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*INTEGRATED STUDY MASTER'S THESIS*

# Dental Bleaching – a Controversial Tendency in Modern Society

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# Table of Contents


**1 Introduction ... 6**

**2 Aetiology of tooth discoloration ... 9**

2.1 Chromophore Concept ... 9
2.2 Extrinsic Stains ... 10
2.3 Intrinsic Stains ... 10
2.4 Internalized Stains ... 11

**3 Healthy and Sound Tooth Structures ... 12**

3.1 Enamel ... 12
3.2 Pulp-Dentin Complex ... 12
3.3 Periodontium and Alveolar Bone ... 14

**4 Bleaching Mechanisms ... 17**

4.1 Chemical Oxidation Reaction ... 17
4.2 Accelerating Mechanisms ... 18

**5 Bleaching Agents ... 21**

5.1 Hydrogen Peroxide ($H_2O_2$) ... 21
5.2 Carbamide Peroxide ($CH_6N_2O_3$) ... 22
5.3 Sodium Perborate ($NaBO_3$) ... 22
5.4 Ozone ($O_3$) ... 23

**6 Dental Tooth Bleaching Techniques ... 23**

6.1 Vital Tooth Bleaching Technique ... 23
6.1.1 In-Office Tooth Bleaching Technique ... 24
6.1.2 At-Home Bleaching technique ... 25
6.1.3 Over- the- Counter Whitening Products ... 25
6.2 Non-Vital Tooth Bleaching Technique ... 28
6.2.1 Walking Bleaching technique ... 28
6.2.2 Modified-Walking Bleaching Technique ... 30
6.2.3 Thermocatalytic Technique ... 30
6.2.4 Combined Technique ... 30
6.3 Macroabrasion & Microabrasion ... 31

**7 Adverse Effects of Dental Bleaching ........ 34**
7.1 Adverse Effects on Intraoral Structures ........ 34
7.1.1 Adverse Effects on Enamel ........ 34
7.1.2 Adverse Effects on Pulp-Dentin Complex ........ 36
7.1.2.1 Tooth Sensitivity ........ 36
7.1.2.2 Hydrodynamic Theory ........ 36
7.1.2.3 Reversible Pulpitis ........ 37
7.1.3 Adverse Effects on Periodontium ........ 38
7.1.3.1 Adverse Effects on Gingiva ........ 38
7.1.3.2 Adverse Effects on Periodontal ligaments and Alveolar Bone ........ 39
7.1.3.3 External Cervical Root Resorption ........ 39
7.2 Adverse Effects on Restorative Materials ........ 42
7.2.1 Direct restorative materials ........ 43
7.2.2 Indirect Restorative Materials ........ 44
7.2.3 Bonding Quality ........ 45
7.3 Adverse Effects on Systemic Health ........ 46
7.3.1 Cytotoxicity ........ 47
7.3.2 Genotoxicity and Carcinogenicity ........ 48
7.4 Effects on Quality of Life and Addictive Behaviours ........ 49
7.4.1 Effects on Oral Health Related Quality of Life ........ 49
7.4.2 Bleachorexia and Body Dysmorphic Disorder ........ 50
**8 Dental Management ........ 52**
8.1 Indications and Contraindications ........ 52
8.2 Patient Management and Preparation ........ 54
8.3 Management of reducing Side Effects ........ 57
8.3.1 Remineralization and Desensitizing Agents ........ 57
8.3.1.1 Fluoride Products ........ 57
8.3.1.2 Casein Phosphopeptide- Amorphous Calcium Phosphate Complex ........ 57
8.3.1.3 Hydroxyapatite based Products ........ 58
8.3.2 Anti-Inflammatory Medication ........ 59
8.3.3 Low-Level Laser Therapy ........ 59
**9 Conclusion ........ 61**
**10 References ........ 62**

## Summary

**Background:** Considering the growing popularity of aesthetic procedures to seek whiter teeth, because of the general desire to improve aesthetic appearance, also spread through different channels of media, this thesis explores the different methods and agents of tooth whitening as well as their possible health consequences.

**Aim:** This master thesis aims to comprehensively examine bleaching agents and their mechanisms, as well the importance of clinical understanding regarding adverse effects and quality-of-life implications.

**Tasks:** Clarify the use of accelerating systems. Examining dental bleaching agents and alternative methods based on their chemical, biological and physical features. Scrutinize common vital and non-vital bleaching techniques and other methods. Investigate the adverse effects of dental bleaching on oral- and systemic health, as well the effects on Oral Health related Quality of Life. Explore Indications and Contraindications as well the management of side effects.

**Hypothesis**: 1) Dental bleaching induces adverse effects on soft tissue structures. 2) At-home bleaching is an ineffective treatment strategy for discolorated teeth.

**Search strategy:** The research compromised 98 articles; systematic literature reviews, meta-analysis, clinical control trials and journal articles from the databases of the National Library of Medicine, Wiley Library, Google Scholar, PubMed, and Research Gate.

**Results**: Literature investigation showed increased interest in dental bleaching among the population due to materials, procedures, and global market available. Dental bleaching causes biological response of soft dental structures seen in the pulp tissue and gingival tissue. It changes chemical and physical properties of hard dental structures and restorative materials.

**Conclusion**: Dental bleaching is an effective treatment of discolorated teeth. It induces changes in hard and soft dental structures of oral tissues but is safe in application if proceeded according to guidelines. It is important to provide evidence-based information to the patient regarding risks, side effects and management of dental bleaching. Bleaching has positive and negative effects on Oral Health Related Quality of Life.

**Keywords**: Tooth discoloration, dental bleaching, bleaching efficacy, systemic health, quality of life, tooth bleaching techniques, tooth bleaching mechanisms, hydrogen peroxide, carbamide peroxide, tooth bleaching materials, aesthetics, adverse effects

# 1 Introduction

Human's natural teeth colour is a hue of white. Teeth can discolorate due to various factors, such as the consumption of foods, drinks, medication, or genetic disorders during lifetime. The teeth will gradually change to shades of yellow, brown, or black, depending on the extent and aetiology of discoloration. Therefore, bleaching is a common conservative aesthetic approach to treat discoloured teeth. In western culture, modern teeth bleaching treatments are done for over 100 years and people have used various methods to bleach their teeth [1]. The most common agents used for bleaching today are hydrogen- and carbamide peroxide. Hydrogen peroxide is a colourless liquid and highly soluble in water. It is an oxidizing agent and a reactive oxygen species [2].

The first tooth whitening procedures were performed in ancient times and continually date back to 1848, when pulp less teeth were bleached using a combination of chloride and lime [3–6]. In 1864, a solution of calcium hydrochloride and acetic acid was used for the first time. The derivate is known as "Labarraques solution" and made of chloride and soda. In 1861, the first "walking-bleach technique" was invented and consisted of a mixture of sodium perborate and water. During the late 19th century, various substances such as cyanide, potassium, oxalic acid, and many other (sulphurous acid, aluminium chloride, sodium hypophosphate, pyrozone, hydrogen dioxide, sodium peroxide) were considered as either direct or indirect oxidizers on the organic portions of a tooth. Whereas sulphurous acid was the only reducing agent [3–5]. These chemical agents were used to treat stained teeth and were categorized based on their effectiveness against different types of stains. Superoxol, pyrozone, and sodium dioxide were found to be the most effective at that time. Superoxol was commonly used due to its high safety, while pyrozone was mainly used in the 1950s to 1960s. Bleaching became increasingly popular in the late 1800s, which was a time of affluence when white teeth were considered a priority [3, 5]. In 1868, vital tooth bleaching was performed by using pyrozone, oxalic acid, or hydrogen peroxide. At that time, the chemical knowledge was further advanced. In 1893, a three percent pyrozone solution, an ether peroxide, and an aqueous solution of hydrogen peroxide were used as mouthwashes for children and adolescents. In 1911, the use of hydrogen peroxide in combination with a heating instrument was considered an acceptable method for teeth whitening [3]. Between 1913 and 1940, a period that included World War I and II, only few reports about teeth whitening treatments exist. In the 1940s and 1950s, as the economy recovered, reports emerged about treating fluorosis and tetracycline-stained teeth. In 1960, Dr. Bill Klusmier, an orthodontist, invented the first successful home bleaching technique using carbamide peroxide to initially treat gingivitis. He instructed the use of an "over-the-counter" oral antiseptic called "Gly-Oxide", which contained 10% Carbamide peroxide via a custom-fitting mouth tray at night. He discovered that, besides improving gingival health, teeth became whiter [3, 5, 7]. In 1989, Haywood and Hayman introduced the dental “nightguard” bleaching method for at-home use with a product called “White Brite”. This invention led to the development of today's most widely used economic technique to whiten teeth – the “at-home bleaching” technique [1, 3, 5, 8]. The first “over-the-counter” whitening product was launched in the United States in the 1990s. These products contained low concentrations of hydrogen peroxide and carbamide peroxide and were sold directly to consumers in various stores [3]. In recent decades, extensive research has been conducted to effectively whiten teeth and promote change and improvement.

The demand for whiter teeth is continually increasing due to a growing interest in aesthetic appearance. There are various reasons for this trend [9, 10]. Smiling is a powerful social tool that expresses joy and satisfaction, and it plays a crucial role in interpersonal relationships across society [11]. Nowadays, the internet, social media, television, and print media are powerful advertising tools that are used to promote idealized images. A smile with white teeth, certain body aesthetics, and facial appearance is considered to give a person a younger and healthier appearance, as well as an idealized beauty standard [11–14]. Especially among the younger generation the desire for teeth whitening is increasing, and a growing number of people are seeking a “Hollywood smile” [12, 15]. The demand for this is reflected in the variety of materials and methods available on today’s market, which are presented in this master theses. For instance, “over-the-counter” products are readily available and sold directly to consumers. Bleaching is a less destructive treatment compared to conservative restorative procedures such as resin-bonded porcelain veneers or composite veneers and shows a variety of advantages [16–18].

Because of an increasing tendency of teeth whitening, it is difficult for dentists to determine a correct indication for teeth whitening as it is an aesthetic approach.

The perception of a person's aesthetics is subjective and varies within society. It is a factor used to evaluate people by the public in modern society. Teeth whitening is a cost-effective and straightforward method to improve the colour of a person's teeth. However, it should not be performed careless or lead to complications [11, 12, 15].

This Master Thesis aims to examine different bleaching agents and their mechanisms and the importance of the clinical understanding of adverse effects and quality of life implications. Throughout this review, compromising evidence-based information from 98 different literature sources, this paper is investigating the use of accelerating mechanisms and examines dental bleaching agents and alternative methods based on their chemical, biological and physical features. The most common vital and non-vital tooth bleaching techniques and methods are discussed. Adverse Effects on the oral and systemic health as well the Oral Health related Quality of Life implications are examined. An overview of the indications, contraindications, and management of side effects, as well as the patient preparation management are presented.

# 2 Aetiology of tooth discoloration

According to the Glossary of Prosthodontic Terms, a stain is defined as "the discoloration of a tooth surface due to ingested materials, bacterial action, tobacco or other substances or circumstances" [19]. As staining of teeth has different aetiologies, it is essential to note the terminology and understanding the underlying cause behind each type of stain. In the means of dental bleaching, the various factors leading to a tooth colour change, can lead to reduced self-acceptance in relation of aesthetics and therefore knowledge about tooth stains can aid in diagnosis and treatment modalities [1, 2, 3].

## 2.1 Chromophore Concept

Tooth stains are coloured compounds called chromophores arranged in aromatic compounds. They can be divided into organic chromophores, which are small molecules with conjugated carbon double bonds such like tannins or furfurals from coffee or tea and inorganic chromophores which are colour transition metal ions such like iron ($Fe^{2+}$, $Fe^{3+}$), magnesium ($Mg^{2+}$), manganese ($Mu^{2+}$) and copper ($Cu^{2+}$) [4, 7, 8, 9, 10]. The chromophores can also be present in combination such like haemoglobin found in blood, which has the organic ions and inorganic metal ions incorporated [9]. A clear distinction has been explained already, as chromophores refer to be responsible for the inherent colour of a molecule. Contrary, chromogens are substances that can develop a colour under certain circumstances or chemical reactions. These chromogenic agents attach to the tooth surface by either electrostatic or van der Waals forces for longer periods of time and by hydrophobic effects, hydrogen bonds and dipole forces for shorter periods of time. The occurrence of these pigmentations can be further classified into N1, which is the colour of chromogen similar to that of a tooth by tea, coffee and wine or bacterial products, N2, stains which are bonded to tooth surface and change the colour later, and N3, indirect stains which are initially colourless pre-chromogens which carry the chemical reaction within them to convert to a chromophore later. Examples are fluoride or chlorhexidine [1].

There is a variety of classifications of dental stains, mainly they are categorized into "extrinsic", "intrinsic" and "internalized" stains based on their location [8]. The colour of teeth as perceived by the human eye is influences by several factors. These include the tooth location, its position among the tooth groups (as premolar- and molar teeth are darker compared to incisor teeth), the age of the patient as younger patients tend to have lighter teeth compared to elderly patients. Additionally, the quality of incident and referred light and the thickness of enamel and dentin also contribute to a certain tooth colour [19].

## 2.2 Extrinsic Stains

Extrinsic stains refer to discolorations located on the outer enamel surface of teeth, they can be removed by a scratch test [4, 5]. These dental stains can result from various factors including enamel defects, poor oral hygiene, and microscopic defects, where stain causing substances accumulate. Additional reduced salivation or xerostomia can also contribute to dental staining, as salivation plays an important role in rinsing food debris and their by-products away. Other factors and main known by the population are foods and beverages with high amounts of tannins or polyphenols, such in coffee, tea, red or foods like berries. As well tobacco in any kind of consumption manner leads to brownish discoloration of teeth. Moreover the intake of chlorhexidine containing mouth washes, medications, chromogenic compounds or metallic compounds are reasons of discoloration of teeth [21].

## 2.3 Intrinsic Stains

Intrinsic stains are found in the internal surface of teeth, they are incorporated into the tooth structure, for example during the tooth formation process in young children. They can't be removed by mechanical prophylactic treatments regimes or regular dentifrices [21]. The defects of intrinsic discoloration are in the deeper enamel or dentin layer, and cannot be removed by a scratch test [21]. Intrinsic discolorations have a different aetiological factor such as hereditary disorders which affect the tooth formation including amelogenesis imperfecta, dentinogenesis imperfecta, dental dysplasia and many other tooth formation anomalies [1, 4]. Medications that are leading to intrinsic tooth discoloration are tetracycline-based medications. These are chelating calcium ions diffusing into the enamel and dentin and incorporate into the inorganic hydroxyapatite [4, 5, 6]. They appear under ultraviolet (UV) light as yellow and at daylight turning into a bluish-greyish colour [21]. Additional factors contributing to intrinsic tooth discoloration are traumata in un-erupted and erupted teeth, as well as intrapulpal haemorrhages, infections, dental materials such as amalgam restorations, nutritional deficiencies or excessive fluoride intake termed as "fluorosis" [19, 21]. Intrinsic stains are divided into local and systemic factors. Tetracycline stains are related to systemic causes. Contrary pulp necrosis, intrapulpal haemorrhages, remnants of tissue in the pulp chamber after root canal treatments related to local factors [4].

## 2.4 Internalized Stains

Lastly, internalized stains are caused by either structural defects or enamel porosity and subsequent incorporation of extrinsic stains by the entry of chromogenic bacteria to enamel and dentin, leading to discoloration [19, 21]. Internalized stains can be either developmental or acquired, examples for developmental defects are enamel hypoplasia or hypocalcification due to fluorosis [21]. Acquired defects are caused by tooth wear or gingival recession, leading to the progressive loss, or thinning of enamel and following shining through of dentin or due to physical trauma. Another recognizable acquired internalized stain, is the cause of dental caries as this clinical condition shows in early stages a white spot because of the enamel porosity and become brown-black in colour due to exogenous factors [19, 21].


***Figure 1: Examples of tooth staining.*** *Extrinsic staining examples: A. Smoking, B. Wine stain, C. Food stain. Intrinsic staining examples: D. Age yellowing, E. Decay, F. Orthodontic white spot lesion, G. Mild fluorosis, H. Amalgam restoration, I. Tetracycline stain, J. Genetic (amelogenesis imperfecta), K. and non-vital colouring. (Clifton M. Carey, 2014)*

# 3 Healthy and Sound Tooth Structures

## 3.1 Enamel

To fully comprehend the bleaching process, procedures, and adverse effects, it is essential to mention the general understanding about the anatomy of the healthy tooth structure and its additional structures of the oral cavity. The human teeth consist of the most outer layer called enamel, formatted by a process called amelogenesis, as the enamel producing cells are ameloblasts [22]. Enamel is the hardest substance found in the human body and covers the entire tooth crown of each individual tooth with an average thickness of two to three millimetres and can vary in size and thickness depending on the tooth class [22]. Chemically, enamel is made up from a mineralized crystalline structure called hydroxyapatite with the chemical formula $Ca_5(PO_4)_3(OH)$ [22]. This highly organized mineral tissue contains inorganic components such like calcium phosphate and organic components such as matrix proteins and water. Within the mineral tissue structure there are millions of hydroxyapatite crystallites called enamel rods or enamel prisms [19, 22]. These enamel rods have an elongated hexagonal shape and vary in size and shape. Due to its composition and structure, the enamel is a very rigid and hard tooth structure making the tooth resistant to fractures [22]. Although Enamel is a rigid hard structure, it is permeable for certain ions and molecules, be the route of structural units such as rod sheaths, enamel cracks or through the small intercrystalline spaces [22]. Enamel rods become important when talking about bleaching procedures as they give the tooth the strength but also creates a passage of permeability of the tooth for certain ions and molecules such as bleaching agents which can penetrate the enamel structure [19].

## 3.2 Pulp-Dentin Complex

Dentin and enamel are two structures that can be clearly distinguished by the dentin-enamel junction (DEJ). Other than enamel, dentin has a more organic component, mainly proteins (collagen), bone and a less mineralized component, this makes the dentin structure softer and more flexible, but remains strong [22]. The dentin remains in close contact with the pulp, and both are derived from embryogenic mesodermal origin during tooth formation; together they form the pulp-dentin complex and therefore considered as a single unit [22]. Dentin can be formed throughout life and has the ability to respond to physiological and pathological stimuli [22]. Additionally, the two structures can communicate with each other through enamel spindles, which act as pain receptors, mainly in procedure in enamel [22]. The pulp comprises three main compartments, the nerve, arteriole, and venule keeping the tooth vital [22]. These structures are important in terms of pain perception and hydrodynamic theory in relation to the adverse effects of bleaching. The teeth are connected by the fifth cranial nerve, the trigeminal nerve (TN), which in turn is divided into three further branches: the ophthalmic nerve (CNV 1), the maxillary nerve (CNV 2) and the mandibular nerve (CNV3) [23]. Each nerve further branches into the interior dental nerve plexus and enters through the apical foramen into the pulp cavity The sensory trigeminal afferent nerve branches then terminate as free nerve endings to the odontoblasts located in the periphery of the pulp [22].

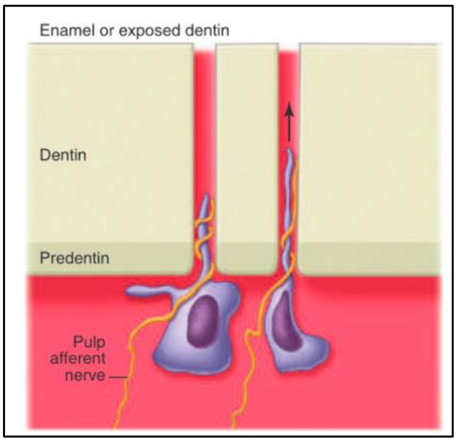


*Figure 2: Stimuli that induce rapid fluid movements in dentinal tubules distort odontoblasts and afferent nerves (arrow), leading to a sensation of pain. Many operative procedures such as cutting or air-drying induce rapid fluid movement. (Ritter AV., 2019).*

The extension of the odontoblasts, the odontoblastic cell processes, continues into the dentinal tubules, which are fluid-filled tubes [22, 23]. The fluid inside the tubules is composed of transudate of water, matrix proteins and mineral ions [22, 23]. The sensory nerve fibres for pain conduction are divided into A- and C-fibres (A-beta and A-delta fibres, 90% correspond to A-delta fibres) [23]. The myelinated A-delta fibres nerve fibres are small in diameter and responsible for producing fast, sharp and slightly localized pain transmitted to the thalamus [23]. These fibres are located at the border between the pulp and the dentin. On the other hand, C-fibres are unmyelinated and produce slow pain, characterized by dull, aching pain, transmitted to the thalamus via modulating interneurons, and located in the core of the pulp [23]. According to the hydrodynamic theory, the vital dental pulp constantly under a slight positive pressure, which leads to fluid flow towards the outer surface. When a stimulus occurs (cutting enamel, hypertonic solutions, acids), it triggers a rapid movement of tubular fluid within the dentinal tubules, resulting in a nerve depolarization and the activation of A-delta nerve fibre endings [22, 24]. This is one theory becomes fundamental later explaining bleaching sensitivity [24].

