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"Enhancing Photostability of Maxillofacial Silicone by the Addition of Ultraviolet Absorbing Bisotrizole (A Review of Literature)"

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Abstract:

This literature review emphasizes the impact of UV light on the deterioration of silicone used in maxillofacial prosthetics. Over time, the physical and mechanical properties of silicone degrade due to photodegradation. To tackle this issue, the study explores the use of Bisotrizole, a photostable filler that effectively absorbs a wide range of harmful UV rays. By incorporating Bisotrizole as a UV stabilizer, the longevity of maxillofacial silicone material can be extended, enhancing its resistance to photo-degradation. The review underscores the importance of including UV stabilizers, specifically benzotriazole components like Bisotrizole, in silicone materials used for maxillofacial prosthetics.

Keywords Silicone, Benzotriazoles, Bisotrizole, Ultraviolet, photodegradation.

INTRODUCTION

Maxillofacial deformities could have a significant impact on a patient's physical and psychological well-being, leading to embarrassment and potential health issues (Goiato et al., 2013). These deformities could arise from various causes, including congenital factors, developmental disturbances, and acquired conditions resulting from pathologies, oncological surgeries, and trauma (Naji, Ali, & Farhan, 2020; de Caxias et al., 2019).

Plastic surgery was often preferred for reconstructive procedures in normal circumstances (Dos Santos et al., 2018). However, there were cases where severe functional and aesthetic defects required alternative approaches. In such situations, prosthetic rehabilitation has proven to be an effective solution for dealing with extensive maxillofacial tissue loss, providing patients with improved functionality and aesthetics. (AbdulKareem and

Hamad, 2019; FATIHALLAH et al., 2017).

Maxillofacial prostheses, According to Ackerman's definition in 1953, were dental interventions that repair and replace damaged facial parts resulting from injuries or surgical interventions as cited in (de Caxias et al., 2019). Patients who require such prostheses often face social, psychological, and economic challenges, as they might experience anxiety about social acceptance and potential stigmatization. These challenges could lead to long-term problems, severe depression, and feelings of rejection in life. (Zardawi, 2013). Facial reconstruction through maxillofacial prostheses helped these patients restore aesthetics, improve functional rehabilitation, correct speech impairments, and provide support for their mental well-being, enabling them to return to their societal interactions (Alanssari and Khalaf, 2020).

Over the years, various materials have been used in the fabrication of maxillofacial prostheses. Silicone elastomers, introduced into maxillofacial prosthetics by Barnhart in 1960, had become the most popular and successful choice due to their superior qualities compared to other materials (Rahman et al. 2018). Silicone elastomers offered excellent tensile and tear strength across a wide temperature range, chemical inertness, stability in the presence of oxidation and heat, ease of processing, low toxicity, and a natural appearance that could be enhanced through staining. Furthermore, they were hygienic and easy to clean as they did not absorb organic waste that could promote bacterial growth (Alanssari, 2019).

Despite the advantages of silicone materials for maxillofacial prostheses, they were not without their disadvantages. One major drawback was their susceptibility to early deterioration caused by various factors such as handling, hygiene, air pollution, ultraviolet (UV) rays, and temperature fluctuations. Heat and UV light exposure could lead to chemical alterations and photo-oxidative potential, resulting in structural changes, mechanical degradation, and optical modifications in the silicone material (Zardawi, 2013). As a result, frequent prosthetic remakes were necessary, typically ranging from every six months to two years, which increased the overall rehabilitation cost (Kheur et al., 2016). Maxillofacial material should have close properties to the missing facial tissue and maintain these properties throughout the lifetime during their clinical use (Eleni et al., 2011).

To address these, numerous research studies have been conducted to enhance silicone materials by modifying the formulation of silicone or reinforcing it with fillers of various types and percentages (Anandkumar et al., 2018). However, it has been concluded that no ideal maxillofacial material could withstand all aging conditions (Rahman et al., 2019).

The Silicone types and their classification:

Poly-dimethylsilane (PDMS), commonly referred to as silicone, is an important synthetic material in the field of maxillofacial prosthetics. Silicone was named by Kipping (1904) based on its composition that resembling the ketone in that it was mostly composed of one oxygen atom for one silicon atom and two methyl groups. The silicone was applied firstly to the maxillofacial prosthetics in the 1960's by Barnhart (Khindria, Bansal, and Kansal, 2009).

