to overcome many drawbacks of the previously mentioned tests, showing better reliability, patient-friendliness and objectiveness. Additionally, it has been demonstrated that the pulp's vascular supply is the true determinant of its vitality. Although a considerable amount of literature has been published on the topic of vitality pulp tests, there are still many unknowns. Currently, a consensus on a specific vitality test to be recommended for daily clinical practice has not been reached. To date, there are only a handful of studies on vitality tests in children, none of which investigate the value of these tests as vitality monitorisation tools in the follow-up of vital pulp therapy procedures. Much uncertainty still exists about the relationship between age/root development stage and pulpal blood flow, as there are conflicting results reported in the few existing studies. To illuminate this uncharted area, the present work aimed to investigate pulp vitality testing in children, in different clinical scenarios.

Within this thesis, two key aspects related to vital pulp therapy in children were addressed: diagnosis of the pulp condition and treatment options.

**The first part of this thesis (the general part)** reflects the current state of knowledge in the field, summarised in the following paragraphs.

Mechanical and sensibility pulp tests are routinely used in adult patients for the diagnosis of pulp conditions, but their use in paediatric patients is limited due to patient understanding and cooperation issues, subjectivity and pain triggering.

Vitality tests have demonstrated in the recent years better reliability, patient-friendliness, and objectiveness, but are lacking implementation in clinical practice. Pulse oximetry (PO) and Laser Doppler Flowmetry (LDF) are the most studied vitality pulp tests, with the best results among the investigated pulp testing methods. Although LDF currently seems to be a more reliable pulp testing method than pulse oximetry, the latter has the advantages of being faster, cheaper, less technique sensitive, and easier to employ, which make it suitable for paediatric use. A commercially-available pulse oximeter for dental use has not been developed yet.

There have been identified aspects related to the pulpal physiology of primary and immature permanent teeth, which have implications for the diagnosis of pulp vitality, especially for the interpretation of pulp sensibility testing results, like the underdevelopment of Rashkow's neural plexus in immature permanent teeth and the potential of primary teeth to retain sensation until advanced resorption stages. Studies on vitality testing in primary teeth are scarce and provide conflicting results regarding variation of pulpal blood flow with age.

Vital pulp therapy (VPT) in primary teeth is an expanding concept in today's paediatric dentistry, with less invasive VPT procedures like indirect pulp treatment, direct and indirect pulp capping, gaining ground in front of the traditional pulpotomy, which is now appreciated by more and more specialists as an overrated treatment option in certain clinical situations. Formocresol has been used extensively in primary dentition in the past, but has become obsolete after concerns over its toxicity have been raised and studies have shown important local and systemic side effects (local pulpal chronic inflammation and necrosis, cytotoxicity, systemic and immunologic disturbances, mutagenic/carcinogenic effect). The use of calcium hydroxide,

regarded for a long a time as the gold standard in the vital pulp therapy of permanent teeth, has become questionable, after multiple studies highlighted important downsides of this material, like internal resorption, lack of antibacterial properties, and necrosis induction at the interface with the pulp tissue, associated with unpredictable and often unsuccessful long-term success. On the other hand, evidence is mounting on calcium-silicate biomaterials, which showed potential for pulp healing and regeneration in multiple vital pulp therapy procedures, with high success rates reported by clinical studies in both permanent and primary teeth.

Given this data, a few questions arose following the literature review: “Is pulse oximetry a reliable tool for pulpal diagnosis in children?”, “Is there an age-related variation of pulpal oxygen saturation (SpO<sub>2</sub>) in primary and permanent teeth in children?”, “Can pulse oximetry be used for monitorisation of the pulp status in the follow-up of vital pulp therapy?”, “Are the bioactive calcium silicate cements able to support the choice for less invasive VPT procedures in primary teeth?”.

**The second part of the thesis (personal contribution)** includes three studies (experimental, histological and clinical), aimed to answer the previously stated questions.

**The first study (the experimental study)** aimed to assess the reliability of pulse oximetry for vitality pulp testing in primary teeth, before and after direct pulp capping with calcium hydroxide, Mineral Trioxide Aggregate (MTA) and Biodentine<sup>TM</sup>. The research methodology implied using a canine model to compare pulse oximetry against laser Doppler flowmetry data and pulp densitometry on computer tomography imaging. Statistical analysis of post-operative pulse oximetry and LDF recordings revealed significant differences between the pulpal microvascular blood flow ( $p = 0.002$ ,  $<0.05$ ) and pulpal oxygen saturation ( $p = 0.002$ ,  $<0.05$ ) of the treated vs. control groups. The mean densitometry values of the capped dental pulp obtained in this study are indicative for pulp inflammation in most of the calcium hydroxide - capped teeth, while all Biodentine<sup>TM</sup> - capped teeth, most of the MTA - capped teeth and all the teeth in the corresponding control groups are indicative for healthy pulp. The results support pulse oximetry as a reliable method of pulp status assessment in primary teeth, for diagnostic and monitorisation purpose.

**The second study (the histological study)** completes the observations obtained in the experimental study. Its purpose was to assess, by histologic means, the pulpal response of

primary teeth following direct pulp capping with calcium hydroxide, MTA and Biodentine™. The histologic analysis of the pulps capped with the three biomaterials confirmed the presence of vital pulp tissue in all specimens, exhibiting different degrees of inflammation, at 14 days post-operative. Statistical analysis of the histologic evaluation criteria revealed significant differences between the responses of teeth to the three biomaterials ( $p < 0.001$ ,  $< 0.05$ ), with the highest statistically significant differences between the Biodentine and calcium hydroxide groups (ptukey  $< 0.001$ ), and no significant differences between the two calcium silicate cements - Biodentine™ and MTA groups (ptukey = 0.712). The results of this study add up to the evidence reinforcing calcium silicate cements as better alternatives for vital pulp therapy in primary teeth.