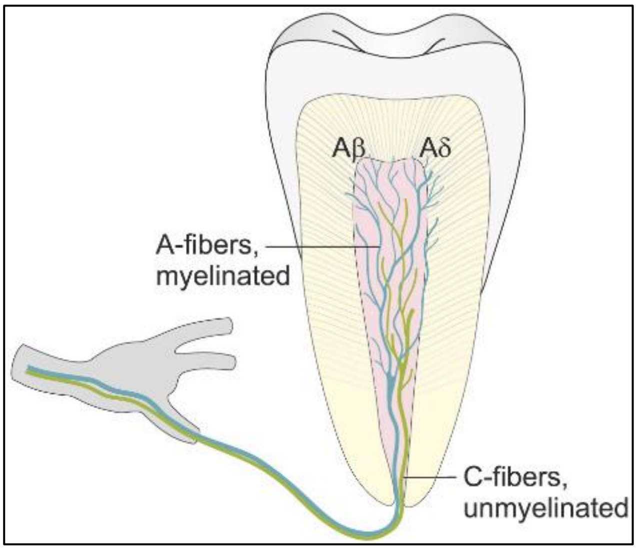


*Figure 3: Illustration showing the distribution of intradental A- and C-fibres. Unmyelinated C-fibres are located in the pulp proper, whereas myelinated A-fibres are extensively distributed in the pulp dentin border, penetrating the inner part of dentin (Närhi M. et al., 2016).*

## 3.3 Periodontium and Alveolar Bone

The periodontium, is made up of the gingiva, periodontal ligaments, cementum and alveolar bone, which together form a functional unit to hold the teeth in place [22, 26]. Different types of mucosa line the oral cavity. The masticatory mucosa covers the gingiva and hard palate. The specialized mucosa is found on the dorsum of the tongue, finally the lining mucosa covers the lips, soft palate, cheeks and oropharynx [22, 26].

Besides the hard tooth structures, the gingiva is an important structure to be discussed regarding tooth bleaching and side effects. The gingiva covers the alveolar bone and tooth root until the level of the cement-enamel junction (CEJ), its primary function is the protection against mechanical and microbial damage [22, 26]. It can be divided into three anatomical areas: the marginal gingiva, the attached gingiva and the interdental gingiva, separated from the mucogingival junction (MGJ) [26]. In addition, the gingival crevice is a shallow, V-shaped crevice and an important clinical landmark for assessing the periodontal status of dental patients [26]. It contains the gingival crevicular fluid (GCF), which is an exudate composed of connective tissue, epithelium, inflammatory cells, serum, microbes, and biomechanical factors. It's functions are to clean material from the sulcus and improve the epithelial adhesion [26]. It also has antimicrobial properties and defends the gingiva through antibody action, additionally it's characteristic that it increases in volume in certain oral inflammatory conditions such like gingivitis [26, 27]. As mentioned before the periodontium is composed of different structures acting as one single unit, best seen in the gingival epithelium structure and function [26]. The gingival epithelium consists of stratified squamous epithelium and is divided into three distinct areas: the oral epithelium, the sulcular epithelium, and the junctional epithelium [8, 26]. The oral epithelium is composed of keratinized epithelium, with the fundamental cell type being the keratinocyte. Its main function is to form a barrier that protects the stratum basale from physical and chemical damage, including the oxygen production in the oxidation reaction during bleaching with hydrogen peroxide ($H_2O_2$) [8, 26]. The oral epithelium responds to infection by signalling further host responses and cell signalling events, which then alter cell proliferation, differentiation, and apoptosis mechanisms, as well as tissue haemostasis [26]. In addition to protection, the oral epithelium also interconnects keratinocytes through desmosomes, allowing ions and molecules to pass from one cell to another [26].

Finally, the junctional epithelium is a non-keratinized barrier against plaque-inducing bacteria. It allows access of gingival fluid and inflammatory cells to the gingival margin [26]. The epithelium contains various non-keratinocytes, including Langerhans cells, Merkel cells, and Melanocytes [26]. Langerhans cells are unevenly distributed, with the largest number found in the oral epithelium and decreasing in number towards the sulcular epithelium, being absent in the junctional epithelium [26]. These dendritic cells belong to the mononuclear phagocyte system and play a fundamental role in immune reactions [26]. Merkel cells, located in the deeper layers of the epithelium and connected to nerve fibres, play an important role as tactile sensors. Lastly, melanocytes which synthesize melanin are responsible for the normal pigmentation of the gingiva and skin in human beings, they are located in the stratum basale [26]. Beneath the stratified squamous epithelium lies the connective tissue known as the lamina propria which can be further divided into two distinct layers: the papillary layer and the reticular layer. The lamina propria contains fibres (elastic, reticular, collagen-/ gingival fibres), fibroblasts (connective tissue forming cells), blood vessels nerves and matrix. Gingival fibres function as bracing the marginal gingiva against the tooth and providing rigidity [26].

The second component of the periodontium are the periodontal ligaments, which are a connective tissue compartments that surround the tooth and connect it to the inner wall of the alveolar bone [26]. These periodontal fibres are arranged in bundles and insert into the cement and alveolar bone in different directions [26]. The terminal ends are called Sharpey fibres [26]. Besides attaching the tooth to the alveolar socket and maintaining its position, periodontal ligaments also provide physical protection against mechanical forces [26]. Furthermore, they play a role in the formation and remodelling of cementum and alveolar bone [26]. Additionally, they have a nutritional function as they supply the alveolar bone, cementum, and gingiva through blood vessels. Moreover, they are supplied by sensory nerve fibres that transmit tactile, pressure, and pain signals to the trigeminal nerve pathway [26].

Root cementum is the third structure found in the Periodontium. It is made from calcified avascular mesenchymal tissue and forms the outer coverage of the anatomic root [26]. The root cementum is composed of two types of collagen fibres: extrinsic (Sharpey-) fibres and intrinsic fibres. Extrinsic Sharpey fibres, which are part of the periodontal fibres, are composed of 90% type I collagen and are formed by fibroblasts. On the other hand, the intrinsic fibres are formed by cementoblasts and belong to the cementum matrix [26]. There are two types of cementum: primary (acellular) cementum, which forms before the tooth reaches the occlusal plane, and secondary (cellular) cementum, which forms after the tooth reaches the occlusal plane [26]. The first type of cementum, known as acellular cementum, does not contain any incorporated cells. The second type, cellular cementum, contains cementoblasts and is less calcified.

The alveolar bone is the final supportive structure of teeth and the periodontium. The alveolar process is a structure in the maxilla and mandible that supports the tooth sockets, it is responsible keeping the teeth in place in the bone [26]. The bone is composed of two types of bone: compact cortical bone and spongy bone [26]. The structure of the alveolar bone is made up of two-thirds inorganic matter, including minerals such as calcium, phosphate, hydroxyl carbonate, citrate, ions, and fluoride, and one-third organic matrix [26]. Cellular compartments such as osteoblasts and osteoclasts function in the continuous exchange of remodelling processes [26]. The blood supply to the teeth is provided by penetrating vessels of the alveolar bone, which originate from the superior and inferior alveolar arteries [26].

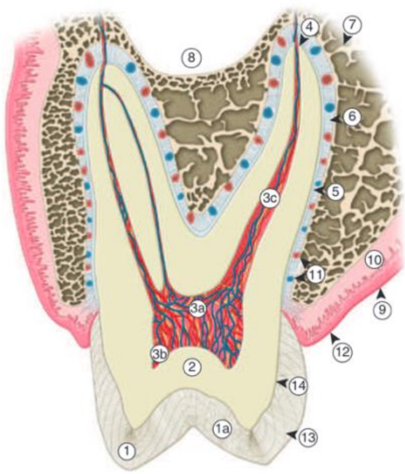


*Figure 4: Cross section of the maxillary molar and its supporting structures. 1, Enamel; 1a, gnarled enamel; 2, dentin; 3a, pulp chamber; 3b, pulp horn; 3c pulp canal; 4, apical foramen; 5, cementum; 6, periodontal fibres in periodontal ligament; 7 alveolar bone; 8, maxillary sinus; 9, mucosa; 10, submucosa; 11 blood vessels; 12, gingiva; 13, lines of Retzius; 14, dentinoenamel junction (DEJ).*
*(Ritter AV., 2019).*

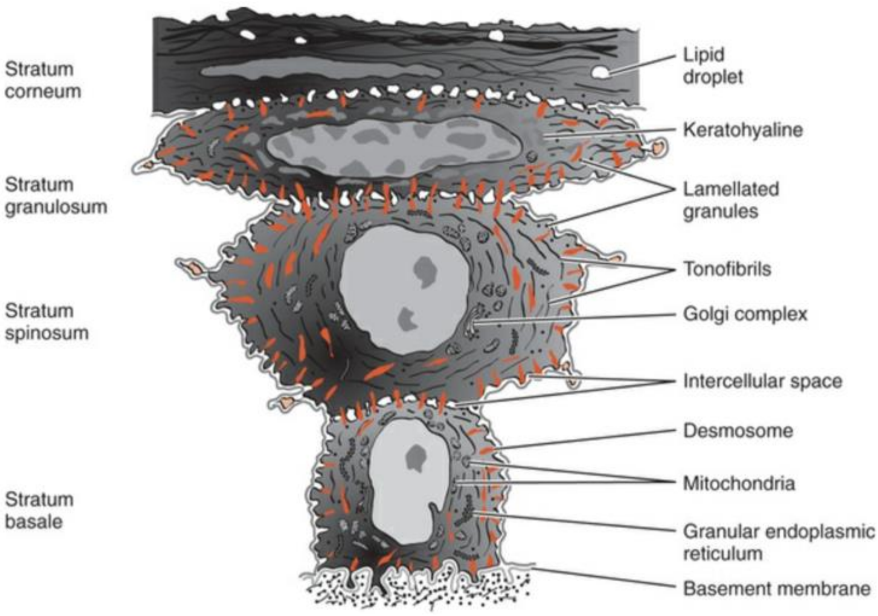


*Figure 5: Diagram showing representative cells from the various layers of stratified squamous epithelium as seen by electron microscopy (Modified from Weinstock A: In Ham AW: Histology, ed.7 Philadelphia 1974, Lippincott.), (Newman Takei, Klokkevold, Perry, 2015)*

# 4 Bleaching Mechanisms

## 4.1 Chemical Oxidation Reaction

Before using any bleaching agent or procedure, it is essential to have a thorough understanding of the bleaching mechanism. This knowledge will enable the dental professional to make an informed decision about which bleaching agent to use on a patient or to provide the correct instructions for home whitening in relation to the different types of tooth stains.

The bleaching mechanism can be divided into three main phases. The first phase is penetration of the bleaching agent into the enamel and dentin structure, followed by the second phase the interaction of the bleaching agent with the stain molecules and the third phase is the modification of the light of the tooth structure in a visible spectrum [15, 28].

As mentioned, the dental structures of enamel and dentin are known to be highly permeable to liquids and certain molecules [15]. As bleaching agents (especially hydrogen peroxide) are strong oxidizing agents and have a low molecular weight, they can easily penetrate enamel and dentin by diffusion [1, 10, 12, 16, 17, 19, 29, 30]. Thus, the oxidation reaction of hydrogen peroxide or carbamide peroxide decomposes it into oxygen, water and free radicals [5, 9, 10, 12, 19, 31]. The free radicals (hydroxyl radicals, perhydroxyl radicals, perhydroxyl anions or superoxide anions) are unstable and bind to molecules to regain stability [3, 10].

The released oxygen and reactive free radicals break down the double bonds of the long carbon chains of organic chromophores into smaller molecules until the light is no longer or less absorbed in the visible light spectrum, resulting in the perception of whiter teeth [3, 5, 9, 10, 12, 15, 19, 31, 32]. On the other hand, inorganic metallic ions are not oxidized and remain coloured in the tooth structure [9].


*Figure 6: Oxidation reaction of bleaching with peroxide bleaching gel. Hydrogen peroxide breaks down to water and numerous by-products including molecular oxygen, oxygen ions, hydrogen ions and free radicals. Breakdown of large, dark colour molecules to ultra-small white molecules. Bleaching factor free radicals break the chromophore bonds of large colour molecules, resulting in tiny molecules with no chromophore bonds. With no chromophore bonds to absorb light, these tiny molecules are white. (Dr. Rod Kurthy, 2016)*

## 4.2 Accelerating Mechanisms

Electromagnetic radiation (ER) is perceived by human as visible light. The visible spectrum of light ranges from red (longer wavelengths between 700 and 750 nanometre) through different colour until violet (shorter wavelength 390 to 400 nanometre). The electromagnetic radiation is delivered in packages of energy which are photons Infrared light is electromagnetic radiation with longer wavelength (lower frequency) and is not visible by the eye. Ultraviolet light is considered to be ionizing, they have shorter wavelength (higher frequency) and the photons carry more energy, being non-visible too [13, 22, 33]. The addition of light activation systems, such as light or laser are generating may accelerate the oxidation reaction of bleaching agents due to the thermocatalytic effect. Regarding the light, different illuminating modes have different wavelengths and power intensities subsequently producing different thermal emissions. The light projected onto bleaching agents is absorbed and induces generation of heat, peroxides may subsequently diffuse faster into dental structures and chemical reactions take place more rapidly. A temperature increases of 10°C doubles the factor of decomposition reaction speed. Light seems to be a catalyst and may increase the diffusion and breakdown of bleaching products and increase release of reactive oxygen species (ROS) [13, 33–37]. Tooth bleaching using 35% hydrogen peroxide and heat or light application in the dental office is the most popular bleaching treatment [1, 13]. However, research indicates that there is a controverse of accelerating systems such as light or laser regarding bleaching efficacy. The efficacy of bleaching still relies on the significant factor's concentration of the bleaching agent, application time and duration of bleaching regimes. Some resources claim that neither risk or efficacy was influenced by the use of light, some others show an improvement using light [6, 36, 38, 39]. Additionally, the heat generation in the pulp is leading to great concern about the safety of light activation sources. Pulps may suffer from irreparable damage because of increase in pulpal temperature. Whereas there is no exact limit of pulpal temperature, some sources state that histopathological changes in pulp tissue occur when the temperature exceeds 5.6°C. Other studies say that 42°C for one minute is a critical temperature and again others say 8.9 to 14.7°C leads to no pulpal pathology. There is no agreement for a critical temperature, nevertheless, intrapulpal temperature increase of 5.5°C regarded as a threshold and should not be exceeded to avoid pulp damage. As well post treatment sensitivity is higher when bleaching is combined with thermal activation [36, 40]. Throughout this chapter, some light and laser sources are briefly explained regarding their functioning principle and efficacy as well the occurrence of potential side effects.

By far the most common light source is the light emitted diode (LED) light. The blue light ranges between 440 to 490 nm and the high energy photons can stimulate the HP molecule. A great advantage is no to minor side effects due to heat generation, this light does not produce heat above 5.5°C. It is found to be effective and save in the use of dental bleaching [1, 13, 38, 41, 42]. A similar LED light source is the violet light. It is believed to enhance the efficacy of bleaching treatments with 17.5% hydrogen peroxide bleaching gel. The violet light ranges between 405 to 410 nm and carries more energy compared to blue LED light [41]. This wavelength coincides with the absorption peak of pigmented molecules and result in a selective interaction with the breakdown of molecules into smaller colourless compounds. This is leading to the use of violet LED light without any bleaching material. Violet light has a lower penetration ability and is only restricted to the enamel surface [39, 41]. Due to the lower penetration, lesser molecule alteration and lesser depth penetration pulp health can be preserved, and lesser tooth sensitivity is experienced. With the potential to be used alone, this could be an alternative for patient who experience low thresholds of pain sensitivity, because the photons can break down pigments even at low heat [39, 41]. Violet light should not be mismatched with Ultraviolet light (UV). This light ranges in a spectrum of 100 to 380 nm. Because this light is not absorbed by water or hydroxyapatite it can easily penetrate through deeper layers of tooth tissues and as very good photobleaching properties. Nevertheless, the prolonged use leads to undesirable adverse effects such as cellular damage, immune suppression, increased risk of skin cancer and photoaging. As well soft tissue damage and pulp heating, make this kind of light impossible to use in dental bleaching procedures [34, 35, 41].

Lasers are an acronym of light amplification by stimulated emission of radiation. Its effect is shown on specific target areas because of its monochromatic character. The elements that determine reaction with the target area depends on energy emitted (nm), power density of the beam and temporal characteristics of beam energy such as continuous or pulsed delivery [13, 22, 35, 37, 42]. The laser target interaction in bleaching mechanisms take place in the bleaching gel, which can be increased when photocatalysts or photosensitizers are added and in the tooth structures [36]. Especially in low-intensity red diode laser (660 nm) and green coloured bleaching gel provides a better absorption of diode laser and less transmission toward pulp chamber, subsequently the coloured bleaching gel leads to a temperature increase of not more than 2.3°. Diode lasers are ranging between 784 to 980 nm wavelength, they are well absorbed by tissues. Studies are not similar opinion about heat generation, as some state they do not produce heat and others say there is an increased temperature change in the pulp. The reason could be the different wavelength used among the lasers and different studies, but the tooth sensitivity is less compared to LED lasers. The only approved diode laser by the Food and Drug Administration (FDA) is the 980 nm diode laser, diode laser with 830 nm generate a temperature increase below the critical 5.5°C [31, 36, 40, 42]. Carbon dioxide ($CO_2$) laser range in much higher wavelength between 9.300 to 10.300 nm, the former is mainly used for caries prevention or soft tissue surgery. The light lies in the infrared spectrum. Due to its temperature increase of 13.1 to 22.3 °C, this laser is not approved by the American Dental Association (ADA) [36]. Similar wavelength shows the Nd: YAG (1.064 nm) laser and the Er: YAG laser (2.940 nm), they are not approved either because of the increased temperature generation and lack of control studies which can potentially lead to ablation of the tooth substance. Concluding, contradictory results showed, that there is a limited number of studies among light and laser, thereby the comparison is difficult. Depending on different wavelengths, initiating photooxidation of chromophores differs very widely. Furthermore, the wavelength must coincide with the absorption peak of chromophores and photocatalyst of the bleaching gel. Among different manufacturer bleaching gels have different absorption peaks, which makes it difficult to get evidence about the expressive utilization. As well, the heterogenicity among the heating temperatures is influenced by the mentioned factors and the power setting of light and laser systems. Hence, bleaching gels have to be manufactured according specific wavelength to be actively used in dental practice [36]. Concluding, low- and high-power diode laser, as well as violet light with the use of 35% hydrogen peroxide does not result in enhanced bleaching effect. Additional due to the limited evidence it is stated there is no improvement of bleaching effectiveness with the use of light seen yet [6, 34, 36, 43]. The colour of the gel may influence the final temperature, as different light sources produce different wavelength and have different absorption potential. Near infrared light only reduced inflammatory pulpal response but did not increase the bleaching efficiency, they can be rather used as preventive measurement to treat bleaching sensitivity [36]. Light activation of hydrogen peroxide therefor showed to not be beneficial for bleaching effect in regard of colour change. The heat generation in the pulp plays a significant factor in the use of light or laser acceleration systems and can cause potential pulp damage [39].

