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Potential use of a polycarbonate-urethane matrix reinforced with polyethylene fibers for shock-absorbing dental implants

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ABSTRACT

The absence of a shock-absorbing mechanism in commercial dental implants is a likely factor in the resulting bone loss and possible implant failure. The aim of the current study is to generate a shock-absorbing dental implant that resembles the periodontal ligament, which naturally absorbs occlusal overloading forces. To achieve this, a polycarbonate-urethane composite reinforced with polyethylene fibers will be constructed. Tests based on finite element analysis and mechanical testing are proposed to further examine this novel implant type.

Introduction

The ideal dental implant should closely mimic the biomechanical properties of a natural tooth. In the presence of overloading, a shock-absorption mechanism should be implemented within or around the implant to help dissipate the impacting forces. However, most commercially available dental implants do not have such overload absorption advancements. It has been reported that occlusal overloading can be destructive for implants and can cause bone loss [1], screw loosening, fracture, or implant failure [2].

In the event of excessive loading, the periodontal ligament (PDL) serves as a shock absorber for the natural tooth [3]. The primary function of the PDL is to connect the teeth to the alveolar bone. The PDL displays both viscous and elastic behavior and is thus considered a viscoelastic material [4]. In completely elastic materials, all stored energy is recovered once the applied force is removed. However, in viscous materials, the stored energy is not recovered. In a viscoelastic system, some of the energy is recovered and the remainder is dissipated. From an anatomical viewpoint, intra- and extravascular fluids in the PDL resist light and moderate forces, while the principal fibers resist heavier forces.

The PDL consists mainly of collagenous fibers, including alveolar crest, horizontal, oblique, apical, and interradicular fibers [5]. Oblique fibers withstand the occlusal forces along the long axis of the tooth. Apical and interradicular fibers (which are only present in multi-rooted teeth) withstand forces in the occlusal direction [6]. When masticatory force is exerted, the tooth rapidly moves apically, and the adjoining teeth support this loading. As the masticatory force grows larger, tooth movement slowly decreases. The tooth will gradually return to its primary position as the force dissipates. These biomechanical actions distribute the force and absorb the shock received by the tooth [7].

Significance/Prevalence

Conventional implants lack the potential to be supported by a cushion-like structure. Therefore, these implants are more vulnerable to traumatic overloading, which has been shown to be a major reason for implant failure [8]. Because the failure rate of implants is 4.93% for the mandible and 8.16% for the maxilla [9], a robust damping system designed to minimize traumatic overloading may help to prevent such failures.

Background literature

The issue of shock absorption by implants has been theoretically discussed in previous literature [10]. To reduce tension on the bone, some studies [11,12] have suggested using a silicone-based abutment (connecting element). Moreover, some of the newly designed prototypes [7] use silicone for part of the model (e.g., the resilient ring). Nonetheless, silicone is not an appropriate bio-inert material for direct contact with the

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Table 1
Various shock-absorbing materials used in the past.

Application	Inventor	Material/Mechanism
Dental	Kanth [15], [11] Koch [16], Kirsch [12]	Silicon abutments, direct contact with gingiva, inflammation
Dental	Mobile-implant (SIS-Inc., Klagenfurt, Austria) Gaggl and Schultes [17]	Conic implant with three silicon rings enclosed in center
Dental	Carvalho [18]	Silicone rubber between abutment and crown
Dental	Compliant Keeper (CK) system Mensor et al. [19]	Selectively controlled progressive loading, silicone O- rings
Dental	Chen, et al. [7]	Partial cannular cylinder, resilient silicone ring

pre-implant tissue region, and it may induce a host immune reaction [13]. In addition, the finite element methods used to analyze and verify the aforementioned model have been restricted to isotropic and homogenous materials, whereby the assumption is that the materials have a consistent structure in all directions. This assumption does not reflect the actual mechanical properties of biological tissues.

