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Biomechanical properties of nano-TiO_2 addition to a medical silicone elastomer: The effect of artificial ageing

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ABSTRACT

Objectives: The aim of this study was to evaluate the effect of TiO_2 nanoparticles on the mechanical and anti-ageing properties of a medical silicone elastomer and to assess the biocompatibility of this novel combination.

Methods: TiO_2 (P25, Degussa, Germany) nanoparticles were mixed with the silicone elastomer (MDX4-4210, Dow Corning, USA) at 2%, 4%, and 6% (w/w) using silicone fluid as diluent (Q7-9180, Dow Corning, USA). Blank silicone elastomer served as the control material. The physical properties and biocompatibility of the composites were examined. The tensile strength was tested for 0% and 6% (w/w) before and after artificial ageing. SEM analysis was performed.

Results: TiO_2 nanoparticles improved the tensile strength and Shore A hardness of the silicone elastomer ($P < 0.05$). However, a decrease in the elongation at break and tear strength was found for the 6% (w/w) composite ($P < 0.05$). All the ageing methods had no effect on the tensile strength of the 6% (w/w) composite ($P > 0.05$), but thermal ageing significantly decreased the tensile strength of the control group ($P < 0.05$). Cellular viability assays indicated that the composite exhibited biocompatibility.

Conclusions: We obtained a promising restorative material which yields favourable physical and anti-ageing properties and is biocompatible in our in vitro cellular studies.

1. Introduction

Defects of the maxillofacial area can cause embarrassment for patients. The first choice of treatment is the fitting of a prosthetic following ablative surgery, which can improve the patient's quality of life.[1,2] Silicone elastomer is a promising functional material used for the correction of maxillofacial defects. However, this material does have drawbacks, since natural or outdoor weathering of silicone elastomers can induce significant changes in its physical and mechanical properties.[3] In addition, the conventional disinfection method can accelerate ageing of the facial epitheses.[4] Ultimately, this means that the patient must undergo several prosthetic replacements. In this regard, there have been several previous studies on the longevity of facial prostheses, with earlier reports indicating that the average prosthetic lifetime is 6–12 months.[5,40]

With the continued improvement of clinical care, the demands from both doctors and patients regarding the

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performance of silicone elastomers are increasing. Unfortunately, this demand has not been satisfied by the conventional silicone elastomers used in facial epitheses. More recent modifications to silicone elastomers have improved their properties. For example, Liu et al.[6] added hollow microspheres into the MDX4-4210 elastomer to decrease density and improve flexibility, and showed that a 5% (v/v) hollow microsphere composite yields a light, soft, flexible, and biocompatible maxillofacial prosthetic material. Han et al.[7] found that the incorporation of nano-oxide (Ti, Zn, or Ce) improved the mechanical properties of the A-2186 elastomer (FACTOR II, USA). However, to the best of our knowledge there have been no reports describing improvements to the anti-ageing properties of facial epitheses used in the oral environment.

Titanium dioxide (nano-TiO_2) nanoparticles have been proposed as a reinforcing material for addition to dental composites. Elsaka et al.[8] showed that incorporation of nano-TiO_2 nanoparticles into conventional glass-ionomer (GI) improved its mechanical and antibacterial properties. Mixing of zirconia nanoparticles with a primer or an adhesive increased the bond strength of the adhesive system through reinforcement of the adhesive layer and resin tags.[9] On the contrary, the addition of TiO_2 and SiO_2 nanoparticles to poly(methyl methacrylate) acrylic resins adversely impacts the flexural strength, and this effect is directly related to the concentration of nanoparticles.[10]

Biocompatibility is the ability of a material to function optimally in a particular application, while having minimal impact on the host response. This is a critical feature that distinguishes materials used in biological applications from other high-tech materials.[11,12] The biological and toxicological properties of dental materials are the most important criteria on which clinicians base their decisions for facial epitheses selection.[13] The MTT assay is a reliable and sensitive method for detecting cell growth and survival.[14]

While the studies outlined above indicate that silicone elastomer is the preferred material for maxillofacial epitheses, the rapid ageing of facial epitheses in a service environment frequently underlies why such facial epitheses ultimately fail. With this in mind, the aim of the present study was to improve the performance of silicone elastomer properties. Specifically, we used three artificial ageing tests that simulate the oral environment to determine the effect of nanoparticle additives on the tensile strength of elastomers.