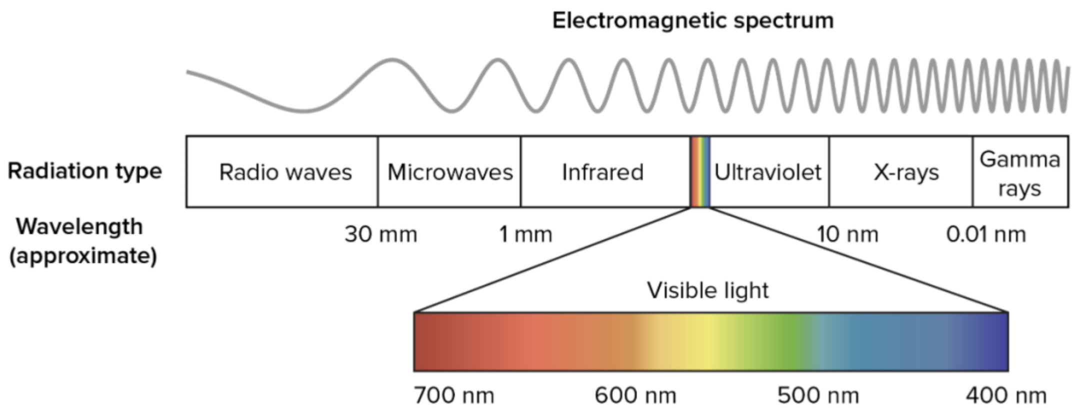


*Figure 7: Image modified from "Electromagnetic spectrum", by inductiveload (CC BY-SA 3.0), and "EM spectrum" by Philip Ronan (CC BY-SA 3.0), (Kahn Academy, 2024)*

# 5 Bleaching Agents

Since a long time, different bleaching agents are present on the market, the most common hydrogen peroxide, carbamide peroxide and sodium perborate are explained further in detail. As these bleaching agents differ in concentrations and composition, thus they are used for different bleaching approaches.

## 5.1 Hydrogen Peroxide ($H_2O_2$)

The most common bleaching agent is hydrogen Peroxide ($H_2O_2$), which is a colourless liquid and more viscous than water with a slightly acidic pH value [1, 15]. It has a relatively low molecular weight and can therefore easily penetrate enamel and dentin [5, 17]. The concentrations of hydrogen peroxide range between 5% to 35%, with 30% to 35% concentration based solutions being the most common used in external tooth bleaching, mainly in the "in-office" bleaching techniques [15, 28]. Because of the high concentration present, more oxidative radicals are able to reach the dental pulp, causing possible tooth sensitivity after bleaching and also being able to cause alterations in hard dental tissue structures [28, 44]. Some studies showed that a lower pH (increased acidity between 3.67 to 6.53) of a bleaching agent showed an increased bleaching effect, because the formation of perhydroxyl anions is influenced by the pH. The lower the pH value the more free radical species are generated and increase in bleaching effect [45].

Hydrogen peroxide is a strong oxidizing agent, and produces oxygen and reactive perhydroxide anions, thereby breaking down double bonds of carbon. It is highly reactive in aqueous conditions and must be handled with care, also because the unstable solution can explode in a warm environment and should therefore be stored in a refrigerator. As well, hydrogen peroxide is a caustic agent, able to corrode organic tissue and will burn tissue on contact [17]. Especially extremes of pH value showed to have stronger side effects on soft tissues [28].

## 5.2 Carbamide Peroxide ($CH_6N_2O_3$)

Another frequently used bleaching agent is carbamide peroxide ($CH_6N_2O_3$), which is a white crystalline, frequently used in the "at-home" bleaching techniques with an average concentration of 10% for 4-8 hours [14, 15]. The concentrations range from 3% to 35% [15, 28]. Ten percent of carbamide peroxide has an average pH value of 5 to 6.5, being slightly acidic [15, 28]. As well as hydrogen peroxide, it releases oxygen in contact with water. The breakdown of carbamide peroxide differs from hydrogen peroxide, as 10% carbamide peroxide breaks down into 3.35% hydrogen peroxide and 6.65% urea, subsequently the urea further breaks down into water and ammonia. Ammonia has the ability to increase the pH of the solution [15, 28]. Urea has a proteolytic effect (hydrolysis of proteins and peptides) and therefor affecting the efficacy of tooth whitening [28]. Additionally, many carbamide peroxide solutions are delivered with containing carbopol (water soluble resin) or glycerine, these ingredients slow down and prolong the release of active peroxides [1, 15, 28]. Moreover, carbamide peroxide is associated to have the ability to generate alterations of dental hard tissue structure [28].

## 5.3 Sodium Perborate ($NaBO_3$)

Sodium Perborate ($NaBO_3$) is an odourless, water soluble chemical oxidation agent delivered in powder form [15, 28]. Since 1907 it is popular in whitening washing agents, washing powders or other washing detergents [15]. It is stable in a dry aggregate state, in contact with water or warm air, it breaks down to form sodium metaborate, hydrogen peroxide and oxygen [15, 28]. Corresponding concentrations are 95% perborate and 9.9% oxygen, when sodium

perborate is mixed with distilled water (2mg/ 1ml), it is equivalent to 16.3% hydrogen peroxide and therefor more easily controlled [15, 28]. The pH value depends on the amount of hydrogen peroxide released in the chemical reaction. Whitening efficacy depends on different oxygen contents. Available oxygen contents are monohydrate, trihydrate and tetrahydrate [15, 28]. Sodium perborate is most often used in internal bleaching of pulp less teeth [28].
The use of alternative bleaching agents such as chlorine dioxide (ClO2), sodium chloride or peroxy-monosulphate are not present in the todays use and literature, thus the focusing is increasingly on standardized and clinically validated methods by using the mentioned bleaching agents [28].

### 5.4 Ozone ($O_3$)

An alternative in bleaching mechanisms is the use of Ozone ($O_3$), which is already applied in various types of dental treatments. Ozone is a natural gas formed by 3 oxygen atoms and can promote tissue repair and aids in healing processes. It is already used in the dental field to treat infections caused by viruses, protozoa, fungi, or bacteria. Ozone is also used in the treatment of oral ulcers, gingivitis or periodontitis, the prevention of dental caries, treatments of temporomandibular disorders (TMD) or halitosis [46, 47]. Due to its high oxidation power, as it has more energy compared to atmospheric oxygen it is introduced in dental bleaching too [46]. The unstable gas, releases oxygen by three mechanisms, the bonding-, substitution- and cleavage mechanism, thereby oxidizing organic chromophores like the conventional used bleaching agents. Hence ozone is an effective alternative treatment modality in treating tetracycline-based dental stains [46, 47]. Nevertheless, a study compared teeth sensitivity of ozone with the additional application of hydrogen peroxide. Results showed, the application of ozone prior hydrogen peroxide treatment results in an intensifying oxidative power and generated a greater contact between the bleaching agent and odontoblastic processes leading to an increased teeth sensitivity. Whereas the application of ozone after hydrogen peroxide application results in less teeth sensitivity, due to the analgesic and anti-inflammatory properties able to restrict inflammatory pathways occurring in the dental pulp [46]. Even so, ozone therapy is not having superior effects on bleaching efficacy compared to conventional bleaching methods and agents [46].

## 6 Dental Tooth Bleaching Techniques

### 6.1 Vital Tooth Bleaching Technique

The dental tooth bleaching techniques can be divided broadly into “vital-“ and “non-vital” bleaching techniques [4]. The former vital tooth bleaching techniques can be classified into "in-office" bleaching, secondly "at-home" bleaching and bleaching with "over-the-counter" products (OTC) [4, 16, 48]. Preliminary, it is also important to mention, that three main aspects determine bleaching efficacy and effectiveness. First the concentration of peroxide, as the higher the concentration, the fewer treatment needed to achieve desired shade and second the amount of time the bleaching agent is applied onto the tooth surface [13].

### 6.1.1 In-Office Tooth Bleaching Technique

The "in-office" bleaching or so called "power bleaching" is a minimal invasive procedure carried out in the dental chair and usually requires high concentrations of hydrogen peroxide [3, 9, 13]. The bleaching agent hydrogen peroxide ranges used in the in-office technique are concentrations between 15% to 40% and can be delivered in different systems such as base and catalyst, ready mixed or power and liquid combination, which must be mixed by a dental professional [3–5, 13, 29, 30, 49, 50]. Thus, the bleaching process only takes 30 to 60 minutes and whitening can already achieved after one treatment appointment, respectively of the already mentioned determining factors [13]. Prior application of the bleaching agents, a protection by a (liquid) rubber dam of the oral soft tissues is applied to prevent soft tissue burns and the process is always supervised by a dental professional [3, 5, 30, 51]. Even so the current literature is controverse, further heat generation by activation with light or laser systems is increasingly used and may lead to a faster reaction. Subsequently this may lead to a faster breakdown of peroxides, and thus accelerate the whitening effect [3, 9, 13, 30]. The advantages of the in-office bleaching method include, that it is a quick method to achieve visible results, additionally it is a good treatment option for patients who lack in cooperation [13]. The disadvantages are due to the rapid process, increasing risk of adverse effects such as tooth sensitivity, gingival irritation (soft tissue burns or throat irritation), but they remain mainly reversible [3, 9]. Some studies highlight, that higher concentrations of hydrogen peroxide produce more oxidate radicals and thereby reaching the pulp and produce higher levels of bleaching sensitivity, compared to lower concentrations [44]. Even though, visible results are achieved quickly, the results are often unpredictable and the duration of application, as well as the duration of the overall treatment regimens remains difficult to predict. Monitoring of the patient is always required in this technique because of the increasing risk of side effects potentially occurring during the treatment [13]. The pH value of an bleaching agent also shows a significant influencing factor on adverse effects, as the bleaching agent with 30% Hydrogen peroxide based on a low pH value of 3.6 compared to a neutral based pH value of 7, showed less adverse effects but the same efficacy [30]. As well, gel based 35% hydrogen peroxide with additional calcium derivate resulted in less pulpal damage and sensitivity compared to the same concentration of hydrogen peroxide without calcium, this can be helpful in the management of pain when bleaching teeth in dental offices [30]. Special consideration should be taken also for patient with special clinical conditions such as gingival recession, abfraction lesions or erosions [13].

### 6.1.2 At-Home Bleaching technique

The at-home bleaching technique, is regarded as a safe and efficient method of tooth bleaching, by the fabrication of a customized dental bleaching tray and the self-application by the patient with additional supervision and recall appointments by the dentist [4, 30, 33, 34]. With this technique, the concentrations varying in much lower concentrations between 10% to 22% of carbamide peroxide and 3.5% to 8% with hydrogen peroxide, whereas 10% carbamide peroxide equals 3% hydrogen peroxide which is one tenth of the concentration used in-office bleaching [5, 12, 23, 45, 47– 49] . Usually, 10% carbamide peroxide should be applied for two to eight hours a day and 15% to 20% Carbamide peroxide for three to four hours per day for an overall period of two to six weeks for both, hydrogen peroxide and carbamide peroxide [13, 52]. The advantages of at-home bleaching is the self-administration by the patient (popular overnight), the less chair time in a dental office, the lower cost and fewer adverse effects due to the higher degree of safety [5, 51, 52]. Nevertheless, the adverse effects, an excessive use can cause tooth sensitivity too, especially in ill-fitting trays, which can leads to gingival irritations such like soft tissue burns, but these side effects are fewer compared to in-office bleaching [5, 51, 52]. An additional disadvantage is the mandatory patient compliance, which determines the colour change and the results depend on the patient wear time, therefore the outcome result can be less ideal compared to the patients expectation [5, 51, 52]. Thus, the prognosis is difficult to predict, but the colours remain stable between 1.0 to 1.25 years and the patient can bleach at their "own pace". [51, 52]. This method is described to be safe, effective, and cost-effective alternative compared to the in-office bleaching technique.

### 6.1.3 Over- the- Counter Whitening Products

Increased popularity in recent years and one of the fastest growing sector in the dental marked with a grow of 4% between 2017 and 2021 are "over-the-counter products" for dental whitening [11, 52, 54]. The purchased products show an attractive, cheap alternative. Thus they are sold directly to the consumer and can be applied without the professional supervision [11, 51, 54]. Concentrations of over-the-counter whitening products are ranging between 3% and 6% (hydrogen peroxide). In the meanwhile, the European Union banned the use of bleaching agents for sale in concentrations higher than six percent due to clinical safety purposes. Consequently, over-the-counter products are only available in concentrations of 0.1% in the European Union since 2012 [52, 54, 55]. The products come in a variety of forms for self-applications such as gum shields, paint-on products, dentifrices, pre-fabricated trays, varnishes, mouthwashes, tooth floss or chewing gums [9, 11, 51, 52, 54].

Dentifrices represent more than 50% of all over-the-counter whitening products, they contain higher amounts of regular detergents and abrasive systems for the mechanical removal of biofilm and extrinsic stains [9, 11, 54]. These include sodium bicarbonate, hydrated silica, calcium carbonate, dicalcium phosphate dihydrate, calcium pyrophosphate, alumina, nanohydroxyapatite and other. This insoluble particles have a higher hardness than stained particles [11]. I is important to mention the low to moderate abrasiveness measured by relative dentin abrasivity and relative enamel abrasivity values to prevent enamel and dentin surface alterations [11]. The advantages are the effective stain removal of extrinsic stains and plaque compared to regular toothpastes, their biocompatibility of sodium bicarbonate, which has an acid buffering capacity and a lower hardness value [11]. Drawbacks of these dentifrices include the little effect on intrinsic stain, and the little amount of hydrogen peroxide combined with a short exposure time on the teeth. This leads to questioning the whitening effect, as well the lack of knowledge of stain aetiology which can lead to several side effects [11]. Too high value abrasive systems can potentially damage the enamel surface of teeth, vice versa, a too low value can lead to the failure of removal of extrinsic stains and increase of staining of teeth [9]. As well, many tooth pastes claim to make teeth white, but they usually contain the ingredient "Blue Covarine", which is a blue dye intended to give the teeth a white colour by shifting the reflected colour from yellow into the blue region and let teeth appear whiter [9, 11].

Charcoal based products (dentifrices) showed an alternative to conventional products as they claim to be animal free products advertised with the words "detox" or "vegan" and promising whiter cleaner teeth or having a whitening effects [11]. Charcoal is an abrasive ingredient produced from carbon-rich materials such as shells, coconut shells, bamboo or wood [11]. A significant drawback is the abrasive characteristic of charcoal, they increase the surface roughness of enamel and leading to an increased biofilm accumulation and induce staining [11]. As they are claimed to be "vegan" or "detox" they often don't include the active ingredient fluoride which acts against caries risk, manufactures conclude to use normal toothpaste before [11]. As well, charcoal can have the ability to inactivate fluoride which has the initial capacity to remineralize dental hard tissues [11]. Currently there is no evidence, that these products are preventing caries or having a whitening effect [11].

Whitening mouth washes can be an attractive alternative too, they include components such like hydrogen peroxide in low concentrations between 1% to 4% (depending on country regulations) for a whitening effect as well as sodium hexametaphosphate and pyrophosphatases for controlling the formation of extrinsic stains [9, 11]. Other than dentifrices, they do not contain any abrasive systems. The user of such mouthwashes can benefit from these mouthwashes as the hydrogen peroxide included can promote a whitening effect [11]. Drawbacks of such products are the limited exposure time and penetration to the tooth, which is again questioning a visible effects of bleaching [11]. As well, a frequent or abusive use can lead to a greater damage to exposure dentin, because the low pH can have an erosive effect to the teeth [11].

Whitening stripes are by far the most effective over-the-counter whitening products and are used as an attractive alternative to the customized dental trays in professional bleaching [11, 54]. They are available in concentrations ranging between 0.1% to 15%, respectively different regulations and restrictions of these concentrations among various countries [11, 55]. The whitening stripes should be applied for 5 to 60 minutes, one to two times per day (depending on product manufacturer instructions) [11, 54]. Regarding the effectiveness, studies found that they are effective like at-home bleaching with carbamide peroxide tray treatment. Drawbacks of these products can be tooth sensitivity and gingival irritation due to the missing mucosal protection [11]. Other over-the-counter products are paint on gels with containing hydrogen peroxide or carbamide peroxide, ranging in a wide variety of concentrations, again depending on varying country regulations [11]. The market with these products started in the year 2000 and are sold as a low cost alternative to professional bleaching [11]. A significant disadvantage is the increased harmful effects on periodontal tissues such as the gingiva or gastroesophageal tracts, as the direct application of the gels on the teeth can come in contact with the oral mucosa very easily, as well as swallowing the agent [11].

Other products such as whitening tooth floss, chewing gum claim to prevent extrinsic stains, but there is no evidence of efficacy compared to other conventional products used for whitening [9, 11].

Especially over the counter products sold by the internet market, seem to be very attractive to people who seek whitening of teeth. They predict result which are often not possible to achieve, leading to false advertisement and expectations by the used. In this manner, many people buy products which often have no effect, spending money on unnecessary products. Instead, it is advisable for people who seek whiter teeth, to talk to their dentist and ask about risks and the safe use with over-the-counter products. Dentists are professionals who can provide evidence-based information to maintain patients’ oral health and safety.

## 6.2 Non-Vital Tooth Bleaching Technique

Non-vital tooth discoloration can occur because of dental trauma, necrotic pulp, intracoronal blood decomposition and haemorrhage or after regenerative endodontic procedures [28, 55, 56]. Thus discolorations often affect the (single) anterior teeth, therefore non-vital tooth bleaching techniques are a conservative, simple effective and low cost procedure to regain natural colour of the teeth [55, 56]. There are different non-vital tooth bleaching techniques including the "walking bleaching" technique, "thermocatalytic" technique and the "inside-out" technique.

Indications of bleaching pulp less teeth are discolorations of pulp chamber origin, discoloration not compliant to external bleaching or dentin discolorations. Contraindications are superficial enamel defects, defective enamel formation, severe loss of dentin due to pathologic clinical conditions, the presence of (interproximal) caries or proximal composite restorations unless they are replaced [28].


*Figure 8: (A) Discoloration as a result of trauma and subsequent treatment. The patient was involved in an accident that caused coronal fracture. Root canal treatment was performed, but gutta-percha and sealer were not completely removed from the pulp chamber. Additional discoloration factor was the defective leaking restoration. (B) Two appointments of walking bleach and placement of a new, well-sealed composite restored aesthetics (Mahmoud Torobinejad, Ashraf F. Fouad, Shahrokh Shabahang, 2021)*

### 6.2.1 Walking Bleaching technique

The most popular bleaching technique is the walking bleach technique, by sealing a mixture of sodium perborate with water, hydrogen peroxide or carbamide peroxide [5, 52, 55]. This mixture is placed into the pulp chamber and the cavity is closed with a temporary filling material, in repeated intervals this procedure is performed until the desired tooth colour is achieved [52, 55]. Generally, the mixture is placed every two to seven days and the number of applications depends on the degree of discoloration. Studies stated that 75% of regaining the desired colour can be achieved after one to two applications. [5, 28]. Regarding the composition and concentration, it is safe to start with a mixture of sodium perborate, which has a high pH value of 10 to 12 (alkaline) and a low concentration of 3% hydrogen peroxide instead of water and stepwise increase of the hydrogen peroxide concentration. This makes the procedure saver and the potential of major clinical changes such as soft tissue burns is decreased [5, 28]. This technique is considered to be saver compared to the thermocatalytic technique [5].