Recently, the shock-absorption capacity of a zirconia implant abutment was assessed using the Periometer®, a percussion device that measures damping [14]. The inclusion of composite resin components (e.g., an abutment or restoration) has demonstrated shock-absorbing characteristics that mimic natural teeth. It was suggested that further studies should be conducted to evaluate the long-term and fatigue behavior of the implant.

Advantages and disadvantages

- All of the shock-absorption solutions in the dental implants listed in Table 1 use silicone. When in direct contact with the gingiva, silicone causes inflammation. For implants that use silicone in an enclosed chamber, there is concern that an accident leading to implant breakage would result in the silicone contacting oral tissue.
- Although plain silicone is viscoelastic, it demonstrates linear behavior [20]. The PDL has a non-linear characteristic.
- The PDL consists of collagenous fibers. A mechanism for mimicking the fibers is absent in all previously described techniques.

Hypothesis

In the search for a biocompatible dental implant material, an approach similar to that for an orthopedic problem was adopted. The meniscus is a C-shaped, bi-phasic piece of cartilage [21] that cushions the knee and acts as a shock-absorber; it consists of water (63–75%) and collagenous fibers [22]. The meniscus may undergo tears during traumatic events. In 85% of cases, surgical intervention (i.e., meniscectomy) is required to remove all or part of the torn meniscus [23]. A synthetic meniscus replacement made from a polycarbonate-urethane (PCU) matrix reinforced with polyethylene fibers (PE) was recently developed to treat patients who suffer from post-meniscectomy syndrome [23]. Importantly, PCU shows a low wear rate [24] and good compatibility with natural tissues [25].

Proposed materials and methods

Objective: Conceptual design of a mechanism for shock absorption in dental implants that is biologically safe for patients.

Procedure: Preliminary design, material selection, finite element analysis (FEA), prototype generation, and mechanical testing.

Materials: Possible materials that can be used to absorb stress include fiber-enhanced viscoelastic damping polymers [26] and PCU with PE fibers.

Devices: Fiber-reinforced polymers are prepared by molding processes that generate the correct shape.

Measurements: The size, dimension, and thickness of the damping structure required for shock resistance must be computed.

Design parameters

To develop an optimal design, the following suggestions, based on FEA available from the literature, will be considered.

Size

In larger diameter implants, the stress distribution becomes more uniform [27,28], and the magnitude of cortical bone stresses decreases [28]. To protect the bone and dissipate occlusal forces over a larger area, it has been recommended to avoid short implants. Lum et al. [29] showed that occlusal forces are primarily distributed to the crestal bone rather than being evenly distributed throughout the surface area of the implant-bone interface. The typical diameter (D) and length (L) for the implant are as follows: D = [3.5 mm, 4 mm, 4.5 mm, 5 mm, 6 mm]; and, L = [9 mm, 10 mm, 11 mm, 12 mm, 13 mm]. Here, mid-range values of D = 4.5 mm and L = 11 mm are selected.

Shape

Mailath et al. [28] reported that implants with cylindrical shapes are more suitable than cone-shaped implants. Holmgren et al. [30] showed how, in terms of distribution, stepped cylindrical implants are preferable.

Mechanical properties

The data available in the literature offer contradictory measures for the elastic modulus of the PDL [31].

The ultimate tensile strength of Bionate PCU 55D is 60.5, which is close to the PDL strength reported by Cook et al. [32]. Although masticatory and bruxing forces may reach 500 N in females and 700 N in males [33], some FEA reports have only considered forces up to 100 N [34].

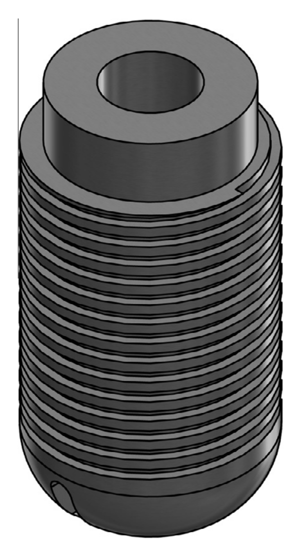

Fig. 1. Suggested design. A cylindrical implant with squared threads is depicted.