The silicone was composed of alternating silicon and oxygen atoms, forming molecular chains that combine organic and inorganic components. The inorganic component was the siloxane bonds (Si—O—Si) and organic component such as methyl, phenyl, tri-fluoropropyl, and vinyl (R—Si—R). This combination of these components gave silicone its unique properties (Alanssari, 2019)

Silicone elastomers had been used widely in maxillofacial prosthetics due to the excellent properties. They exhibited high tensile and tear strength over a range of temperatures, were chemically inert, thermally stable, and had good oxidative resistance. Silicone was easy to process, less toxic, and could be stained to achieve a natural appearance. Additionally, silicone elastomers were hygienic and could be easily cleaned without promoting bacterial growth (Alanssari, 2019).

The adaptability and accommodation of soft tissue movement required in maxillofacial prosthetics made silicone elastomers a suitable choice. They had a flexible bonding structure with high freedom of motion, resulting in low viscosity, glass transition temperature, and melting point and high elasticity. (Zardawi, 2013)

Overall, silicone elastomers had proven to be a versatile and effective material for maxillofacial prosthetics, providing excellent functional and aesthetic outcomes.

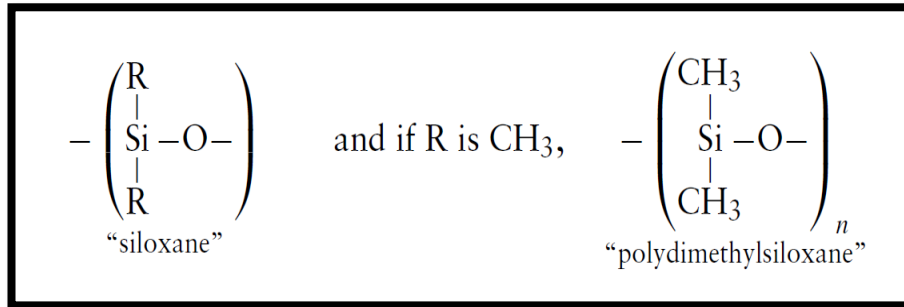


Figure 1.2: Polydimethyl siloxane (Colas and Curtis, 2004).

The classification of silicone materials can be categorized based on their application and the vulcanization process they undergo. (Abraham and others, 2018) provided a comprehensive classification of silicone materials as follows:

1. Classification based on application:

- a) Class I - Implant grade: This grade of silicone is extensively tested to meet FDA approval requirements and is primarily used for implantation purposes, such as breast implants.
- b) Class II - Medical grade: This grade of silicone is suitable for fabricating facial prostheses and is typically limited to external applications. It has undergone cytotoxicity testing, and no adverse effects have been reported.
- c) Class III - Clean grade: This grade of silicone is used for applications such as food packaging and covering. It ensures a high level of cleanliness and safety for contact with food.
- d) Class IV - Industrial grade: This grade of silicone is primarily used for industrial applications where specific properties and durability are required.

2. Classification based on the vulcanization process:

- a) High-temperature vulcanization (HTV) silicones: HTV silicones have advantages such as high tensile and tear strength, excellent elongation ratio, and good thermal and chemical stability. However, they have drawbacks such as fair aesthetics due to opacity, less flexibility, low margin strength, and difficulty in processing. Examples of HTV silicones include Silastic 370, 372, 373, 4-4574, 4-4515, PDM Siloxane, SE-4524U, Q7-4650, Q7-4735, and Q7-4635.
- b) Room temperature vulcanization (RTV) silicones: RTV silicones cure at room temperature and consist of a catalyst (e.g., stannous octoate) and a crosslinking agent (typically an ortho-alkyl silicate). They offer advantages such as excellent color stability, biologically inert properties, ease of handling, and translucency for easy staining to match the patient's skin color. Commercially available products of RTV silicones include Cosmesil, Realistic, LSR (Liquid Silicone Rubber), and VST (Systems and Versital).

3. Classification of silicone elastomer according to the curing reaction:

- a) Condensation reaction: This type of silicone undergoes cross-linking through a condensation reaction between Si-OH and Si-H groups, releasing hydrogen as a by-product. However, it has limitations such as lower marginal strength compared to tear strength, susceptibility to hydrolysis, and longer curing time.
- b) Additive curing reaction: Additive curing reaction utilizes palladium or platinum catalysts at room temperature. It results in the formation of a three-dimensional network structure without by-products and offers advantages such as better tear strength. However, it can be affected by impurities and may exhibit selective adhesion and hydrophobic properties.
- c) Peroxide curing reaction: The peroxide curing reaction requires the application of heat and utilizes organic peroxide free radicals to initiate cross-linking in HTV silicone polymers, forming a three-dimensional network structure.
- d) Irradiation curing system: This curing system involves exposing the material to high-energy radiation, such as gamma rays or electron beams, resulting in cross-linking between polymer chains. Additives can be incorporated to enhance properties, and the material becomes resistant to heat and UV light.