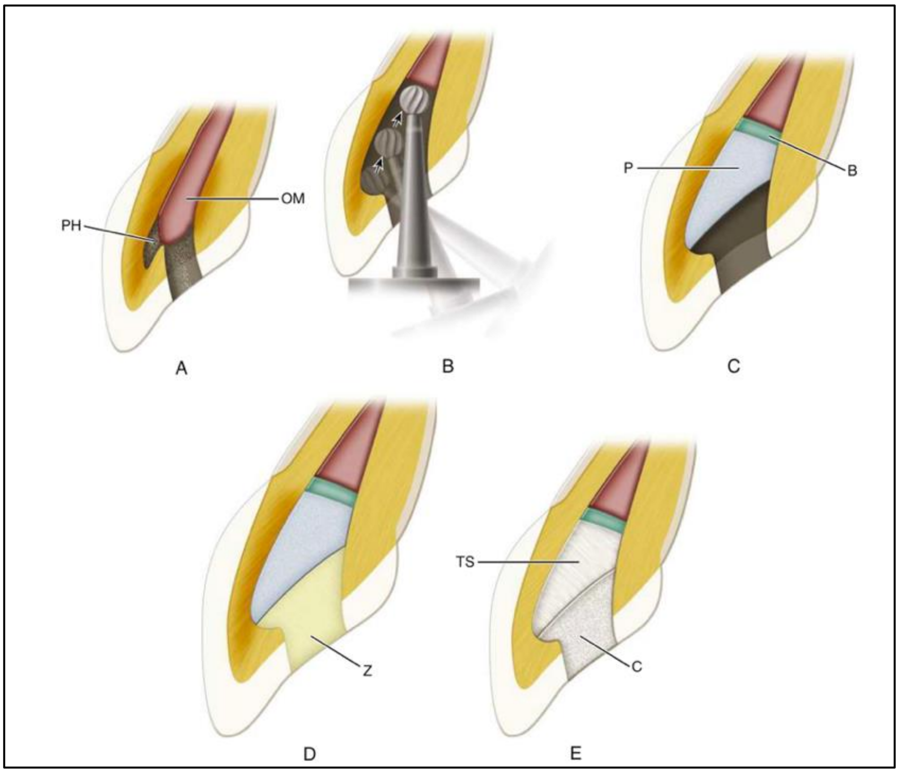


*Figure 9: Walking bleach. (A) Internal staining of dentin caused by remnants of obturating materials (OM) in the pulp chamber and by materials and tissue debris in the pulp horns (PH). (B) Coronal restoration is removed completely, access preparation is improved, and gutta-percha is removed apically to just below the cervical margin. Next, the pulp horns are cleaned with a round bur. (Shaving a thin layer of dentin from the facial wall is optional and may be attempted at later appointments if discoloration persists.) (C) An optional protective cement base (B) is placed over the gutta-percha, not extending above the cervical margin. After the removal of sealer remnants and materials from the chamber with solvents, a paste (P) composed of sodium perborate and water (mixed to the consistency of wet sand) is placed. The incisal area is undercut to retain the temporary restoration. (D) A thick mixture of a zinc oxide–eugenol–type temporary filling (Z) seals the access. (E) At a subsequent appointment, when the desired shade has been reached, a permanent restoration is placed. A suggested method is to fill the chamber with white temporary stopping (TS) or with light polycarboxylate or zinc phosphate base. Acid-etched composite (C) restores lingual access and extends into the pulp horns for retention and to support the incisal edge. (From Walton RE: Bleaching procedures for teeth with vital and nonvital pulps. In Levine N, editor: Current treatment in dental practice, Philadelphia, 1986, Saunders.),*
*(Mahmoud Torobinejad, Ashraf F. Fouad, Shahrokh Shabahang, 2021)*

### 6.2.2 Modified-Walking Bleaching Technique

The todays use of combination of sodium perborate and higher concentrations of hydrogen peroxide such as 30% with a pH value of two to three, is exemplified as the modified walking bleach technique [5, 52, 55]. The mechanism of this procedure is the same as the conventional walking bleaching technique. They are illustrated in the figure number nine.

### 6.2.3 Thermocatalytic Technique

The “thermocatalytic” bleaching or “non-vital power bleaching” technique requires a high concentration bleaching agent on a cotton pellet placed into the pulp chamber and additional activation of heat or light systems similar to vital power tooth bleaching technique [28, 52, 55]. The concentrations of hydrogen peroxide range from 30% to 35% which regard to high concentration bleaching agents. With the activation of light or heating systems the release of reactive oxygen species may be accelerated [55]. The temperature of the activation systems range about 50 °to 60° Celsius and is applied in a two to five minute with a subsequent cooldown cycle [52]. Thus, the application of protection of the oral soft tissues with a rubber dam is mandatory. The overall bleaching time is 15 to 20 minutes, after that the bleaching agent is removed and can be repeated if necessary [57].This is the least advisable non-vital bleaching method, due to the increased adverse effects. In the 1970s increased cases of external root resorptions characterised by the combined damage of periodontal- and root tissue were noted, due to the application of high concentration bleaching agents especially in combination with light or heating systems [5, 28, 55]. Today, intracoronal bleaching non-vital teeth is the third largest risk factor of external root resorption on maxillary incisors [58]. Therefor the placement of sealing agents such like calcium hydroxide as a biomechanical barrier is an important consideration prior non-vital tooth bleaching, as well as regular recall appointments to evaluate periodontal and pulp status [5, 28, 55].

### 6.2.4 Combined Technique

The “combined technique” or “inside-outside” technique first introduced by Settembrini 1997, is a combination of simultaneous internal non vital bleaching and the at-home bleaching technique with a custom fitted tray [52, 55]. Before starting the procedure, the patient gets a custom fitted vacuum fabricated tray. The seating and position are checked in the dental office, as the procedure requires application of the bleaching agents internally and externally. A mixture of sodium perborate with hydrogen peroxide is then placed into the cavity, whereas the cavity remains open during the bleaching process for a subsequent replacement of the bleaching agent [28, 57]. At home, the patient applies the custom fitted tray with a 10% carbamide peroxide bleaching agent on the tooth which is being bleached and wears it during the night. At the next day, the patient is removing the tray and cleans the tray and cavity [57]. A significant asset is the control over the bleaching effect and avoidance of overbleaching, shorter time of treatment time and exposure to the bleaching agent [55]. Controverse is the less number in appointments which is questionable, as the patient is advised to come to recall appointments every two to three days, to monitor the bleaching process, but definitely it is less chair time, compared to the walking bleaching technique [5, 55]. A significant drawback is the access cavity, which remains open during the bleaching regime, this leads to an increased risk of fractures or incorporation of food products and needs improved patient cooperation to clean the cavity regularly [55].

Concluding the walking technique is considered to be saver compared to the thermocatalytic technique because sodium perborate has a higher pH value compared to the thermocatalytic technique, where high concentrations of hydrogen peroxide with a lower pH value are used [5]. Nevertheless, the combined technique is a safer method compared to the walking bleaching technique, as the concentrations of bleaching agents are lower [55].

## 6.3 Macroabrasion & Microabrasion

Some intrinsic tooth discolorations cannot be effectively removed by oxidation agents. Some of them include mild tooth fluorosis, enamel hypoplasia, amelogenesis imperfecta, traumatic calcifications, molar incisor hypomineralization due to pre-eruptive damages or post-orthodontic treatment in permanent dentition [59, 60]. An effective treatment is the macroabrasion and microabrasion. Macroabrasion is a simple, low cost, efficient alternative to microabrasion. It is performed by using a fine tapered diamond bur or finishing bur to remove superficial stains or more pronounced deep intrinsic stains such in severe fluorosis [61, 62]. The use of a LED photopolymerization unit can be helpful to examine enamel surface stains and depth of the lesion. A clinician is using a high-speed turbine and with light pressure carefully removes superficial stains. Attention must be taken to avoid formation of cavities. Simultaneous irrigation and cooling are fundamental in this process and recommended. The cooling effectively prevents sensitivity when heat is produced during application of the bur on the tooth surface. As well, dehydrated teeth exaggerate appearance of white spots, this makes it difficult to differentiate actual defects and white spots from removed tooth substance. Subgingival margins and incisal angles are not involved in this procedure. One advantage is no need for full isolation required for this procedure. Macroabrasion technique can be done combined with microabrasion technique. Additional bleaching procedure and the application of biomimetic hydroxyapatite or Casein Phosphopeptide-amourphous Calcium Phosphate Nano-complexes (CPP-CAP), which has a remineralizing effect can be done too [61, 62].

Enamel microabrasion is the procedure to treat discoloration limited to the enamel surface in permanent teeth or in paediatric dentistry if eruption is sufficient. It includes the chemical-mechanical removal of thin layers of enamel and sub-superficial enamel by abrasive and acid-etch technique [59, 60, 63]. The main ingredient of the materials is a paste containing hydrochloric acid, sometimes the use of phosphoric acid is also possible. The hydrochloric acid concentration ranges between 6.6% to 16% in an aqueous solution. Additional ingredients are silicon carbide micro particles with 20-160 microns. This paste demineralizes layers of enamel and has an abrasive effect to remove the demineralizing enamel [19, 59, 60]. According the "Opalustre™ Enamel Micro-Abrasion Slurry", the procedure is done as followed. Initially, photographs should be taken, followed by the isolation of teeth. A layer of the material is applied to the teeth and by using a low-speed handpiece with a bristle cup with approximately 500 rotations per minute, the teeth are treated. Thereby light to medium pressure (similar to prophylaxis treatments) for approximately 60 seconds is applied. This procedure is done in a stepwise manner, repeatedly, the material is rinsed off, the teeth are evaluated if less than 0.2 mm is removed and can be repeated if necessary [63]. The duration of application and pressure needed differs among manufacturers and individual clinical cases. After that the rubber dam is removed and a final polishing procedure is done. The application of fluoride is recommended, for example with 2% sodium fluoride topical gel. During the microabrasion procedure the enamel appears lustrous, shiny or glass like and reflects and retracts light differently, this is known as the "abrasion effect" [60, 61]. An average enamel thickness reduction between 20 to 200 micrometres can be achieved. Depending on pressure applied, greater quantity of enamel can be removed [60].

A subsequent side effect is the increase in surface roughness and loss of surface enamel structure. The acid acts in deeper layers of enamel and reducing the microhardness until the superficial enamel layer. As well an alteration of enamel permeability can be seen too, and eroded enamel becomes more susceptible to wear [60, 63]. Due to the erosive effect, this leads to a thinner enamel and higher transmission through the tissues resulting in an increased visualization of dentin, the teeth appear darker, yellowish or reddish [19, 59, 61, 63]. Additional bleaching procedure can be done afterwards.

Regarding the roughness resulting after microabrasion, this can be reversed by the polishing and exposure to saliva. The enamel layers become less conducive to bacterial adhesion and colonization by Streptococcus mutans because the polishing products are incorporated to mineral matrix. Subsequent increase in microhardness is achieved as the simultaneous abrasion and erosion of enamel prisms compact the mineralized tissue within the organic area and replacing the outer layer of prism-free enamel with dense prism rich region [60]. Following bleaching procedures can be effective, as the microabraded teeth promote greater hydrogen peroxide penetration into the pulp chamber compared to bleaching without microabrasion procedure. Microabrasion procedure and following “at-home” bleaching is considered to be safe and 10% hydrogen peroxide is more effective compared to 4% hydrogen peroxide application. This combined technique of microabrasion and subsequent bleaching leads to more satisfaction in patients undergoing this procedure [61, 63].

The success of microabrasion technique is limited by several factors, such as depth of enamel alteration, concentration of acid used, duration of application and the characteristics of abrasive particle and pressure effect. In this regard, sometimes additional more invasive restorative treatments are required, such like composite resin or laminate veneers [19, 59, 60, 63]. The microabrasion technique is a proven cost-effective technique and no side effects after microabrasion such as gingival irritation or tooth sensitivity were recorded among the listed research papers. The macro- and microabrasion technique provides a positive outlook for patients who suffer from mild to severe intrinsic stains.

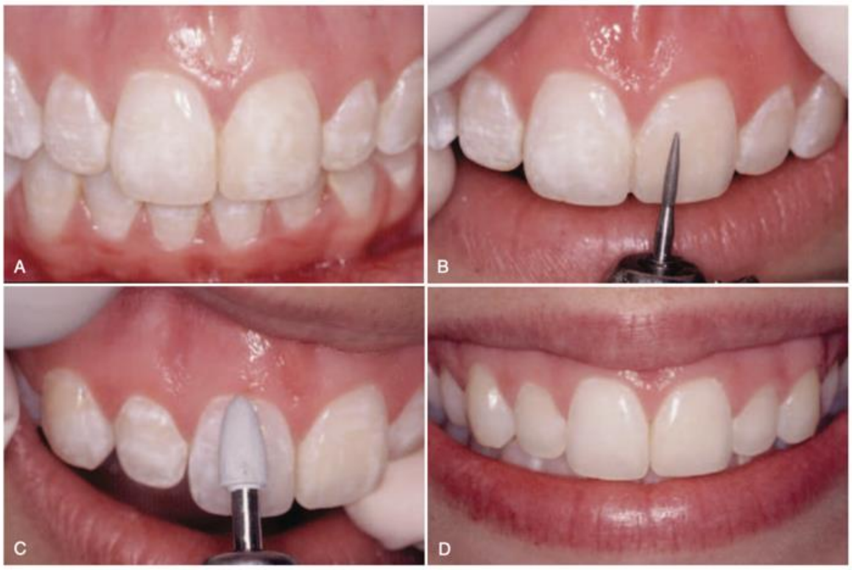


*Figure 10: Macroabrasion. A, outer surfaces of maxillary anterior teeth are unesthetic because of superficial enamel defects. B and C, Removal of discoloration by abrasive surfacing and polishing procedures. D, Completed treatment revealing conservative aesthetic outcome. (Ritter AV., 2019)*

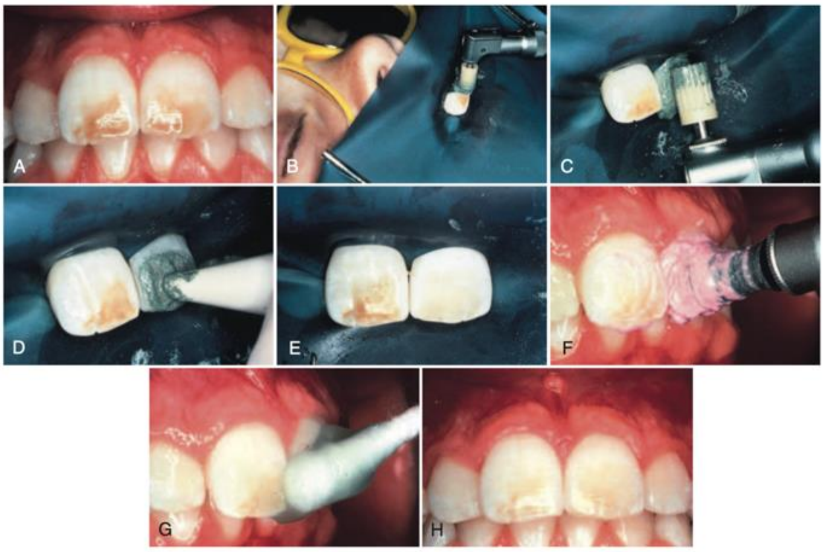


*Figure 11: Microabrasion. A. young patient with unesthetic fluorosis stains on central incisors. B and C, Prema compound applied with special rubber cup with fluted edges. Protective glasses and rubber dam are needed for the safety of the patient. D, Hand applicator for Prema compound. E, Stain removed from the left central incisor after microabrasion. F, Treated enamel surfaces polished with prophylactic paste. G, Topical fluoride applied to treated enamel surface. H, Final aesthetic result (Courtsy Dr. Ted Croll.) (Ritter AV., 2019)*

# 7 Adverse Effects of Dental Bleaching

Due to the variety of bleaching techniques available, it is expected that these methods, whether performed professionally or at home, may result in adverse effects. These effects can impact both the soft and hard tissues of the oral cavity but also restorative materials and systemic health. In order that integrity and longevity of sound and healthy tooth structure and health of a patient is maintained, adverse risks that affect the tooth structure should be minimized [9].

## 7.1 Adverse Effects on Intraoral Structures

### 7.1.1 Adverse Effects on Enamel

The studies about the effects on the physical properties remain controverse, as the results differ in the variety of studies. Some studies detect noticeable changes and others do not.

The bleaching mechanism includes the chemical degradation of chromophores but also includes the potential to induce structural alterations with the effect on the optical properties [3, 15]. The morphologic alterations include increased enamel porosity, demineralization of enamel, decreased protein concentration, organic matrix degradation, modifications to the calcium-phosphate ratio and increased surface roughness [3, 7, 15, 16]. The reason for the several

enamel morphological and texture changing factors are hydroxyl radicals which are highly reactive and unstable molecules, they attach to the organic molecules to achieve stability but could lead also to changes in mechanical properties [3, 32]. The demineralization process is affected by the degree of acidity of the bleaching agent but also the prolonged contact time between teeth and bleaching agent [14]. The more the pH value of a bleaching agent decreases, the greater the solubility of calcium and phosphate. A critical pH between 5.2 and 5.8 causes demineralization of the hard tooth substance, most bleaching agent's pH range from 4.0 to 7.5 [7]. Considering that saliva contributes to the dilution of the bleaching agent, which has a remineralising effect by replacing the lost calcium and phosphate ions in the tooth structure, shows that saliva plays an important role in the oral cavity in regard to bleaching [3, 14, 16, 32]. Bleaching agents with a high acidic peroxide concentration lead to increased surface roughness and enamel erosion, which also contributes increased enamel porosity [3]. It is shown, that 10% to 35% carbamide peroxide contributes the roughening of the enamel surface leading to an increased risk of the adhesion of bacteria such as Streptococcus mutans and following caries decay risk [3, 16, 17]. The resulting roughened enamel surface by the 10% carbamide peroxide concentration depends also on the brand and application time, additionally the effects of surface roughness reversed to normal after three months [17].
Regarding the chemical composition of enamel, it is shown that the ion release of enamel and dentin is increased with enhancing concentrations of hydrogen peroxide, which results in a loss of calcium and phosphate from the tooth structure, but the amounts are equal compared to the intake of juice or soft drinks [3, 13, 15]. Dental bleaching also affects the protein concentration and promotes organic matrix degradation, by the modification of polypeptide chains and lysis of organic matrix due to the hydrogen radicals resulting in an alteration of organic matrix in enamel and in dentin [9, 15, 16]. Additionally, some studies stated changes in the dentin structure too, as the dentin is more permeable and factors such as increased hydrogen peroxide concentration, prolonged application and increased temperature leading to a faster penetration of the bleaching agents [3, 13, 15]. The following decreased dentin microhardness similar to that of enamel, leads to the sensitivity phenomenon after bleaching [13]. The changes in the tooth surface structure, are still varying from no changes to changes detected in the specimens, among studies. Bleaching involves some degree of risks regarding the tooth structures in enamel and dentin and they should be minimized.

#### 7.1.2 Adverse Effects on Pulp-Dentin Complex

##### 7.1.2.1 Tooth Sensitivity

Tooth sensitivity is one of the most common side effects in bleaching [7, 10, 13, 17, 24]. It is important to note that the findings regarding this issue vary among different studies. Prior to undergoing a bleaching regime, it is important for the patient to be informed about the potential side effects. This will help to ensure that any side effects, such as bleaching sensitivity, remain mild, transient and tolerable [1]. According to referenced articles, bleaching sensitivity can affect daily activities such as eating or drinking [49]. This sensitivity is characterized by a painful sensation in response to various stimuli. The prevalence of bleaching sensitivity ranges from 15% to 87% in patients who undergo bleaching with hydrogen peroxide or carbamide peroxide. The incidence of bleaching sensitivity is higher in in-office regimes that use hydrogen peroxide and heat application [12, 16, 19, 64]. The severity of bleaching procedures can result in patient discomfort and may lead to the cessation of the bleaching process [16, 49]. Regarding patient-specific tooth data, pre-existing sensitivity, teeth with defects or cavities, gender, age, or dietary habits are factors influencing the extent of bleaching sensitivity. Especially patients with previous high tooth sensitivity or low pain tolerance are in an increased risk of experiencing the side effect [7]. The extent of bleaching sensitivity is closely linked to the composition and concentration of the bleaching gel, as well as the length of application [24, 49]. The patient often reports experiencing a tingling sensation or widespread pain without any apparent stimulus. Side effects may occur during or after the bleaching regime. Typically, they persist for up to four days but can extend to 36 days after cessation of the bleaching regime [7, 10, 16, 17, 49]. As previously stated, the aetiology of tooth sensitivity after bleaching procedures remains unclear. The presence of pain in intact teeth without exposed dentin gives rise to the hypothesis that bleaching agents are leading to increased enamel porosity and microscopic defects. Subsequently this allows the diffusion of the bleaching agent through the dental structures and reaching dentinal tubules and dental pulp leading to thermal sensitivity [7, 9, 10, 24, 49, 53].There several possible theories explaining possible pathologic pathway of dental sensitivity. The two most convincing are discussed in the following.

##### 7.1.2.2 Hydrodynamic Theory

The Hydrodynamic Theory was first stated by Brännström in 1964 and is the most convincing theory of bleaching sensitivity [1, 16, 65, 66]. As previously mentioned, the dentin tubules provide a connection between stimulus and intradental nerve endings. Due to hard substance defects in enamel and dentin caused by the bleaching agent, there is a better diffusion of the bleaching agent toward the pulp dentin complex [24]. The Hydrodynamic Theory states, that a stimulus triggers the dentinal lymph inside the dental tubules, leading to a rapid tubular fluid movement and causes the activation of intradental nerve fibres. The triggering impulse result in a spontaneous sharp pain, this pain is related to activation the A-delta nerve fibre endings [24].