2. Materials and methods

Test samples were obtained by blending 2%, 4%, and 6% (w/w) proportions of TiO_2 (P25, Degussa, Germany) nanoparticles and the medical silicone elastomer (MDX4-4210, DOW Corning, USA) in Teflon molds. Thinners (Q7, DOW Corning, USA) were added at a mass ratio of 1:0.8 to the total mass of MDX4-4210, and TiO_2 nanoparticles were weighed using a balance with an accuracy of ± 0.0001 g (BSA234S, Sartorius, Germany). Subsequently, the TiO_2 nanoparticles and curing agent (maintained at a SE:curing agent mass ratio of 10:1) were mixed with the silicone elastomer using a bull magnetic stirrer (HJ-6, Jintan Fuhua Electric Apparatus Co Ltd, China) in a 50-ml glass beaker. Blank silicone elastomer served as the control group. Air bubbles in the mixture were eliminated by 30 min incubation in a vacuum oven (SHZ-DIII, Nanhe Zhicheng Science and Technology Development Co Ltd, China). Finally, the mixture was allowed to cure for 2 h at room temperature to allow for gas escape. Further curing was then carried out in a high temperature chamber (YLCD-8000P, KELONG, China) at 60 °C for 4 h. The specimens were stored at 23 ± 1 °C for 24 h before testing.

2.1. *Tensile strength and Elongation at break*

Thirty-six type 2 dumbbell-shaped specimens were prepared using a silicone elastomer cutter ($N = 36$, $n = 9$) (Fig. 1). The tensile strength was measured according to ISO 37:2005 standard on a servo control computerized tensile testing machine (TH-8201S, Tuobo Machinery Co Ltd, China) at a crosshead speed of 500 mm/min. Tensile strength, TS (MPa), was calculated as follows:

$$TS = \frac{F}{Wb}$$

where F is the peak force (N), W is the specimen width of narrow parallel portion (mm), and b is the specimen thickness (mm).

The elongation at break, E_b (%), was calculated using the following equation:

$$E_b = 100 \times \frac{(L_b - L_0)}{L_0}$$

where L_b is the test length at break (mm) and L_0 is the initial test length (mm).

2.2. *Tear strength*

Twenty-four crescent-shaped specimens were prepared using a silicone elastomer cutter ($N = 24$, $n = 6$) (Fig. 2). The tear strength was measured based on the ISO 34-1:2004 standard using a servo control computerized tensile testing machine at a crosshead speed of 500 mm/min. Tear strength, TS (KN/m), was calculated according to the following formula:

$$TS = \frac{F}{d}$$

where F is the tearing force (N) and d is the specimen thickness (mm).

2.3. *Shore A hardness*

Twelve bar-shaped specimens were prepared in a Teflon mold (70 mm × 40 mm × 6 mm) ($N = 12$, $n = 3$). Each sample was

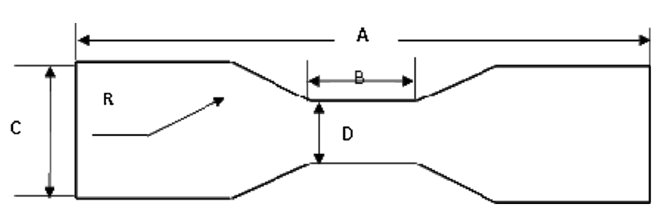

Fig. 1 – Sample size of tensile strength (mm): A = 152 mm, B = 55 mm, C = 25 mm, D = 13 mm, R = 13 mm.