The classification provided by Abraham et al. (2018) offers a comprehensive understanding of silicone materials based on their application and the vulcanization processes they undergo. This knowledge is crucial for selecting the appropriate silicone material for specific applications in various industries.

Maxillofacial silicone elastomers additives

The success of facial prostheses depended on several factors, including durability, biocompatibility, flexibility, color stability, thermal conductivity, and availability (Zardawi, 2013). While there was no single ideal material that possesses all these properties, there were various materials available that exhibit most of them, including increased tear strength, tensile strength, and durability (Beumer, Curtis, and Marunick 1996).

Silicone elastomers without fillers were generally considered inadequate for most appliances. They could wear, degrade, and discolor within a two-year period, tear easily if not handled properly, and be challenging to maintain and keep clean. Therefore, improvements were necessary to enhance the long-term durability of prostheses (Ariana, 2015).

Based on their action, fillers could be classified into two types: active (reinforcing) and passive (extenders). Reinforcing fillers could improve mechanical properties and other composite properties. Examples of reinforcing fillers included fumed silica, aerogel silica, and carbon black. On the other hand, extenders acted as semi-reinforcing or non-reinforcing materials and could impart desirable characteristics while reducing material costs. Commonly used extenders included ground quartz, titanium dioxide, and clay (Momen and Farzaneh, 2011).

Fillers could also be classified based on their composition into organic and inorganic fillers. Organic fillers were predominantly natural materials, while inorganic fillers were mainly composed of inorganic compounds. In the past, these fillers were obtained from natural raw materials, but now they were chemically synthesized. Inorganic fillers have the advantage of being cost-effective but could also demonstrate high hardness and relatively high mass density (around 2.5 g/cm³). Commonly used inorganic fillers included silica, alumina, mica, kaolin, glass beads, and chalk (Alanssari, 2019).

The physical and mechanical properties obtained after adding fillers to silicone elastomer depended on several factors, such as the type and morphology (size and structure) of the filler used, filler concentration, length of polymer chains, degree of cross-linking, molecular weight, dispersion and orientation of the fillers in the matrix, and adhesion with the polymer chains. These factors could result in the production of a strong and elastic material that meets clinical criteria (Stathi et al., 2010).

To achieve the most appropriate physical and mechanical properties for maxillofacial materials, the ratio of the matrix to filler particles could be adjusted and tested until the desired properties were achieved (Mitra et al., 2014).

In 2008, Gunay et al. found that the addition of tulle (nylon art 2429) to silicone resulted in a successfully reinforced maxillofacial silicone elastomer with improved mechanical properties, particularly in terms of elongation.

Fillers could also affect other material properties, and commonly used fillers include carbon black, titanium dioxide, and barium sulfate. These fillers were used to improve electrical conductivity, and dielectric constant, and increase radio-opacity, respectively (Colas and Curtis, 2005)

To improve silicone durability and stability against UV light the addition of UV stabilizers or absorbers. Zinc oxide and titanium oxide are some of the most effective UV-absorbing inorganic particles (Reinosa, 2014).

Aging of the maxillofacial silicone prosthesis

Longevity was a critical property in the clinical application of maxillofacial prostheses. The success of treatment relies on the mechanical and physical properties of the materials, as well as their ability to withstand alterations under various weathering conditions (Zardawi, 2013). However, maxillofacial prostheses have been associated with short-term durability, often requiring frequent replacement (Hatamleh et al., 2011b). Silicone-based prostheses, for example, might need to be replaced every 6-12 months, while prostheses made from other materials like acrylic may last 1.5 to 2 years (Al-Dharrab et al., 2013)

The need for frequent replacement of maxillofacial prostheses could be burdensome for patients. Material properties played a significant role in determining the lifespan of the prosthesis. Both resin and elastomer materials used in maxillofacial prostheses were susceptible to degradation and discoloration over time (Haug et al., 1992).

The main causes of prosthesis deterioration are environmental elements, such as exposure to ultraviolet light, air pollution, and humidity (Al-Dharrab et al., 2013).

Exposure to UV radiation, particularly from sunlight, was a primary cause of material degradation in maxillofacial prostheses. This degradation process was known as photooxidation, where the polymers underwent physical and chemical changes due to radiation absorption (Zardawi, 2013).