#### 7.1.2.3 Reversible Pulpitis

Reversible pulpitis can occur during the bleaching process, as the penetrating bleaching gel reaches through the enamel and entering the pulp, causes an inflammatory reaction and reversible histological changes [10, 24, 29]. When the bleaching agent reaches the pulp-dentin complex, via the porous enamel and dentin, the first defence to the irritation is happening in the odontoblastic cell layer, as odontoblasts initiate vacuolization (formation of vacuoles helping to sequester waste products) in the cell layer, before inflammatory processes had begun [10]. Additionally, hydrogen peroxide and the resulting perhydroxyl free radical initiating the expression of the Interleukin Factor 8 (IL-8), which is a proinflammatory enzyme stimulating the chemotaxis of polymorphonuclear neutrophils (PMN) and macrophages from local blood vessels [10]. Macrophages then begin the local protective immune response and start to eliminate inflammatory or irritating material [18, 19]. This is happening by the degradation of extracellular matrix, recruiting leukocytes and other pro-inflammatory Interleukins such as Interleukin-1 (IL-1) and Tumour Necrosis Factor alpha (TNF-α) [10, 29]. Besides that, macrophages are also involved in neovascularization, pulp repair and fibroblast proliferation [29]. Not only macrophages are primarily involved in the defence mechanism, also catalase and peroxidase enzyme break down hydrogen peroxide compartment to remove them from the pulp tissue [10]. In certain studies, it is found that the number of active Macrophages and Polymorphonuclear neutrophils were increased after five days after the bleaching procedure (with 38% $H_2O_2$ in office bleaching) and started to decrease eight days after the application. Hence it is shown that bleaching gels cause an inflammatory reaction inside the pulp tissue which are reversible [10, 29]. It is also shown that there is a difference regarding the concentrations of bleaching gels. As the higher the concentration (i.e. 38% $H_2O_2$ in office bleaching compared to 15% carbamide peroxide at home bleaching) leading to higher pulpal penetration and inflammatory response [10, 29].

### 7.1.3 Adverse Effects on Periodontium

#### 7.1.3.1 Adverse Effects on Gingiva

Gingival irritation is considered a local effect of dental bleaching, resulting in soft tissue burns, epidermal hyperplasia, and induction of keratinocytes [9, 13, 16, 52]. The clinical presentation of soft tissue burns is characterized by a white discoloration of the gingiva, indicating epithelial damage [52]. Soft tissue burns are reversible and do not have any long-term consequences. They typically begin one day after treatment and can subside after several days [13, 52]. The temporary burn is a sign of oxidative stress and inflammation [30]. A study resulted showing changes in Gingival Crevicular Fluid, which increased in neutrophil content and showed changes in the abundance of proteins associated with nitrogen oxide synthesis and neutrophil recruitment, regardless of hydrogen peroxide concentration [16, 30]. High concentrations of hydrogen peroxide can cause inflammation and changes in cell morphology in gingival fibroblasts, which are important for the tissue structure and integrity of the periodontium. When hydrogen peroxide comes into contact with gingival tissue, it can trigger a cellular response through an inflammatory cascade of Tumour Necrosis Factor Alpha (TNF-α), leading to subsequent inflammation, acute oedema, and chemical burns [67]. However, there is a higher risk of gingival irritations with at home dental bleaching and over-the-counter products [5, 68]. Gingival irritation can occur because of dental bleaching, regardless of the method used. Ill-fitting dental trays are a major cause of gingival irritation, as they can come into contact with soft tissue or accidentally come into contact with dental bleaching agents [5].

Over-the-counter products generally lack in protective measures for oral soft tissues and can lead to increased gingival inflammation [68]. These techniques make it nearly impossible to avoid contact with soft tissues [3, 5, 7, 68]. Studies have shown that high concentrations of hydrogen peroxide (for example, 30% to 35%) are highly irritant and caustic, while lower concentrations cause less tissue damage. The adverse effects of gingival irritation caused by at-home bleaching are dose-dependent and influenced by other factors such as duration and application methods [7, 13, 30]. A study using 10% carbamide peroxide showed an increase in the quantity of cells in the basal cell layer, indicating gingival irritation and chemical burn immediately after the procedure [16, 67]. It should be noted that the side effects of bleaching with 10% carbamide peroxide are equivalent to those of other materials, such as eugenol [5]. In conclusion, gingival irritation is a common side effect of dental bleaching, regardless of the method used. However, these effects are temporary and usually subside after several days, without any long-term consequences. In addition, it is important to correctly apply a gingival barrier, such as a rubber dam, during in-office treatment or to ensure safety effectively with a custom-fabricated tray. If a soft tissue burn occurs, it is easily managed by the application of an antiseptic ointment, a catalase or bicarbonate which is applied to the ulcerated lesion to arrest the burning effect [52, 69].

*Figure 12: Chemical burning of the cervical gingiva of several teeth after an in-office bleaching application with a high-concentration hydrogen peroxide. (Reis A et al., 2018)*

#### 7.1.3.2 Adverse Effects on Periodontal ligaments and Alveolar Bone

Research in this area has shown that adverse effects are limited to the gingiva, which is part of the periodontium. These effects manifest as gingival irritation, as described. No precise studies have been found to show that bleaching affects pathologies of the periodontium, specifically periodontal fibres, and diseases such as periodontitis or osteomyelitis. Further research is needed to determine whether dental bleaching has adverse effects on periodontal tissues and bone.

#### 7.1.3.3 External Cervical Root Resorption

Tooth resorption, specifically External Cervical Root Resorption (ECRR), is a pathological condition characterized by a dynamic destructive process [16, 70]. The term "resorption" is defined as the loss of dentin, cementum, or bone resulting from either a physiological or pathological process [71]. Dental resorptions can be classified as either physiologic or pathologic. Physiologic resorption occurs during the exfoliation of deciduous teeth, while pathologic resorption can be either external or internal, depending on its location. Whereas Internal Root Resorption (IRR) refers to the inflammatory process initiated within the pulp, this section focuses solely on external root resorption (ERR). The definition of External Root Resorption varies in different studies, but it is basically referred to the resorption process initiated in the periodontium affecting external surfaces of the tooth. They can be further classified into inflammatory, replacement and surface resorption [58, 71]. External Cervical Root Resorption (ECRR) is a type of external root resorption and occurs in the coronal one third of a tooth root. It’s resorptive process starts as a small defect and resorptive tissue extends circumferentially and in apico-coronally (horizontal) direction, leaving the pulp intact [58, 70]. That is why, the destructive process remains asymptomatic until later stages. Subsequently making the treatment difficult for dentists [58, 70]. The prevalence of this condition remains rare, about 0.02% to 0.08% [58]. Histopathological, the portal of entry seems to be the continues level of the cemento-enamel-junction (CEJ), the subsequent disruption of periodontal ligaments induces an inflammatory process [58]. Further sequential infiltration of inflammatory cells and granulation tissue penetrates the dentin and forms multiple resorption channels inside the root. Thereby the dentin provides a favourable environment for resorptive cells. The resorptive tissue is composed of blood vessels, fibrous tissue and a variety of cellular components such like fibroblasts, vascular endothelial cells, adipocytes and leukocytes [58]. During the resorptive process, multinucleated cells (similar to osteoclasts) form within the resorptive lacunae and the lesion is partially repaired by osseous like tissue which demonstrate a major drawback of this condition [58]. The condition is broadly progressing in three phases. First the resorptive initiation, second the resorptive progression and third the repair. The resorptive process and repair take place simultaneously.

To classify the resorptive process, a gold standard is the classification by Heithersay (1999), based on the extension and pattern of the resorptive process. Later on, the Cone Beam Computed Tomography (CBCT) was introduced to make prognosis and treatment plan for resorption processes [70].

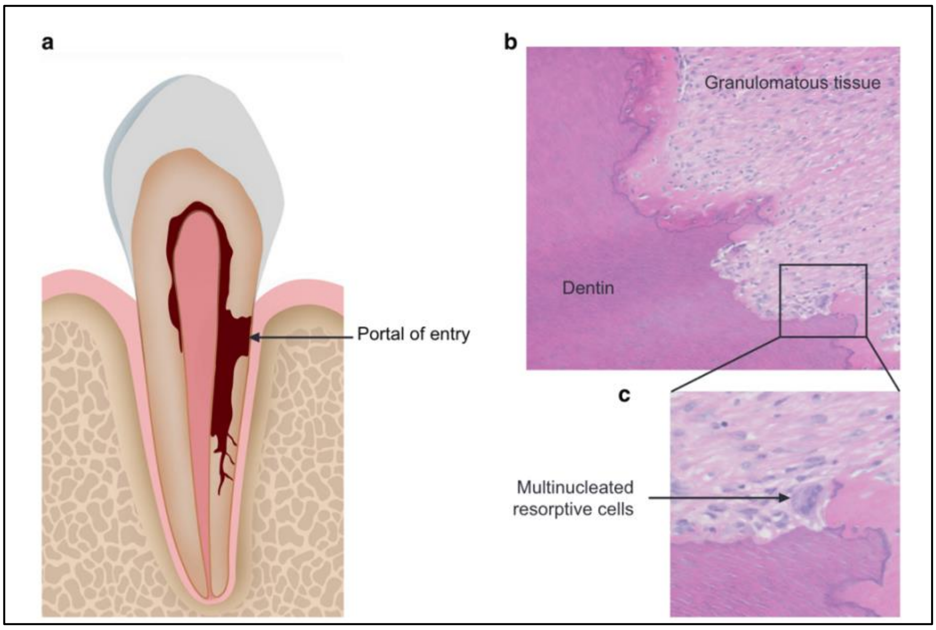


*Figure 13: Schematic image and histological sections of ECR. a Schematic image presenting the histopathological patterns of ECR lesion. b Pathological section of ECR lesion showing granulomatous tissue and the impaired dentin. c Pathological section of ECR lesion showing multinucleated resorptive cells located in resorption lacunae [Chen et al., 2021]*

In relation to aetiology of external cervical root resorption, the aetiology is unknown, but there are several predisposing or risk factors contributing to External Cervical Root Resorption. Despite the major risk factors being orthodontic treatment and trauma, others are malocclusion, parafunctional habits, undesirable oral hygiene, intracoronal restorations, viral infections or medications, intracoronal bleaching is identified as the third largest risk factor [58, 70]. Maxillary incisors are the most affected teeth in intracoronal bleaching related to External Cervical Root Resorption. Contributing factors include physical and chemical properties, as well as dentin permeability. Specifically, the temperature of bleaching agents, thickness of cervical dentin, diameter of dentin tubules, and presence or absence of smear layer play important roles. While there has been a significant decrease in the incidence of External Cervical Root Resorption in recent decades due to standardization and new treatment protocols for bleaching, there is still a risk of developing this condition. For instance, the gap between cementum and dentin in the cervical area allows bleaching agents to reach the periodontal ligament space. Hydrogen peroxide has been shown to reduce dentin hardness by degrading organic and mineral components. Bleaching agents can activate osteoclast differentiation when they diffuse through dentin tubules and come into contact with the periodontal ligaments [58]. Despite the intracoronal bleaching method leading to External Cervical Root Resorption, also at home bleaching can lead to a risk of developing this condition shown in a study, where 22%

of carbamide peroxide was used. Histologically the gaps inside the dentin were observed from activity of fibroblast like cementoblasts. As well it is shown, that hat at home bleaching with low concentrations showed reduced enamel surface microhardness contributing the risk of developing External Cervical Root Resorption [72]. Therefore, it is essential to closely monitor patients and schedule regular follow-up appointments during bleaching, whether it is at-home, in-office, or with over-the-counter products. It is important for dentists to prioritize patient safety and follow established protocols for bleaching procedures. This ensures the safe and proper use of bleaching agents and prompt treatment of any complications occur, such as External Cervical Root Resorption.

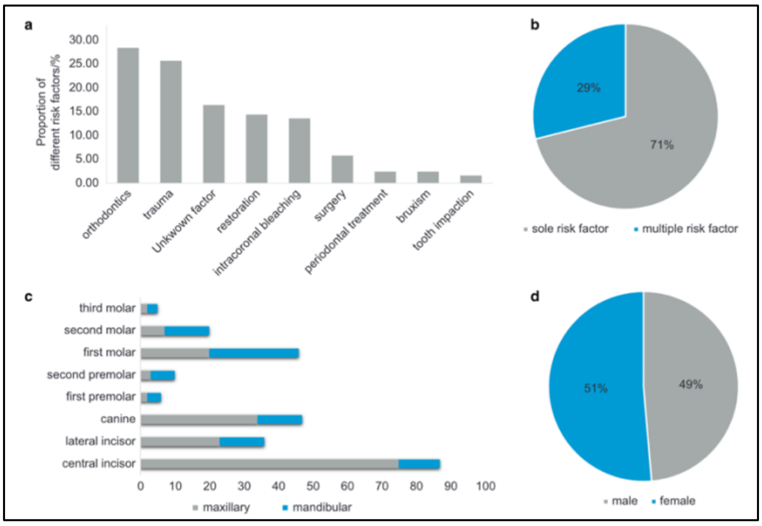


*Figure 14: Potential predisposing factors and distribution of ECR presented in a cross-sectional study carried out in Australia. a: Proportion of different risk factors identified in patients. b: Comparison of the percentage of patients detected with sole risk factors and multiple risk factors. c: Distribution of teeth diagnosed with ECR. d: Distribution of patients' gender [Chen et al., 2021]*

## 7.2 Adverse Effects on Restorative Materials

Whereas adverse effects not only affect tooth natural structures, also restorative materials can take up stains [73]. The adverse effects of dental bleaching agents could impact surface properties, microhardness, colour change or leading to microleakages of dental restorations [3]. The subsequent discussion provides a summary of adverse effects from bleaching agents on both direct and indirect restoration, encompassing implications for bonding quality.

### 7.2.1 Direct restorative materials

Restorative materials such like composite restorations can discolorate on three levels. One, "surface discolorations" due to accumulation of food, beverages, and plaque. Second, "subsurface discolorations" whereby surface stains diffuse into superficial resin layers and react chemically with composites. Or third, "intrinsic discolorations" which are physicochemical reactions deep within composites [73]. Indeed, studies demonstrated that both 10% and 15% carbamide peroxide effectively removed extrinsic stains, such as those from juice, tea, chlorhexidine, red wine and coffee, returning stained composite resins to their baseline colour [73, 74]. By the ability of bleaching agents to penetrate resin composites and subsequent surface alteration and oxidation, they are able to decompose chromogenic double bonds in composite restorations [73, 74]. The drawback of the ability is that carbamide peroxide and hydrogen peroxide can cause increased surface roughness and increased risk of subsequent Streptococcus biofilm formation [73]. Initially it is important to mention, that most of the studies have been done "in vitro", as well a limited amount of studies is available and thus contrary influence clinical trials [73].

Regarding surface properties and microhardness of composite restorations, it was stated that 10% to 16% carbamide peroxide leads to an increased surface roughness and increased porosity of microfilled and hybrid composites. As shown, bleaching with 10% carbamide peroxide over three weeks was able to change surface roughness of packable composite resins. In situ studies showed that microhardness and surface texture of nanohybrid and packable composites remained stable after 28 days bleaching with 15% carbamide peroxide [74]. After bleaching with 10% carbamide peroxide, cracking was observed too. Additionally interfacial fracture toughness of dentin and resin composites are reduced when bleached with 16% to 21% carbamide Peroxide [16, 52]. Also, an increased micro-leakage could be seen due to bleaching with 35% Hydrogen peroxide and 10% to 16% carbamide peroxide (after 42 hours) which increased the marginal seal between composite restorations and dentin and enamel margins. Controversy, in the same paper it was shown, that bleaching 20% carbamide peroxide did not affect margins of Class I composite restorations [16, 52].

Older types of tooth restorations are Amalgam restorations; however, it is important to acknowledge the significance of amalgam restorations. As many individuals either have pre-existing amalgam restorations or choose them due to the high cost as an alternative restorative material. As bleaching agents generate high levels of free radicals, which are strong oxidizing agents, they can cause changes in surfaces of amalgam metallic restorations and potentially release mercury. The level of mercury release can lead to oxidation, corrosion and dissolution of amalgam. [75]. Bleaching with 10% carbamide peroxide lead to an increased amount of mercury and silver release, which was found near the surface of silver amalgam restorations. Limitations occur in this study, as it was performed in vitro or in vivo the results could be reduced by the dental biofilm effect [7, 16, 75]. A hypothesis can be stated that there is a correlation between the release of mercury and peroxide concentration. The increased release of mercury is dependent from the age of the amalgam restoration, surface roughness and acidity of the bleaching agent. A significant increase of release of mercury and silver components of amalgam restorations was found when bleached with 10% to 16% carbamide peroxide and different concentrations of hydrogen peroxide (3,6% to 6% and 30%) and related to the variation of concentration and application time. The reported concentration of mercury release was still below the level of health concerns [74]. The only concern is in one case by which the green discoloration of amalgam restorations was caused after extensive bleaching with 10% carbamide peroxide. After removal of the restoration, a carious lesion was found under the restoration. After the replacement of a new amalgam restoration and bleaching and subsequent removal of the new amalgam filling, no carious lesion was found, and no more green discoloration was observed. Therefore, the green discoloration was due to marginal discrepancies [75].

Glass ionomer cements (GIC) are biocompatible, translucent filling materials with the ability to chemically bond to dental tooth structures. Their use is limited to primary teeth, small cavities, non-occluding surfaces in permanent teeth or temporary restorations. Besides the effects on composite restorations, effects are also well recognizable on dental Glass ionomer restorations and may increase the surface roughness, decrease the hardness and by the dissociation of peroxides there is an increased susceptibility of the dissolution of Glass-ionomer cements. Important factors which play a crucial role in adverse effects are concentration, time, type of Glass ionomer cement and bleaching agent [16, 76]. Bleaching can alter the interface between dental tissues and Glass-ionomer. The penetration of bleaching agents into the pulp chamber is relatively common with resin modified glass ionomer cement fillings, but 6% hydrogen Peroxide did not cause significant surface dissolution of Glass-ionomer restorations. [16]. Studies showed, that the surface morphology and microhardness altered after 28 days of bleaching with 15% carbamide Peroxide, as well, cracks and pits were localized too leading to increased susceptibility for staining [74].

### 7.2.2 Indirect Restorative Materials

Besides resin-composite restorations, nowadays, many indirect restorations are CAD/CAM fabricated and most common materials are ceramics and indirect fabricated resin composites. They are used for crowns, bridges in- and onlay restorations. The literature varies regarding the results expressed in the studies. Various types of ceramics are available on today's market and various types of bleaching gels from different manufacturers are available, which makes it difficult to make a conclusive statement. Indirect resin-composite materials fabricated for inlays or onlays, show an increased microhardness, which sounds initially odd. Due to the dissociation by free radicals by bleaching agents, they break the double bonds of the polymeric chains. This disintegrates the interface between the inorganic matrix and polymeric matrix, subsequently the polymeric matrix decomposes, and monomers release from the composite. The high amount of inorganic matrix left leads to the increased microhardness. Polymer infiltrated ceramic (which contains polymeric molecules such as urethane dimethacrylate (UDMA) and triethylene glycol dimethacrylate (TEGDMA) showed no surface roughness and microhardness affected by the bleaching gel applied [77]. Additionally, no changes in colour by means of contrast and translucency was found in lithium disilicate ceramic after bleaching. In contrast to that, increased surface roughness was found in ceramics tested after 6% hydrogen peroxide and 16% carbamide peroxide in another study. Indicating, that these materials are more prone to plaque adhesion after dental bleaching. Zirconium dioxide was found to be adequate to aesthetic bleaching procedures, as it showed minor adverse effects of surface roughness, microhardness and other parameters tested [78]. As mentioned before, the current literature, gives only a small insight of adverse effects on indirect restoration materials, as well the results mentioned vary among studies, as the effects differ among different ceramic materials used as well different bleaching gel material (from different manufacturers) were used. This leads to the challenging assessment.