**The third study (the clinical study)** aimed to investigate the age-related variation of blood oxygen saturation from the dental pulp during different stages of dental development in all types of primary and permanent teeth in children. The study was carried out in 200 children aged 2 to 15 years. Four rounds of comparisons were performed on the data including oxygen saturation values recorded in 650 teeth, divided in five groups: primary vs permanent, open apex vs closed apex, superior vs inferior, and comparisons between tooth types. The statistical analysis revealed several significant differences between teeth in different developmental stages. In primary teeth, values of vital pulp ranged between 72 % (min.) and 98% (max.), with a mean value of 90% for teeth with closed apex (in stability stage), and 89% for teeth with open apex (in resorption stage); in permanent teeth values of vital pulp ranged between 77 % (min.) and 94% (max.), with a mean value of 91.6% for teeth with open apex (immature) and 86.4% for teeth with closed apex (mature). Statistically significant differences ( $p < 0.001$ ) were registered in the comparison between canines and the other tooth types, in both primary and permanent teeth. The results indicate that values of pulpal oxygen saturation tended to decrease with age progression in both primary and permanent dentitions, and that the thickness and the optical properties of hard dental tissues (enamel and dentin), as well as the shape and volume of the coronal pulp, which differs among tooth types, seems to have some influence on the oxygen saturation reading as well.

This work brings valuable contribution for the establishment of reference pulpal oxygen saturation values in multiple age categories in children and highlights some key aspects related to factors which might influence the readings performed using pulse oximetry.

## Conclusions:

1. Pulse oximetry can be considered a valuable assessment method for the pulpal status in primary teeth;
2. Pulse oximetry can be a useful monitoring tool for the follow-up of direct pulp capping in primary teeth;
3. Different degrees of pulpal inflammation seem not to correlate with the measured oxygen saturation values;
4. LDF, in its current version, is not suitable for pulp monitorisation (multiple measurements performed at different time intervals) in experimental setting involving primary teeth of dog model, due to technique-related limitations;
5. The use of CT densitometry for diagnostic purpose of the pulp status is a reliable tool, but cannot be recommended as a routine diagnostic test for pulpal pathology in children due to radiation concerns;
6. Calcium silicate biomaterials used for direct capping of the pulp elicit a better pulpal response compared to calcium hydroxide, in the short-term (14 days follow-up);
7. Biodentine<sup>TM</sup> seems to be related to a reduced inflammatory reaction within the dental pulp, two weeks following direct pulp capping;
8. The pulpal oxygen saturation differs slightly between healthy primary and permanent teeth;
9. The difference in oxygen saturation between primary and permanent teeth is more notable in case of closed-apex teeth;
10. The pulpal oxygen saturation of healthy primary teeth ranges between 72 % (min.) and 98% (max.), with a mean value of 90% for teeth with closed apex (in stability stage), and 89% for teeth with open apex (in resorption stage);
11. The pulpal oxygen saturation of healthy permanent teeth (in children aged 7-15 years) ranges between 77 % (min.) and 94% (max.), with a mean value of 91.6% for teeth with open apex (immature) and 86.4% for teeth with closed apex (mature);
12. The patient's age is an important factor affecting the results of pulp testing by pulse oximetry;
13. Oxygen saturation values tend to decrease with age progression in children, in both



- primary and permanent teeth;
14. The decrease in oxygen saturation with age progression is more pronounced in permanent teeth than in primary teeth;
  15. Oxygen saturation values of healthy teeth (of the same type) vary according to the root development; thus, the development stage of the tooth must be taken into consideration when establishing reference SpO<sub>2</sub> values;
  16. Oxygen saturation values in healthy primary and permanent teeth vary between tooth types;
  17. The thickness and the optical properties of hard dental tissues (enamel and dentin), as well as the shape and volume of the coronal pulp, which differ among tooth types, seem to influence the oxygen saturation reading; thus, reference SpO<sub>2</sub> values should be established with consideration for tooth type;
  18. The pulpal oxygen saturation registered in healthy canines (both primary and permanent) is lower compared to other tooth types: 87.7% (primary canines with closed apex), 86.8% (primary canines with open apex), 88% (permanent canines with open apex), 83% (permanent canines with closed apex);
  19. The pulpal oxygen saturation registered in healthy open apex premolars (93.3%) is higher, compared to other tooth types;
  20. There are differences in the oxygen saturation values of healthy primary upper and lower canines;
  21. With limitations related to stability, retention, and in some instances, size, the configuration of a small alar PO probe can be considered adequate as a starting model for the development of a probe for dental use; however, this configuration should be adapted to meet the needs of the dental field.

The results of this thesis present significant clinical inference, contributing to the improvement of pulse-oximetry as a dental pulp-testing method, and its applications in paediatric dental practice. It brings valuable contribution for the establishment of reference pulpal oxygen saturation values in multiple age categories in children and highlights some key aspects related to factors which might influence the readings performed with this pulp test. The present work also adds to the evidence supporting the use of calcium silicate cements, especially



Biodentine™, for vital pulp therapy in primary teeth, in conjunction with less invasive procedures.