When polymers were exposed to UV radiation, the energy from sunlight triggers the formation of free radicals by breaking hydrogen-carbon bonds within the polymer chain. This process was initiated by the dissociation of these bonds and the subsequent formation of free radicals. The effects of UV light were predominantly observed in the surface layer of the material, with a lesser impact on deeper layers. The free radicals utilized surface oxygen at the surface, and the interaction between UV light and oxygen diffusion promoted this reaction (Zardawi, 2013).

The heat played a crucial role in the kinetics of the photooxidation reaction. Additionally, other weathering factors such as humidity and air pollution could exacerbate the effects of UV radiation on the mechanical breakdown of the polymers, accelerating the aging process. To mitigate the detrimental effects of UV radiation, materials, and techniques could be employed to enhance the UV resistance and overall durability of maxillofacial prostheses. These measures aimed to prolong the lifespan of prostheses and minimize the need for frequent replacements (Zardawi, 2013).

At the macromolecular scale, photodegradation can result in numerous effects ranging from losses of molecular chain segments to the unzipping of polymer chain structures. Polymeric ultraviolet stabilizers transform this energy through a series of photochemical reactions to a less harmful state (Crawford, 1999)

Other factors influencing prosthesis longevity included the specific material used and the patient's attitude toward the prosthesis (Zardawi, 2013). Researchers continued to explore ways to improve the longevity of maxillofacial prostheses, aiming to develop materials and techniques that could withstand the challenges posed by environmental factors and patient usage (Stathi et al., 2010).

The deterioration of polymers and changes in their properties could be attributed to various factors, including light, temperature, and humidity. When these factors act together, they pose a significant threat to polymers. Individually, each factor could cause damage, but when combined, they had a synergistic effect, leading to further deterioration. The main cause of degradation was exposure to UV radiation from sunlight, also known as photo-oxidation (Zardawi, 2013).

Benzotriazole UV stabilizers (BUVSs)

Benzotriazole UV stabilizers (BUVSs) are widely used organic UV filters derived from benzotriazole, a heterocyclic compound with the molecular formula $C_6H_5N_3$ (29). These stabilizers contain a phenolic group attached to the benzotriazole structure and are capable of absorbing the entire spectrum of ultraviolet light, including UV-A (320-400 nm) and UV-B (280-320 nm) wavelengths (Montesdeoca-Esponda, 2013).

Benzotriazole UV stabilizers, including benzotriazoles, find extensive use in various personal care products such as sunscreen, soap, shampoo, toothpaste, hair dye, nail polish, and cosmetics. They are also utilized as corrosion inhibitors, UV-light stabilizers in plastics, and additives in industrial products like dishwasher detergents, aircraft anti-icing fluids, automotive antifreeze formulations, and metal-cutting fluids (Montesdeoca-Esponda, 2013).

Ultraviolet (UV) light can be divided into three segments: UVC (100-290 nm), UVB (290-320 nm), and UVA (320-400 nm). The Earth's stratosphere acts as a protective shield against harmful UV radiation below 280 nm. The damaging effects of UV radiation are particularly significant in the range above 290 nm, and in outdoor applications, the region between 290 and 400 nm is of great concern (Crawford, 1999). Therefore, UV light stabilizers are specifically designed to effectively absorb wavelengths above 280 nm, as this is where polymeric materials are most vulnerable to the detrimental effects of solar radiation in this range (Crawford, 1999).

Bisotrizole

Bisotrizole, also known as Tinosorb M or UV 360, is a specific benzotriazole compound used as a UV filter in sunscreens, skincare products, and skin lightening products. It belongs to the hydroxyl phenyl benzotriazole class and has a chemical formula of $C_{41}H_{50}N_6O_2$ (Montesdeoca-Esponda, 2013). Bisotrizole can absorb ultraviolet radiation in the range of 280-400 nm, providing protection against both UVB and UVA rays (Bologna, Jorizzo, Schaffer, 2012).

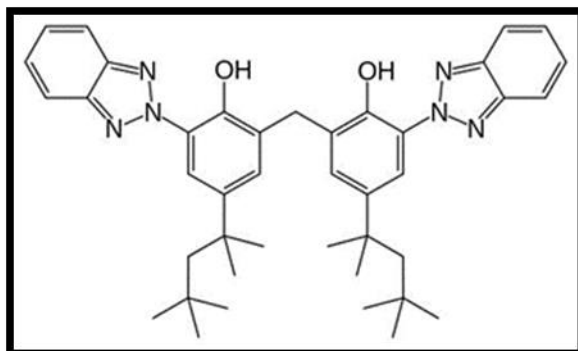


Figure 1: Chemical structure of Bisotrizole that is responsible for UV absorbance property (Lawrence, 2015).