### 7.2.3 Bonding Quality

Adverse effects on the bonding quality of restorations can be divided into "pre-operative bleaching" and "post-operative bleaching". Pre-operative bleaching adverse effects are described as the reduction of bon strength after dental bleaching. Dental bleaching causes several changes on the tooth substance, the presence of peroxides on the tooth surface alters the protein and mineral content of superficial enamel. This reduces bond strength and prevents complete polymerization. Studies have found that the enamel surface of bleached teeth were resin tag free and poorly defined under Scanning Electron Microscope (SEM) evaluation, thereby reducing the penetration ability of dental adhesives. In many studies the shear bond strength (SES) was tested and results stated, that the conversion of dental adhesives and resin composites was impaired [16]. Management to improve bond strength can be the use of several antioxidants. Sodium ascorbate, ascorbic acid, butylhydroxyamisole, catalase, ethanol, acetone, and many others are examples of antioxidants. Ascorbic acid has been found to increase the time interval between dental whitening and the placement of a definitive restoration [7]. To manage and improve bond strength after bleaching, the use of 10% sodium ascorbate is the most widely accepted. Its ability is to reverse compromised bond strength in enamel. Sodium ascorbate removes residual oxygen and promotes adhesion and is well accepted in acid etch and rinse adhesive systems. Additionally, it reverses compromised shear bond strength regardless of the increased concentration. Thus, sodium ascorbate can be an alternative to delay bonding of resin composite restorations and restorations could be done immediately after bleaching. Nevertheless, the best method is to postpone bonding mechanisms for a period varying between 24 hours to four weeks. A two week postponement is considered as a safe standard [7, 52]. Regarding pre-operative composite fillings followed by bleaching, found to have adverse effects too. Oxygen radicals released from bonding agents are highly reactive and damage the substrate bond to resin tags or hybrid layer. As known, the hybrid layer is fundamental for adhesives between teeth and composite restorations. Bleaching adversely affects interfacial fracture thoroughness of dentin-resin composite adhesive interfaces. As well, carbamide peroxide affects micro-tensile bond strength between teeth and restorations and risk is increasing with increased concentration of the bleaching agents. As a result, durability of adhesive restorations and the interface between materials and dentin is significantly in risk of fracture and risk to fall out of the cavity [16, 52].

Concluding, the literature indicates that whitening treatment may induce alteration of restorative materials, leading to impaired adhesion, modify the interface between the biomaterials and teeth. Vital tooth bleaching can consequently lead to a release of mercury from amalgam restorations and modification of surfaces due to bleaching can lead to increased bacterial adhesion. The effects of bleaching on restorative materials are material-time dependent. As well bonding quality can decrease when bleaching treatments are done prior placement of a restoration. Further research should be done to assess and achieve clinical evidence to the adverse effects of bleaching gel on direct and indirect restoration materials. Currently the literature is not explicit about results among various studies regarding.

## 7.3 Adverse Effects on Systemic Health

Dental bleaching can have adverse effects not only on dental or restorative structures, also they can affect the systemic health on cellular and genetic level. Bleaching and the long term use of high concentration hydrogen peroxide based bleaching agents could promote oral mucosal injuries, cytotoxicity, genotoxicity and carcinogenicity [16, 79]. In this part the author is presenting the effects of bleaching on systemic health.

### 7.3.1 Cytotoxicity

Cytotoxicity is defined as the quality of certain agents, chemicals or other environmental factors being toxic to eukaryotic cells [80]. Two possible routes of entrance of an oxidizing agent into the blood circulation could be either by swallowing small amounts during the application (especially during at-home bleaching) and subsequent absorption by the gastrointestinal tract or by the local absorption through the oral mucosa (during long application time in in-office bleaching) [16, 79]. Bleaching agents can cause changes in oral soft tissue morphology like proliferation of basal keratinocytes, apoptosis of cells in all epithelial stratae or alterations in expression of cytokines and associates to inflammatory processes [16]. In a study it is stated that bleaching induces dose dependent gastric ulcerations causing hyperkeratosis, hyperplasia, and dysplasia on the cellular level in a mouse population fed with 30% hydrogen peroxide. This leads to the subsequent inhibition of gap junctional intercellular communications and the mice were in an increased risk to develop tumours or neuropathy teratogenesis [13, 16]. The lowest dose related to death was found in a 16 months old baby which accidentally ingested 3% hydrogen peroxide [16]. Despite the possible consequences mentioned above, oxidative stress is one of the leading factors of cytotoxic effects. The oral cavity and the mucosal membranes allow daily absorption of harmful chemicals (food, tobacco, and drinks) and is vulnerable to trauma, bacteria, and other harmful stimuli like dental bleaching agents. Thereby the oral mucosa and saliva are highly susceptible for oxidative stress, leading to aphthous ulcers, lichen planus or cancer development and other diseases [7]. Thus, the role of Antioxidants plays an important role in bleaching mechanism. Antioxidants are substances which can reduce the free radical concentration in cells in the body. They are classified into enzymatic and non-enzymatic. The enzymatic antioxidants are produced within the cells and examples are: superoxide dismutase, glutathione peroxidase, catalase enzyme, glutathione reductase and thioredoxin [7, 79]. As dental bleaching leads to an increase of oxidative stress, antioxidants can remove harmful effects of free radicals. When bleaching agents are applied, the chemical reaction inside the tooth leads to the formation of Reactive Oxygen Species (ROS). The antioxidant superoxide dismutase can convert these into hydrogen peroxide and together with the enzyme catalase it is converted into water by reduction and thereby able to compensate the oxidative stress and leading to a balanced state [7, 16]. Oxidative stress is a transient, short term side effect because of dentist-supervised at home bleaching observed after the end of tooth bleaching. Reactive Oxygen Species can oxidize cellular components and can cause damage to lipids, desoxyribonucleic acid (DNA) and proteins. By ingestion leading to cerebral infarction, cardiac ischemia, and other diseases. These findings are only possible side effects when there is a significant abuse or misuse of bleaching agents. Thereby the dentist plays and important role and risk education should be done by a dental specialist especially when the bleaching is not supervised or over the counter products are used [79].

### 7.3.2 Genotoxicity and Carcinogenicity

In the means of genotoxicity, it is related to the damage and the first mechanism to induce carcinogenesis. As dental bleaching agents generate free radicals, and subsequent oxidative stress, there is a potential risk of genotoxicity from hydrogen peroxide and carbamide peroxide as the free radical formation is damaging intracellular structures [81]. In the theory especially at-home bleaching is under increased susceptibility for inducing genotoxicity because of an increased risk getting in contact with the gingiva and leading to gingival irritation as a side effect. But studies have rejected the assumption of being genotoxic in the practice with the help of a Micronuclei test (micronuclei as a biomarker). Micronuclei originate from fragments or chromosomes not included in the main nuclei of daughter cells during cell division, they simply show a chromosomal damage meaning damage to the DNA. Studies have stated that there is no increase in micronuclei in at home bleaching with 10% carbamide peroxide whether in "in-office" bleaching with 35% hydrogen peroxide [81]. Genotoxic effects cannot be excluded, as studies shown that bleaching agents have a potential genotoxic effect on bacterial cultures, but the evidence is limited in animal and human studies, thereby "The International Agency for Research on Cancer (IARC)" classified the bleaching agent chemical into the group of "unclassifiable as to carcinogenicity to humans". It is very unlikely that bleaching agents (releasing up to 3.6% $H_2O_2$) will increase genotoxicity or carcinogenicity in people. Except for those in an increased risk of oral cancer (tobacco use, alcohol abuse or genetic pre-disposition) [7]. Another study showed that in-office bleaching did not cause any DNA damage to the gingival tissue, the resulting oxidative stress induced by hydrogen peroxide was repaired by the DNA repair system and human defence system. Thereby, the Gingival crevicular fluid was used as a biomarker to show increased inflammation values of 8-hydroxy-2'-deoxyguanosine. The values showed a temporary increase immediately after bleaching but reversed to normal after two weeks. Concluding, in some way free radicals are able to induce temporary oxidative stress and somewhat genotoxicity in oral epithelium, however, the body's defence system is capable of compensating this damage, and there is little to no risk of genotoxicity or carcinogenicity [31].

## 7.4 Effects on Quality of Life and Addictive Behaviours

### 7.4.1 Effects on Oral Health Related Quality of Life

As written in the beginning, oral health is related to peoples physical, psychological and social well-being, also termed as Oral Health Related Quality of Life (OHRQoL) [50]. In today's society it means that unsatisfactory oral conditions can affect social relationships, emotional well-being corelated to anxiety and low self-esteem [12, 18, 50, 82]. Either way, good oral health can have a positive effect on Quality of Life. Even though aesthetics is a subjective and variable perception, a study in the United States and United Kingdom showed that about 20%-35% recognized a discoloration of teeth and were dissatisfied about it, in this means bleaching can be considered to improve patient satisfaction [12, 51]. To evaluate if bleaching is affecting the Quality of Life of people, it is interesting to consider, why people do aesthetic treatments on their teeth. Several determining factors contribute to the decision to have desire to bleach their teeth, one is that a person's smile is linked to attractiveness and reflecting a favourable self-perception. A study has stated that tooth discoloration can be a decisive factor in the decision to undergo aesthetic treatments such as bleaching. This is because tooth discoloration is associated with a favourable aesthetic self-perception and attractiveness. In particular low-income populations have a greater interest in tooth whitening as it can have a positive psychosocial impact by offsetting their social disadvantages and improving their aesthetic perception. By improving their appearance, they can minimize unfavourable social conditions [18]. Not only low-income groups present a higher desire for dental bleaching, also smokers present a higher dissatisfaction about their teeth colour compared to non- smoker, this is related to the continuous habit which makes the teeth discolorate faster [18]. Since dental bleaching is relative safe and effective, also dentist play a factor too, that people consider tooth bleaching. In another study, it has been shown that people who regularly visited the dentist, had a higher demand to consider dental bleaching, that might be because the dentist actively recruit people to do a dental bleaching [18]. With the dentist being an important person who should inform patients about the positive, negative aspects as well as risks and benefits from dental bleaching, it is shown that dental bleaching can have a positive effect and a negative effect on the Oral Health Related Quality of Life (OHRQoL) [5]. To evaluate the impact of bleaching on quality of life, many studies have employed questionnaires. These questionnaires were designed to measure the effects of bleaching on quality of life. Examples of such questionnaires include the 'Oral Health Impact Profile' (OHIP), which assesses a patient's discomfort with oral conditions, and the 'Oral Aesthetic Subjective Impact Scale' (OASIS), which measures self-perception in relation to oral aesthetics [12]. It is shown that positive effects are related to the colour of teeth. Negative effects are related to the concentration of a product correlating with potential side effects for example: discomfort, dental sensitivity which is most often transient but still can impact a person's Quality of Life [12]. Concluding, the results of many studies showed that bleaching has an overall positive effect on Oral Health Related Quality of Life, in the means of impacting a person's aesthetic self-perception and psychosocial factors. Both at-home and in-office bleaching techniques, have an equal positive effect on Oral Health Related Quality of Life [82]. Regardless if high (35% hydrogen peroxide or 35% carbamide peroxide) or low (6% hydrogen peroxide) percentage bleaching agents were used, both had a positive impact on OHRQoL [43, 83]. As well, non-vital tooth bleaching with 35% hydrogen peroxide or 35% carbamide peroxide with the walking-bleach technique showed a positive impact on aesthetic self-perception [84]. The studies showing the positive effect on OHRQoL were measured in a time span of one to twelve months post bleaching, and were considered positive as long the tooth whitening effect was maintained [82]. Concluding, in the view of the patient, bleaching can have negative effects on OHRQoL, which are mostly related to pain, discomfort or difficulty in maintain oral hygiene (because of gingival sensitivity). Bleaching has an overall positive psychological influence, able to change a person's self-esteem and self-perception [43, 50, 82].

### 7.4.2 Bleachorexia and Body Dysmorphic Disorder

It is important to acknowledge that dental bleaching often has positive impacts on quality of life, such as improved self-esteem. Additionally, negative effects include the possible development or enhancement of addictive behaviours, by certain individuals, such as bleachorexia, which can have detrimental consequences.

Bleachorexia is defined "as an unhealthy obsession with whitening one's teeth", first mentioned by Dr. Jablow in 2005, simply being tooth whitening addictive. This condition is also featured by the American Dental Association (ADA) [68, 85]. The addictive syndrome is closely linked to Body Dysmorphic Disorder (BDD) and low self-esteem [86]. Factors such as social pressure from media seeking for a perfect smile, distorted self-perception, low self-esteem, perfectionism and anxiety contribute to the development of addictive behaviour such as bleachorexia and Body Dysmorphic Disorder [85]. Additionally, low cost, effective dental whitening with over-the-counter products home whitening is increasing in popularity and rising risks of such behaviour [85]. As mentioned before, addictive behaviour such like Bleachorexia and Body Dysmorphic Disorder are in close relationship. In today's society, dentists face increased patient expectations to have whiter teeth instantly and a perfect smile and shape. The whiteness of teeth in patient expectations has reached an extreme and patient expect dentists to be able to achieve these expectations immediately with new treatment methods [86]. The philosophy is imported into the culture and society, that white teeth are a certain fashion trend implemented by media which show, that white teeth is nowadays a “must-have”. Indeed, the prevalence for Body Dysmorphic Disorder is 2.4% in the population in the United Stated of America, and steadily increasing. Furthermore, the prevalence is closely related to age groups in high social media use or people exposed to body-image distortion messaging. The average ages are between 19.1 and 32.6 years, there is no difference between men and women. The link between the prevalence and social media use rises an increased risk to develop this disease or addictive behaviours [86, 87]. Body Dysmorphic Disorder is an obsessive-compulsive disorder as defined by the Diagnostic and Statistical Manual of Mental Disorders. This disease is a “preoccupation with one or more perceived defects or flaws in physical appearance that are not observable or appear slight to others” [87]. The symptoms of Body Dysmorphic Disorder related to dental health are the compulsive mirror checking, unrealistic expectations, over-enthusiasm about dental aesthetics and stress related to minor tooth defects. In addition, addictive behaviour such like Bleachorexia is characterized by obsessive tooth whitening, people feel the temptation to frequently bleach teeth, they have an enduring attention to the shade of their teeth and excessively participate in bleaching session, as well they tend to bleach more frequently and over prolonged time as advised [85, 87]. The addictive behaviour can lead to the exacerbation of body dysmorphic disorder symptoms and manifest this disease. The psychological mechanisms and link between the addictive behaviour and the disease is that patient have an affective dysregulation. They have difficulties to cope with negative emotions related to their appearance and the addictive behaviours help to temporarily regulate or suppress their negative feelings. Teeth are the third most prevalent preoccupation those with Body Dysmorphic Disorder [85, 87]. The symptoms of the syndrome bleachorexia furthermore caused local clinical symptoms, such as gingival irritation, tooth sensitivity, enamel erosion and excessive bleeding, as a case report showed [68]. Patients presenting with such symptoms of addictive behaviour or Body Dysmorphic Disorder are showing legal and ethical issues related to informed consent. Unsurprisingly, the preoccupation with an aspect of one’s physical appearance is a leading motivating factor for being committed to whitening treatments. Contrary, these patients are compliant until they are unsatisfied with the results. A dilemma is arising to decline or providing those procedures. On the one hand treatment will rarely improve the patient perceptions, simultaneously, not fulfilling the request increases the risk of seeking unsafe medical procedure elsewhere [87]. Therefore, the dentist can use a Body Dysmorphic Disorder screening tool to assess signs or symptoms for Body Dysmorphic Disorder. Hereby a collaboration with the clients doctor, psychologist, psychiatrist can be helpful to make a definitive diagnosis and aid in a coordinating strategy in treating those patients [85, 87].

Moreover, patient's having an addictive behaviour to tooth whitening or having the disorder Body Dysmorphic Disorder it is difficult for them to understand information's about risks, and possible outcomes. For a dentist therefore it is fundamental to explain realistic results and what outcome can be expected, as well recognizing syndromes or disease symptoms. One helpful measurement to detect an addictive behaviour can be that people present with teeth whiter in shade compared to the sclera of their eyes. It is important to reduce unnecessary treatments in those people, offering preventive oral hygiene care might lessen the need for frequent whitening operations. As well, symptoms of certain psychological diseases and addictive behaviours can be easily managed by medication but prescribing these kinds of medications is outside the field of dentistry. The dentist, should rather aid and manage the patient and possibly refer patient to general doctors to treat those diseases [68, 86, 87].

# 8 Dental Management

In the following, general recommendations regarding dental bleaching are given below, for clinicians and patient safety. This following part entails comprehensive patient preparation and utilization of structured question forms. Presentation of Indications and Contraindications for dental bleaching as well as the management of side effects are emphasized too.

## 8.1 Indications and Contraindications

As nearly every dental procedure has its indications and contraindications, dental bleaching has so too. Dental bleaching is concerned as an aesthetic procedure, it may be difficult to determine what the indications or contraindications are, as it is a personal desire of the patient to whiten their teeth. Nevertheless, there are indications which are same for both at-home bleaching and in-office bleaching.

In general, practically dental bleaching is indicated in all situations, a person is dissatisfied about their tooth colour or desires a whiter tooth colour [73]. Overall indications for tooth whitening are intrinsic discoloration of teeth, due to ageing, trauma, or medications, such as tetracycline, as well as fluorosis. Also generalized or superficial staining due to smoking habits or dietary related discolorations can be an indication for tooth whitening [5, 89].

The main contraindications are the patient high expectations and resultant unrealistic expectations. Clinicians can only suspect, what the clinical outcome after bleaching is, thus the patient should be informed about these concerns. Additionally, patient who do not comply with the regulations, limitations and risks involved in the procedure are considered to be contraindicated too [89, 90]. Regarding dental contraindications, these are caries and periapical lesions, cracks and exposed dentin or low sensitivity tolerance. Important to mention is that patient who will undergo bonding of direct restorations (such as composite fillings), two within two weeks, are contraindicated because the bonding efficiency will decrease and the filling could be redone, which leads to unnecessary costs and time for the patient. Existing crowns, or larger restorations especially in the anterior tooth area are considered as contraindicated because they are difficult or nearly not able to change their colour, this could lead to dissatisfaction of the patient and poor results. Patients with visible recession (especially in elderly people seen) exposed root surfaces of teeth, as well the fact that cementum does not lighten, whitening would be inefficient in this case. As well untreated periodontal diseases are increasing the risk of adverse effects such as Cervical Root Resorption and are contraindicated too. Regarding systemic health, people with allergies to hydrogen peroxide or carbamide peroxide or any other bleaching agent used is contraindicated. As well, people with gastro-intestinal diseases such as gastro-oesophageal reflux disease (GERD) are also contraindicated, the bleaching materials are mostly of acidic nature and lead to increased acid production in those patients. Consequently this could increase the risk to weaken enamel and dentin as well increasing the risk for tooth decay [89, 90]. Other diseases or conditions include diabetes and drugs inducing diabetes or xerostomia, here at home bleaching is not recommended as it can further decrease the salivary flow of those patients. [91]. Respiratory diseases or deficiencies are contraindicated (especially in in office bleaching treatments) because the applications of protective barriers such as rubber dam or mouth openers used for isolation make it difficult for these patients to breath especially in supine position. Immunosuppressive therapies or oncologist patient are in an increased risk regarding the cytotoxic effects, even that bleaching agents are regarded as non-carcinogenic. Especially oncology patients, who undergo chemotherapy experience poor oral health which makes it unfeasible to bleach teeth safely. As well psoralen or UV therapies (PUVA therapies) or other phototherapies are contraindications for dental bleaching. Obviously the consumption of alcohol and smoking is contraindicated too, the use of alcohol or smoking during dental bleaching can lead to further discoloration and ineffective treatment of teeth regarding bleaching [91]. The last mentioned and controverse opinion throughout the studies involve children. Generally, children under the age of 18 are not allowed for dental bleaching. Some studies mention, tooth bleaching under the age of ten is contraindicated, some studies state under the age of 14 is contraindicated for tooth bleaching. However, sometimes, parents or children desire whiter teeth anyway and dental bleaching is regarded as a conservative approach. In this regard, bleaching in young ages is possible, but risks should be considered. Considering the age, tooth coloration varies during the developmental stage (mixed dentition) subsequent dental bleaching could result in mismatched appearance of teeth. Therefore the child should be over 14 years old and have a full permanent dentition [92]. Regarding the stated opinion, dental bleaching is contraindicated under the age of ten, an exception could be the discoloration due to trauma. If the child experiences dental trauma and dental haemorrhage occurs, the tooth colour could appear reddish to black, but primary teeth are sometime able to return to normal colour, because dental canaliculi are wider and allowing the reabsorption of haemoglobin, turning the tooth to the original colour. Tooth bleaching would then be an unnecessary treatment [88]. Generally primary teeth have thinner enamel and larger pulp chambers, therefore they are more susceptible to adverse effects such as tooth sensitivity after bleaching [93]. The American Academy of Paediatric Dentistry (AAPD) stated they are discouraging dental bleaching in mixed dentition state, they are encouraging dental whitening procedures in young children supervised by a dental clinician. As pregnant or breastfeeding women are generally not involved in experimental researched, also the evidence regarding effects on the unborn foetus is unknown. Hence, to avoid any risks and adverse effects, which could harm the child (whether unborn or born) even after breastfeeding period, pregnant women and breastfeeding women are also considered as a contraindicated regarding dental bleaching [90–93].

## 8.2 Patient Management and Preparation

Before starting with any bleaching procedure, the dentist needs to handle certain steps and make a correct decision for the appropriate bleaching approach. Since bleaching is an aesthetic conservative treatment, only knowledge and experience can lead to correct decisions and successful treatment. Factors for decision making are to respect the patient expectations, lifestyle of a patient, considering the amount of time to be allocated, sensitivity tolerance of a patient, baseline shade of the tooth colour and possible aetiology of staining. Knowledge about the aetiology of discoloured teeth can help the clinician to better evaluate the treatment outcome and time. For example, brown stained teeth (from tobacco) are more difficult to treat compared to yellow stained teeth, similar in tetracycline stained teeth they generally respond longer to bleaching regimes [89]. Initially, a clinician starts with a clinical assessment including the medical history and dental examination. The medical history is important to rule out any contraindicating diseases or conditions. As well as allergies to any bleaching material or latex or certain circumstances such like pregnancies. Regarding dental examinations, the dentist checks the periodontal state, existing restorations, caries and rules out any potential oral diseases or infections [89, 90, 93]. If caries lesions or periapical lesions are present, the priority should be given to treat these conditions before any bleaching regime [89]. Asking the patient for previous tooth sensitivity and pain tolerance, will help the clinician to choose the appropriate whitening procedure. Together with all necessary information's, the clinician can plan the overall process [90]. These information's can be also gathered by a question form handed out to the patient. After the clinician choose the appropriate approach, he should discuss the process of procedures, potential upcoming risks, and possible outcome of the result. The patient's signature is fundamental to obtain. If the patient will do an "at-home" bleaching, the clinician should read and discuss the instructions and should answer upcoming questions from the patient. Subsequently in every procedure, the dentist should obtain initial shade and take a photo to compare it with follow up appointments or later result. Lastly, the clinician should perform a professional oral hygiene (remove calculus and extrinsic stains). Due to the reason, that bleaching may result in side effects such like tooth sensitivity, the clinician can indicate appropriate management of treating tooth sensitivity, discussed in the. Further on the clinician should discuss follow up appointments with the patient. Concluding, an ideal candidate for dental bleaching is a healthy individual with a permanent dentition and willing to be compliant and understands potential risk and side effects [89, 90].

**Cosmetic Teeth Whitening Consultation Form**

Date: ….. /….. /…..

**A. CLIENT INFORMATION**

Name: …………………………………………………………………………… Sex: M / F Date of Birth: ….. /….. /…..

Address: …………………………………………………… Town / City: ………………………… Post Code: …………………..

Telephone: ………………………………………… E-mail: ……………………………………………………………………………

| | | |
|---|---|---|
| How do you hear about Bright White Smiles? | Reason for teeth whitening? *E.g., wedding, holiday* | Are you aged 18 or older? ☐ Yes ☐ No |

**Please answer the following two sections as completely as possible. Any questions which you are unsure of will be covered in the consultation.**

**B. DENTAL HISTORY**

| | | |
|---|---|---|
| Have you had any form of teeth whitening before? ☐ Yes ☐ No | When was your last visit to a dentist / hygienist? | *If yes, please provide details of any treatment performed:* |

| | | |
|---|---|---|
| Please rate the sensitivity of your teeth to hot/cold: ☐ High ☐ Low ☐ Average ☐ None | Do you have any fillings? Front: ☐ Yes ☐ No Back: ☐ Yes ☐ No | Do you have any crowns / veneers / bridges? Front: ☐ Yes ☐ No Back: ☐ Yes ☐ No |

| | | |
|---|---|---|
| Do your gums bleed when brushing or flossing? ☐ Yes ☐ No | Do you have any sores in your mouth? ☐ Yes ☐ No | Do you have any untreated dental issues or worn teeth? ☐ Yes ☐ No |

| | | |
|---|---|---|
| Are your teeth discoloured due to trauma, medication or a genetic disorder? ☐ Yes ☐ No | Do you drink any of the following? ☐ Tea ☐ Red wine ☐ Coffee ☐ Dark soft drinks | Do you use tobacco products? ☐ Yes ☐ No |

**C. MEDICAL HISTORY**

| | |
|---|---|
| Are you, or suspect that you might be, pregnant or breastfeeding? ☐ Yes ☐ No | Are you allergic to: ☐ Latex? ☐ Peroxide, carbamide or glycerine? ☐ Other? *Please state:* |

| |
|---|
| Have you any medical Conditions? |

Are you taking any medication? Yes/No (if yes please list below)

| |
|---|
| |

*Figure 15: Cosmetic Teeth Whitening Consultation Form (DocHub)*

## 8.3 Management of reducing Side Effects

### 8.3.1 Remineralization and Desensitizing Agents

In the manner to reduce tooth hypersensitivity there are a variety of methods used. Non-invasive methods such like of products containing calcium carbonade, arginine, potassium and fluoride ions, calcium, strontium or oxalate components and many other are used to treat tooth sensitivity [94].

Most of the desensitizing agents have two main actions, their main target is to block mechanisms which result in tooth sensitivity [94]. One is to obliterate dental tubules and preventing the fluid movement inside dental tubules and assisting in the remineralization effect in dentin and enamel and the other is the blocking activity of the pulp nerve which leads in a decreased excitability of sensory neurons [95].

#### 8.3.1.1 Fluoride Products

Fluoride based products, are remineralizing agents and can be applied before or after the bleaching process and favour the reduction of tooth hypersensitivity [49, 64]. They act by reducing the nerves ability to respond to changes from dentinal fluids, especially potassium ions are able to depolarize pulpal sensory nerves and interrupt the transmission of pain [2, 64, 96].

Overall, fluoride-based products, whether sodium based or other, they favour enamel remineralization by the ability to resist to acidic attacks such as from bleaching products.

The topical application of fluoride containing products can reduce the mineral loss, re-establish microhardness and increase the enamel resistance [96]. These products do not have an effect on the colour resulting from bleaching [64].

#### 8.3.1.2 Casein Phosphopeptide- Amorphous Calcium Phosphate Complex

Casein phosphopeptide-amorphous calcium phosphate complex (CPP-ACP) are nano complexes promoting the precipitation of minerals to dental hard tissues. Amorphous calcium phosphate complex is a precursor of hydroxyapatite [2, 64, 94]. CPP-ACP can be used in the reduction of tooth sensitivity by calcium and phosphate ions from ACP. They diffuse through phosphorylated fibrils of exposed dentin collagen and promotes the formation of hydroxyapatite and occlude the dentin tubules, thereby blocking the fluid movement inside the tubules [64, 94]. Another great ability is, that CPP-ACP limits the penetration of a bleaching agent to the tooth chamber and prevent or reduce the development of pulpal inflammation, studied showed they are effective in reducing tooth sensitivity in 20% carbamide peroxide at home bleaching and 35% hydrogen peroxide bleaching [94]. As well CPP-ACP has a buffering capacity to prevent caries on weakened surface by bleaching processes, by slowing down the growth and number of bacteria and raising the low pH. Contrary, this formed complex, can be easily neutralized by tooth brushing and diet rich foods, which are low in pH, reducing the buffering capability [64, 94]. As bleaching can damage the enamel microstructure, the remineralizing property of CPP-ACP results in a significant thickness of structure and calcium concentration after 7 days of application after 35% bleaching with hydrogen peroxide, therefor CPP-ACP can aid in reducing the porosity of enamel.

#### 8.3.1.3 Hydroxyapatite based Products

Hydroxyapatite based desensitizing product are by far superior compared to fluoride-based products. The first hydroxyapatite product was invented by the National Aeronautics and Space Administration (NASA) in 1970, to counteract in the loss of minerals found in astronaut's teeth. Later in 1978, a Japanese company produced the first enamel restorative dentifrice with hydroxyapatite. The ideal properties of hydroxyapatite-based products should ideally be non-irritating, minimal abrasive and effective in protecting against caries and biofilm formation. Additionally, they should be cost effective and easy to handle for the user. Hydroxyapatite occurs naturally in enamel and dentin but can be also synthesized in various crystallite morphologies. The particles are available in various sizes. Crystallites are typically 50 nanometre in diameter, while micro hydroxyapatite particles are five to ten microns therefore larger than the enamel and dentin tubules. On the other hand nano hydroxyapatite is rod-shaped and has a size about 20 to 100 nanometre, allowing it to penetrate dentinal tubules [2]. Nano-sized hydroxyapatite has a remineralization effect on hypomineralized enamel by acting as a scaffold and reducing dental hypersensitivity symptoms. These particles penetrate the demineralized collagen matrix of dentin and reach dental tubules, where they bind biochemically to collagen and hydroxyapatite from dentin [2, 64]. Studies have stated that hydroxyapatite-based products can have a whitening effect, as demonstrated in both in vitro and in vivo studies. Additionally, these products have a remineralization effect that can make teeth appear smoother and shinier, resulting in increased brightness and the formation of a second layer of synthetic enamel [2]. Zinc-carbonate hydroxyapatite-based products have also been found to reduce hypersensitivity through a dentin tubule plugging action, like other hydroxyapatite products. The inclusion of potassium nitrate depolarizes the nerve action within the dentinal tubules. This has been shown to reduce hypersensitivity after 48 hours to two weeks [2].

### 8.3.2 Anti-Inflammatory Medication

Another approach is to reduce tooth sensitivity with the help of anti-inflammatory medication. They are used to support the theory of the pulp inflammation and resultant tooth sensitivity and act by modulating inflammation and pain. Their mode of action is the inhibition of the enzyme Cyclooxygenase-2 (COX-2) and suppressing the production of prostaglandins, which are involved in the process of inflammation [49]. In a study, there Ibuprofen (400 mg) which is a non-steroidal anti-inflammatory drug is compared to Cyclooxygenase-2 inhibitor. The drug was used one hour before the bleaching process and could effectively reduce the sensitivity during and immediately after the bleaching process. After one to 24 hours the reduction of sensitivity was not regained, but there was no effect on the colour [49]. Etoricoxib is a selective Cyclooxygenase-2 inhibitor, commonly used in the pain treatment of rheumatoid arthritis or osteoarthritis. The study used 60 mg given one hour before the bleaching process and 24 hours after, this medication failed in the reduction of tooth hypersensitivity. This leads to the conclusion, that anti-inflammatory drugs could help reducing tooth sensitivity during a bleaching process, but more studies are needed to give a definitive statement.

### 8.3.3 Low-Level Laser Therapy

Current attempts to reduce bleaching sensitivity after in-office bleaching are limited to the application of products containing potassium nitrate, fluoride, or CPP-ACP desensitizing products. Non-steroidal-anti-inflammatory drugs and ascorbic acids found to be ineffective not capable to manage post-bleaching tooth sensitivity [97]. Alternatively, the use of laser could be advantageous. Low-level laser therapy is used for pain reduction in dentistry and medicine already. It has an analgesic, anti-inflammatory and bio-stimulating effect [39, 42, 97, 98]. They may be able to treat damaged or inflamed pulp tissue induced by in-office bleaching, as it is capable of attenuating damaged and inflamed pulp tissue. As there is still limited evidence, that low-level laser therapy can enhance bleaching efficacy [39], they found to be effective in treating tooth sensitivity. A study compared two different diode lasers, one the low-level red laser (LLRL) with a 660 nm wavelength and low-level infrared laser (LLIL) with 810 nm wavelength. The incidence rate of post-bleaching tooth sensitivity accounts for about 67% to 87% after in-office bleaching regardless of the use of light application or not (102). In the three tested groups (LLRL, LLIL, and placebo group), most sensitivity occurred 24 hours after bleaching. It has been found that low-level laser therapy cannot reduce the risk of pain or sensitivity after in-office bleaching, this result in having no immediate effect after one hour. After 24 hours the pain was significant lower in the low-level infrared group compared to low-level red light and placebo group. Additional 24 hours later, showed lowest pain levels in both groups compared to the placebo group. The lower pain level was seen in group with infrared laser application. Low-level laser therapy is considered an effective treatment strategy for post-bleaching treatments, being able to reduce pain levels. Preferably the low-level infrared light is used, due to its penetration depths which is 2-3mm (compared to red laser 8-10mm). The irradiation on the cervical area of teeth, showed that the laser beam passes through enamel, cement and some part of gingival tissue until effectively reaching the pulp tissue. Presumably, one-time application is shown to be effective, as the pain persist maximum two to three days with decreasing severity, multiple application therefore is not potentially needed [97].

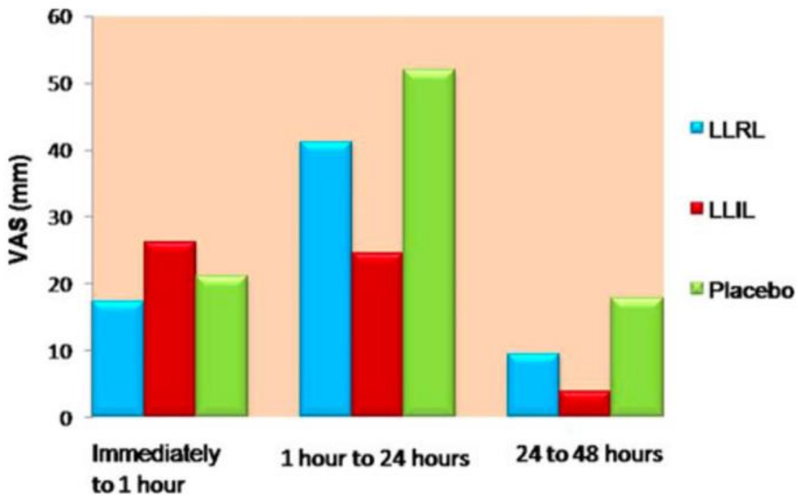


*Figure 16: Comparison of tooth sensitivity score in the study groups over the experiment. (Moosavi et all, 2016)*

# 9 Conclusion

The conclusions drawn from this research shows following outcomes. The literature states controverse statements regarding accelerating mechanisms and lead to the assumption that they are ineffective regarding bleaching efficacy. Accelerating systems lead to an increased risk of tooth sensitivity. The most widely used bleaching agents are hydrogen Peroxide, carbamide peroxide and sodium perborate. Ozone is an alternative bleaching agent but has no superior effect compared to conventional bleaching products. The in-office power bleaching technique is the most common and effective bleaching technique used today. At-home bleaching is an effective and safe alternative. The walking-bleach technique is the most common method to treat discolorated pulpless teeth. Intrinsic stains can be effectively removed by the mechanical macro- and microabrasion techniques. The main adverse effect is tooth sensitivity, the hydrodynamic theory and signs of inflammatory reversible pulpitis are evident theories contributing to tooth sensitivity. The second most observed adverse effect is the reversible gingival irritation. Bleaching showed to have cytotoxic effects on cells induced by oxidative stress. No genotoxicity or carcinogenicity were found to be present in current literature. No adverse effects were seen to affect periodontal fibres or the alveolar bone directly. External Cervical Root Resorption, an underlying pathologic condition is seen commonly after non-vital tooth bleaching. Adverse effects are seen on direct and indirect restorations. The bonding quality of restorations is significantly reduced after bleaching. Bleaching has positive and negative effects on people's Oral Health Related Quality of Life, related to the positive outcome results and side effects. People with Body Dysmorphic Disorder and addictive behaviour termed "Bleachorexia" are in an increased risk to develop unrealistic outcomes and adverse effects. There were no exact clinical indications found in the literature regarding bleaching, the outcome of treatment depends on certain aetiology of discolorations. Contraindications are limited to the age, health related conditions-, disorders- or situations. Certain desensitizing agents can be used to treat tooth sensitivity. Anti-inflammatory medications are found to be ineffective. The alternative Low- Level laser therapy gains more attraction and is effective in managing side effects. The Literature states that dental bleaching is in increased interest of today's society, it is an effective treatment for discolorated teeth.

The first hypothesis, bleaching leads to adverse effects is accepted. The second hypothesis at home bleaching is an ineffective treatment strategy is rejected.

# 10 References


1. *Féliz-Matos L, Hernández LM, Abreu N. Dental Bleaching Techniques; Hydrogen-carbamide Peroxides and Light Sources for Activation, an Update. Mini Review Article. (2015) Open Dent J 8:264–268*
2. *Chen L, Al-Bayatee S, Khurshid Z, Shavandi A, Brunton P, Ratnayake J. Hydroxyapatite in Oral Care Products—A Review. (2021) Materials 14:4865*
3. *Alqahtani MQ. Tooth-bleaching procedures and their controversial effects: A literature review. (2014) Saudi Dent J 26:33–46*
4. *Fioresta R, Melo M, Forner L, Sanz JL. Prognosis in home dental bleaching: a systematic review. (2023) Clin Oral Investig 27:3347–3361*
5. *Haywood VB. History, safety, and effectiveness of current bleaching techniques and applications of the nightguard vital bleaching technique. (1992) Quintessence Int. Jul;23(7):471-88. PMID: 1410249.*
6. *Baroudi K, Hassan N. The effect of light-activation sources on tooth bleaching. (2014) Niger Med J 55:363*
7. *V. Tamara P. Tooth-bleaching: Mechanism, Biological Aspects and Antioxidants. (2015) Int J Dent Oral Health. https://doi.org/10.16966/2378-7090.116*
8. *Lin K-Y, Chung C-H, Ciou J-S, Su P-F, Wang P-W, Shieh D-B, Wang T-C. Molecular damage and responses of oral keratinocyte to hydrogen peroxide. (2019) BMC Oral Health 19:10*
9. *Epple M, Meyer F, Enax J. A Critical Review of Modern Concepts for Teeth Whitening. (2019)Dent J 7:79*
10. *Andriani A, Handajani J, Haniastuti T. Pulpal inflammation after vital tooth bleaching with 38% hydrogen peroxide. (2012) Dent J Maj Kedokt Gigi 45:89*
11. *De Freitas MR, De Carvalho MM, Liporoni PCS, Fort ACB, Moura RDME, Zanatta RF Effectiveness and Adverse Effects of Over-the-Counter Whitening Products on Dental Tissues. (2021) Front Dent Med 2:687507*
12. *Tavarez Rj, Lima S, Malheiros A, Menezes L, Bandeca M, de Miranda Rc, Ferreira M Assessment of the aesthetic impact and quality of life of home dental bleaching in adult patients. (2021) J Clin Exp Dent e440–e445*
13. *Noorsaeed, Dr & Alkhatti, Eman & Aletayani, et al. Overview on Mechanisms and Complications of Dental Bleaching: (2022) Life Sciences-Medicine. International Journal of Life Science and Pharma Research. L24-L34. 10.22376/ijlpr.2023.13.1.SP2.L24-L34.*
14. *Zanolla J, Marques A, da Costa D, de Souza A, Coutinho M Influence of tooth bleaching on dental enamel microhardness: a systematic review and meta-analysis. (2017) Aust Dent J 62:276–282*
15. *Kwon SR, Wertz PW. Review of the Mechanism of Tooth Whitening. (2015) J Esthet Restor Dent 27:240–257*
16. *Goldberg M, Grootveld M, Lynch E Undesirable and adverse effects of tooth-whitening products: a review. (2010) Clin Oral Investig 14:1–10*
17. *AlOtaibi F. Adverse effects of tooth bleaching: A review. (2019) Int J Oral Care Res 7:53*