One notable characteristic of Bisotrizole is its photo-stability, meaning it can maintain its effectiveness over time without significant degradation when exposed to light. It is also considered non-mutagenic and non-estrogenic (Bologna, Jorizzo, Schaffer, 2012; Lawrence, 2015). In industrial and engineering applications, Bisotrizole is used to stabilize polymers, preventing undesired processes such as oxidation, uncontrolled recombination, chain fission, and cross-linking caused by polymer photo-oxidation (Kheur et al., 2016).

The incorporation of Bisotrizole may extend the lifespan of maxillofacial silicone materials by increasing their resistance to photo-degradation (Zardawi, 2013).

Bisotrizole are derived compound of Benzotriazole which is a heterocyclic compound. Bisotrizole and other BUVSs have a phenolic group attached to the benzotriazole structure, allowing them to absorb the full spectrum of ultraviolet light (including UV-A and UV-B) (Montesdeoca-Esponda, 2013).

Bisotrizole functions by absorbing UV photons and converting them into less harmful forms of energy, such as heat. This process occurs through the reversible movement of electrons within the Bisotrizole's molecular structure. When UV light hits the chromophore (a double bond in a conjugated configuration) of Bisotrizole, the energy of the UV rays is absorbed. Ultimately this led to photo-excitation of the electron and made that electron move from its ground state into an excited state (electron movement type $\pi-\pi^*$) (specifically, a movement from the highest occupied molecular orbital [HOMO] to the lowest unoccupied molecular orbital [LUMO]). Additionally, the presence of a hydroxyl group (referred to as auxochromes) attached to the chromophore can modify the wavelength or intensity of Bisotrizole's UV light absorption (Skoog et al., 2013). This mechanism empowers the elastomer to resist the damaging effects of UV radiation and preserve its mechanical and optical properties over time.

Conclusion

Bisotrizole has gained attention as a promising material for use in maxillofacial silicone applications. Maxillofacial silicone prosthetics are used to restore facial features in individuals who have experienced facial trauma, congenital deformities, or undergone surgical procedures. These prosthetics require materials that closely resemble natural facial tissue in terms of appearance, texture, and durability.

One of the key advantages of Bisotrizole is its ability to provide enhanced protection against the harmful effects of UV radiation. UV exposure can cause degradation and discoloration of silicone materials over time, leading to a decrease in their aesthetic and functional properties. Bisotrizole acts as a UV absorber and helps to minimize the absorption of UV rays by the silicone matrix, thereby reducing the rate of photodegradation. This property is crucial in maintaining the long-term

durability and stability of maxillofacial silicone prosthetics, ensuring that they retain their color and structural integrity over extended periods of use.

In addition to its UV absorption properties, Bisotrizole is known for its stability and inertness. It does not undergo significant chemical reactions or atomic exchanges with the silicone matrix, making it a suitable

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"تعزيز الثبات الضوئي لسيليكون الوجه والفكين عن طريق إضافة البيسوكتريزول الممتص للأشعة فوق البنفسجية (مراجعة للأدبيات)"

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خلاصة:

تؤكد مراجعة الأدبيات هذه على تأثير الأشعة فوق البنفسجية على تدهور السيليكون المستخدم في الأطراف الاصطناعية للوجه والفكين. مع مرور الوقت، تتدهور الخصائص الفيزيائية والميكانيكية للسيليكون بسبب التحلل الضوئي. ولمعالجة هذه المشكلة، تستكشف الدراسة استخدام Bisotrizole ، وهو حشو مستقر ضوئياً يمتص بشكل فعال مجموعة واسعة من الأشعة فوق البنفسجية الضارة. من خلال دمج Bisotrizole كمثبت للأشعة فوق البنفسجية، يمكن إطالة عمر مادة السيليكون للوجه والفكين، مما يعزز مقاومتها للتحلل الضوئي. تؤكد المراجعة على أهمية تضمين مثبتات الأشعة فوق البنفسجية، وتحديدًا مكونات البنزوتريازول مثل بيسوكتريزول، في مواد السيليكون المستخدمة في الأطراف الاصطناعية للوجه والفكين.

الكلمات الدالة: سيليكون، بنزوتريازول، بيسوكتريزول، الأشعة فوق البنفسجية، التحلل الضوئي.