18. *Silva FBD, Chisini LA, Demarco FF, Horta BL, Correa MB Desire for tooth bleaching and treatment performed in Brazilian adults: findings from a birth cohort. (2018) Braz Oral Res. https://doi.org/10.1590/1807-3107bor-2018.vol32.0012*
19. *Kapadia Y, Jain V Tooth Staining: A Review of Etiology and Treatment Modalities. (2018)*
20. *Clifton M. Carey BA, MS PhD Tooth Whitening: What We Now Know. (2014) J Evid Based Dent Pract 14:77–86*
21. *Tabassum A Classification of tooth staining. (2021) 5:*
22. *Ritter AV (ed) Sturdevant's art and science of operative dentistry, Seventh edition. (2019) Elsevier, St. Louis, Missouri*
23. *Abd-Elmeguid A Dental Pulp Neurophysiology: Part 1. Clinical and Diagnostic Implications. (2009)75:*
24. *Andrej M. Kielbassa, Prof Dr med dent Dr hc1, Maximilian Maier2, Anna-Katharina Gieren, Dr med dent3, Eli Eliav, DMD, MSc, PhD4 Tooth sensitivity during and after vital tooth bleaching: A systematic review on an unsolved problem. (2015) Quintessence Int 46:881–897*
25. *Närhi M, Bjørndal L, Pigg M, Fristad I, Rethnam Haug S Acute dental pain I: pulpal and dentinal pain. (2016) Den Nor Tann Tid. https://doi.org/10.56373/2016-1-4*
26. *Newman Takei, Klokkevold, Perry. Carranza's Clinical Periodontology, 13th edition. (2015)*
27. *Khurshid Z, Warsi I, Moin SF, Slowey PD, Latif M, Zohaib S, Zafar MS Biochemical analysis of oral fluids for disease detection (2021). In: Adv. Clin. Chem. Elsevier, pp 205–253*
28. *Mahmoud Torobinejad, Ashraf F. Fouad, Shahrokh Shabahang. Endodontics principles and practice 6th ed. (2021)*
29. *Vaz MM, Lopes LG, Cardoso PC, Souza JBD, Batista AC, Costa NL, Torres ÉM, Estrela C Inflammatory response of human dental pulp to at-home and in-office tooth bleaching. (2016) J Appl Oral Sci 24:509–517*
30. *Genaro LE Efficacy and Adverse Effects of Dental Bleaching in the Office: Literature Review. (2021) Biomed J Sci Tech Res. https://doi.org/10.26717/BJSTR.2021.35.005694*
31. *Sürmelioğlu D, Gündoğar H, Taysi S, Bağiş Y Effect of different bleaching techniques on DNA damage biomarkers in serum, saliva, and GCF. (2021) Hum Exp Toxicol 40:1332–1341*
32. *Mondelli RFL, Gabriel TRCG, Rizzante FAP, Magalhães AC, Bombonatti JFS, Ishikiriama SK Do different bleaching protocols affect the enamel microhardness? (2015) Eur J Dent 09:025–030*
33. *Qi F, Otsuki M, Hiraishi N, Hatayama T, Wijethunge CL, Tagami J Effect of photo-thermal acceleration on in-office bleaching. (2021) Odontology 109:828–835*
34. *Gallinari M, Fagundes T, Da Silva L, De Almeida Souza M, Barboza A, Briso A. A New Approach for Dental Bleaching Using Violet Light With or Without the Use of Whitening Gel: Study of Bleaching Effectiveness. (2019) Oper Dent 44:521–529*
35. *De Moor RJG, Verheyen J, Diachuk A, Verheyen P, Meire MA, De Coster PJ, Keulemans F, De Bruyne M, Walsh LJ Insight in the Chemistry of Laser-Activated Dental Bleaching. (2015) Sci World J 2015:1–6*

36. *De Moor RJG, Verheyen J, Verheyen P, Diachuk A, Meire MA, De Coster PJ, De Bruyne M, Keulemans F Laser Teeth Bleaching: Evaluation of Eventual Side Effects on Enamel and the Pulp and the Efficiency In Vitro and In Vivo (2015). Sci World J 2015:1–12*
37. *Bhutani N, Venigalla B, Patil J, Singh T, Jyotsna S, Jain A. Evaluation of bleaching efficacy of 37.5% hydrogen peroxide on human teeth using different modes of activations: An in vitro study. (2016) J Conserv Dent 19:259*
38. *Maran BM, Burey A, De Paris Matos T, Loguercio AD, Reis A In-office dental bleaching with light vs. without light: A systematic review and meta-analysis. (2018) J Dent 70:1–13*
39. *AIshammery SA Evaluation of Light Activation on In-office Dental Bleaching: A Systematic Review. (2019) J Contemp Dent Pract 20:1355–1360*
40. *Calderini A, Sciara S, Semeria C, Pantaleo G, Polizzi E Comparative clinical and psychosocial benefits of tooth bleaching: different light activation of a 38% peroxide gel in a preliminary case–control study. (2016) Clin Case Rep 4:728–735*
41. *Rossi B, Morimoto S, Tedesco TK, Cunha SR, Horliana ACRT, Ramalho KM Effectiveness of Violet LED alone or in association with bleaching gel during dental photobleaching: A Systematic Review. (2022) Photodiagnosis Photodyn Ther 38:102813*
42. *Tekce AU, Yazici AR Clinical comparison of diode laser- and LED-activated tooth bleaching: 9-month follow-up. (2022) Lasers Med Sci 37:3237–3247*
43. *Fernández E, Bersezio C, Bottner J, Avalos F, Godoy I, Inda D, Vildósola P, Saad J, Oliveira O, Martín J Longevity, Esthetic Perception, and Psychosocial Impact of Teeth Bleaching by Low (6%) Hydrogen Peroxide Concentration for In-office Treatment: A Randomized Clinical Trial. (2017) Oper Dent 42:41–52*
44. *Maran BM, Matos TDP, De Castro ADS, Vochikovski L, Amadori AL, Loguercio AD, Reis A, Berger SB In-office bleaching with low/medium vs. high concentrate hydrogen peroxide: A systematic review and meta-analysis. (2020) J Dent 103:103499*
45. *Wijetunga CL, Otsuki M, Hiraishi N, Luong MN, Tagami J Effect of pH of bleaching agent on tooth bleaching action in vitro . (2021) Dent Mater J 40:566–572*
46. *Dietrich L, De Assis Costa MDM, Blumenberg C, Nascimento GG, Paranhos LR, Da Silva GR A meta-analysis of ozone effect on tooth bleaching. (2021) Sci Rep 11:13177*
47. *Alpan AL, Bakar O. Ozone in Dentistry. (2018) Ozone Nat Pract. https://doi.org/10.5772/intechopen.75829*
48. *Pereira R, Silveira J, Dias S, Cardoso A, Mata A, Marques D Bleaching efficacy and quality of life of different bleaching techniques — randomized controlled trial. (2022) Clin Oral Investig 26:7167–7177*
49. *Dent J Sensitivity in Dental Bleaching and the Use of Anti-Inflammatory Agents. (2013)*
50. *Pereira R, Silveira J, Dias S, Cardoso A, Mata A, Marques D Bleaching efficacy and quality of life of different bleaching techniques — randomized controlled trial. (2022) Clin Oral Investig 26:7167–7177*
51. *Fioresta R, Melo M, Forner L, Sanz JL Prognosis in home dental bleaching: a systematic review. (2023) Clin Oral Investig 27:3347–3361*

52. *Alqahtani MQ Tooth-bleaching procedures and their controversial effects: A literature review. (2014) Saudi Dent J 26:33–46*
53. *Zanolla J, Marques A, Da Costa D, De Souza A, Coutinho M. Influence of tooth bleaching on dental enamel microhardness: a systematic review and meta-analysis. (2017) Aust Dent J 62:276–282*
54. *Naidu ArtiS, Bennani V, Brunton JMAP, Brunton P. Over-the-Counter Tooth Whitening Agents: A Review of Literature. (2020) Braz Dent J 31:221–235*
55. *Coelho AS, Garrido L, Mota M, Marto CM, Amaro I, Carrilho E, Paula A. Non-Vital Tooth Bleaching Techniques: A Systematic Review. (2020) Coatings 10:61*
56. *Fagogeni I, Falgowski T, Metlerska J, Lipski M, Górski M, Nowicka A. Efficiency of Teeth Bleaching after Regenerative Endodontic Treatment: A Systematic Review. (2021) J Clin Med 10:316*
57. *Zimmerli B, Jeger F, Lussi A. Bleaching of nonvital teeth. A clinically relevant literature review. Schweiz Monatsschr Zahnmed. 2010;120(4):306-20. English, German. PMID: 20514558.*
58. *Chen Y, Huang Y, Deng X. External cervical resorption—a review of pathogenesis and potential predisposing factors. (2021) Int J Oral Sci 13:19*
59. *Perete-de-Freitas CE, Silva PD, Faria-e-Silva AL Impact of Microabrasion on the Effectiveness of Tooth Bleaching. (2017) Braz Dent J 28:612–617*
60. *Blanchet I, Camoin A, Tardieu C, Jacquot B. Microabrasion in the management of enamel discolorations in paediatric dentistry: a systematic review. (2023) J Clin Pediatr Dent. Jan;47(1):17-26. doi: 10.22514/jocpd.2022.015. Epub 2023 Jan 3. PMID: 36627216.*
61. *Sundfeld D, Pavani C, Pini N, Machado L, Schott T, Sundfeld R. Enamel Microabrasion and Dental Bleaching on Teeth Presenting Severe-pitted Enamel Fluorosis: A Case Report. (2019) Oper Dent 44:566–573*
62. *Gaião U, Pasmadjian ACP, Allig GR, Rezende LVMDL, Da Silva VBS, Da Cunha LF Macroabrasion and/or Partial Veneers: Techniques for the Removal of Localized White Spots. Case Rep (2022) Dent 2022:1–6*
63. *Bernardi LG, Favoreto MW, De Souza Carneiro T, Borges CPF, Pulido C, Loguercio ADEffects of microabrasion association to at-home bleaching on hydrogen peroxide penetration and color change. (2022) J Esthet Restor Dent 34:335–341*
64. *Gümüştaş B, DiKmen B. Effectiveness of remineralization agents on the prevention of dental bleaching induced sensitivity: A randomized clinical trial. (2022) Int J Dent Hyg 20:650–657*
65. *Mantri V, Maria R, Alladwar N, Ghom S Dentin Hypersensitivity: Recent Concepts in Management. (2011) J Indian Acad Oral Med Radiol 23:115–119*
66. *Lee K, Lee B-M, Park C-K, Kim YH, Chung G Ion Channels Involved in Tooth Pain. (2019) Int J Mol Sci 20:2266*
67. *Putra Gofur NR Impact in Oral Cavity due to the Use of Hydrogen Peroxyde in Dental Treatment. (2020) Interv Pediatr Dent Open Access J. https://doi.org/10.32474/IPDOAJ.2020.04.000199*
68. *Lee DK, Kastl C, Chan DCN Bleachorexia—an addictive behavior to tooth bleaching: a case report. (2018) Clin Case Rep 6:910–914*
69. *Reis A, Mendonça Da Silva L, Martins L, Loguercio A. In-office tooth whitening. (2018) Clin Dent Rev 2:10*

70. *Irinakis, E.. External cervical root resorption : determinants and treatment outcomes (2018) (T). University of British Columbia.*

71. *Ave NS. American Association of Endodontists. Glossary of Endodontic Terms. (2020)*

72. *Velloso G, De Freitas M, Alves A, Silva A, Barboza E, Moraschini V Multiple external cervical root resorptions after home whitening treatment: a case report. (2017) Aust Dent J 62:528–533*

73. *Irusa K, Alrahaem IA, Ngoc CN, Donovan T. Tooth whitening procedures: A narrative review. (2022) Dent Rev 2:100055*

74. *Yu H, Zhang C-Y, Cheng S-L, Cheng H. Effects of bleaching agents on dental restorative materials: A review of the literature and recommendation to dental practitioners and researchers. (2015) J Dent Sci 10:345–351*

75. *Oskoee PA, Kahnamoui MA, Oskoee SS, Zadfattah F, Pournaghi-Azar F Effects of In-Office and Home Bleaching Gels on the Surface Mercury Levels of Dental Amalgam. (2010) Eur J Dent 04:023–027*

76. *De Camargo FLL, Lancellotti AC, De Lima AF, Geraldo Martins VR, Gonçalves LDS Effects of a bleaching agent on properties of commercial glass-ionomer cements. (2018) Restor Dent Endod 43:e32*

77. *Mendes Tribst JP, Rodrigues Rangel JH, Ferreira Zanatta R, Albuquerque AL, Silva-Concílio LR, Baroudi K, Amaral M. The effect of bleaching gel application on the physical properties of different CAD/CAM restorative materials. (2022) J Dent Health Oral Disord Ther 12:41–44*

78. *Morkūnaitė, G.; Ožiūnas, R.; Čeplauskas, V.; Tučkutė, S.; Laurikaitienė, J.; Adlienė, D. Surface Morphology Changes of Bleached Dental Ceramics. (2022) Appl. Sci. , 12, 4557. https://doi.org/10.3390/app12094557*

79. *Akbari M, Nejat A, Farkhondeh N, Mehraban Moghadam S, Hashemy S, Mohammadipour H Does at-home bleaching induce systemic oxidative stress in healthy subjects? (2017) Aust Dent J 62:58–64*

80. *Çelik TA. Introductory Chapter: Cytotoxicity. Cytotoxicity. (2018) https://doi.org/10.5772/intechopen.77244*

81. *Menezes LDS, Ribeiro PML, Takeshita WM. Can tooth bleaching agents cause genotoxicity in the oral epithelium? A systematic review with meta-analysis. (2022) Res Soc Dev 11:e11411124928*

82. *Goettems ML, Fernandez MDS, Donassollo TA, Henn Donassollo S, Demarco FF. Impact of tooth bleaching on oral health-related quality of life in adults: A triple-blind randomised clinical trial. (2021) J Dent 105:103564*

83. *Estay J, Angel P, Bersezio C, Tonetto M, Jorquera G, Peña M, Fernández E The change of teeth color, whiteness variations and its psychosocial and self-perception effects when using low vs. high concentration bleaching gels: a one-year follow-up. (2020) BMC Oral Health 20:255*

84. *Bersezio C, Martín J, Mayer C, Rivera O, Estay J, Vernal R, Haidar ZS, Angel P, Oliveira OB, Fernández E. Quality of life and stability of tooth color change at three months after dental bleaching. (2018) Qual Life Res 27:3199–3207*

85. *Journal S. Exploring Bleachorexia - Examining the Interplay of Addictive Behavior and Body Dysmorphic Disorder. (2021) https://doi.org/10.51168/sjhrafrica.v2i9*

86. *Greenwall L. Tooth whitening: the last 25 years. (2016) Journal Article.*

87. *Davies L. Body Dysmorphic Disorder: What Dental Hygienists Should Know. (2023) Body Dysmorphic Disord.*

88. *Junior MT, Rodrigues CA, Bernardes VL, Berlanga De Araujo TS, Antonio Nicoli G, Dos Reis Derceli J. Dental Bleaching and New Possibilities: Literature Review. (2018) Health Sci J. https://doi.org/10.21767/1791-809X.1000600*

89. *Şişmanoğlu, Soner. An Overview of Vital Tooth Bleaching. (2020) J. Health Sci. 115-139.*

90. *Mennito Anthony S. Tooth Whitening: Comprehensive Review and Clinical Guidelines. (2012)*

91. *Malcangi G, Patano A, Inchingolo AD, et al. Efficacy of Carbamide and Hydrogen Peroxide Tooth Bleaching Techniques in Orthodontic and Restorative Dentistry Patients: A Scoping Review. (2023) Appl Sci 13:7089*

92. *American Academy of Pediatric Dentistry. Policy on the use of dental bleaching for child and adolescent patients. (2023) The Reference Manual of Pediatric Dentistry. Chicago, Ill.: American Academy of Pediatric Dentistry; 128-32.*

93. *Jane L. Forrest, EdD, BSDH; Lesley McGovern Kupiec, RDH, MSDH. What to Know About Whitening. (2019)*

94. *Kula Ł, Mocny-Pachonska K. CPP-ACP complex as a solution to the problem of complications after teeth bleaching - a literature review: Usage of PP-ACP complex after teeth bleaching. (2022) J Educ Health Sport 12:366–377*

95. *Pierote JJA, Prieto LT, Dias CTDS, Câmara JVF, Lima DANL, Aguiar FHB, Paulillo LAMS Effects of desensitizing products on the reduction of pain sensitivity caused by in-office tooth bleaching: a 24-week follow-up. (2020) J Appl Oral Sci 28:e20190755*

96. *Alencar CDM, De Paula BLF, Araújo JLN, Alves EB, De Albuquerque Jassé FF, Silva CM Effect of low-level laser therapy combined with 5000 parts per million fluoride dentifrice on postbleaching sensitivity: A clinical, randomized, and double-blind study. (2018) J Esthet Restor Dent 30:352–359*

97. *Moosavi H, Arjmand N, Ahrari F, Zakeri M, Maleknejad F. Effect of low-level laser therapy on tooth sensitivity induced by in-office bleaching. (2016) Lasers Med Sci 31:713–719*

98. *Carneiro AMP, Barros APO, De Oliveira RP, De Paula BLF, Silva AM, De Melo Alencar C, Silva CM. The effect of photobiomodulation using low-level laser therap*y on tooth sensitivity after dental bleaching: a systematic review. *(2022)* Lasers Med Sci 37:2791–2804

## References of Figures


1. *Clifton M. Carey. Examples of tooth staining. Journal of Evidence Based Dental Practice, Vol. 14. (2014) https://en.m.wikipedia.org/wiki/File:Examples_of_tooth_staining.jpg*
2. *Ritter AV (ed) Sturdevant's art and science of operative dentistry, Seventh edition. (2019) Elsevier, St. Louis, Missouri*
3. *Närhi M, Bjørndal L, Pigg M, Fristad I, Rethnam Haug S  Acute dental pain I: pulpal and dentinal pain. (2016) Den Nor Tann Tid. https://doi.org/10.56373/2016-1-4*
4. *Ritter AV (ed) Sturdevant's art and science of operative dentistry, Seventh edition. (2019) Elsevier, St. Louis, Missouri*
5. *Newman Takei, Klokkevold, Perry. Carranza's Clinical Periodontology, 13th edition. (2015)*
6. *Rod Kurthy. The Science of Whitening. (2016) http://www.korwhitening.com/wp-content/uploads/2016/09/MKT-70-1046-Rev-1-Science-of-Whitening-Science-Paper.pdf*
7. *Kahn Academy. What is light energy – Electromagnetic Spectrum.(2024) https://www.khanacademy.org/science/biology/photosynthesis-in-plants/the-light-dependent-reactions-of-photosynthesis/a/light-and-photosynthetic-pigments*
8. *Mahmoud Torobinejad, Ashraf F. Fouad, Shahrokh Shabahang. Endodontics principles and practice 6th ed. (2021)*
9. *Mahmoud Torobinejad, Ashraf F. Fouad, Shahrokh Shabahang. Endodontics principles and practice 6th ed. (2021)*
10. *Ritter AV (ed) Sturdevant's art and science of operative dentistry, Seventh edition. (2019) Elsevier, St. Louis, Missouri*
11. *Ritter AV (ed) Sturdevant's art and science of operative dentistry, Seventh edition. (2019) Elsevier, St. Louis, Missouri*
12. *Reis A, Mendonça Da Silva L, Martins L, Loguercio A.  In-office tooth whitening. (2018) Clin Dent Rev 2:10*
13. *Chen Y, Huang Y, Deng X.  External cervical resorption—a review of pathogenesis and potential predisposing factors. (2021) Int J Oral Sci 13:19*
14. *Chen Y, Huang Y, Deng X.  External cervical resorption—a review of pathogenesis and potential predisposing factors. (2021) Int J Oral Sci 13:19*
15. *DocHub.  Cosmetic Teeth Whitening Consultation Form https://www.dochub.com/fillable-form/12175-teeth-whitening-consultation-form*
16. *Moosavi H, Arjmand N, Ahrari F, Zakeri M, Maleknejad F.  Effect of low-level laser therapy on tooth sensitivity induced by in-office bleaching. (2016) Lasers Med Sci 31:713–719*