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Occlusal loading during biting from an experimental and simulation point of view

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ABSTRACT

Objectives. Occlusal loading during clenching and biting is achieved by the action of the masticatory system, and forms the basis for the evaluation of the functional performance of prosthodontic and maxillofacial components. This review provides an overview of (i) current bite force measurement techniques and their limitations and (ii) the use of computational modelling to predict bite force. A brief simulation study highlighting the challenges of current computational dental models is also presented.
Methods. Appropriate studies were used to highlight the development and current bite force measurement methodologies and state-of-the-art simulation for computing bite forces using biomechanical models.
Results. While a number of strategies have been developed to measure occlusal forces in three-dimensions, the use of strain-gauges, piezo-electric sensors and pressure sheets remain the most widespread. In addition to experimental-based measurement techniques, bite force may be also estimated using computational models of the masticatory system. Simulations of different bite force models clearly show that the use of three-dimensional force measurements enriches the evaluation of masticatory functional performance.
Significance. Hence, combining computational modelling with three-dimensional force measurement techniques can significantly improve the evaluation of masticatory system and the functional performance of prosthodontic components.

Contents

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1. Introduction

The function and integrity of the masticatory system has a significant bearing on the quality of life of an individual [1–4]. Poor health of the masticatory system may arise from a multitude of often interrelated factors including dental cavities, tooth loss, malocclusion, temporomandibular (TMJ) joint dysfunction and/or mandibular fractures [5,6]. Correct and timely diagnosis and treatment of these pathologies is therefore vital in improving quality of life. The use of imaging modalities such as X-ray or Cone Beam Computed Tomography (CBCT), can facilitate evaluation of the masticatory system structure and infer from its form any deficiencies in its function, however, a rigorous functional diagnosis may not be feasible using these approaches. A common quantity used to evaluate masticatory function is the maximum voluntary bite force (MVBF) (e.g., [7–12]). MVBF may be used to diagnose pre-existing masticatory pathologies including TMJ disorders [13–15], mandibular fractures [16] and malocclusion [17,18] and can be used to asses the performance of dental implants through comparison of post-intervention MVBF to expected values [19–21,9,22,23]. In most cases, the MVBF corresponds only to the vertical component of the overall bite force. However, given the complex kinematic nature of mandibular movement, bite forces occur not only in the vertical direction but also in the transverse directions [24,25], particularly in chewing or bruxism. Therefore, even at this global level, i.e., when considering the *total* force exerted by the mandible, three-dimensional force measurements may ultimately enrich the diagnoses of masticatory pathologies and the use of mouth guards and also the design and assessment of dental prostheses.

Whereas total bite force is a indicator for overall masticatory functional performance, forces experienced by individual teeth ought to be considered when designing partial or full dental implants, choosing the appropriate filling material, or planning root canal treatment. Occlusal force varies over different regions of the dental arch [26,27]. Furthermore, the per-tooth or *local* occlusal force magnitude has been identified as one of the major causes of dental implant fractures [28,29]. Therefore, dental implants should be rigorously tested at the design stage to assure robustness and longevity while maintaining masticatory performance. The use of virtual environments may be beneficial to achieve this, since implant designs may be rapidly analysed and tested under a variety of occlusal conditions. As such, the use of simulations to aid in the virtual design of dental implants has become widespread over the past few decades (e.g., [30–37]). Within virtual environments, various other masticatory conditions have been represented, including tooth morphology influence during chewing [36], or investigating masticatory system function when loads are applied to the occlusal surface [38]. However, if only single point forces are considered to load a masticatory system, which remains the state of the art in many applications, occlusal loading conditions may be greatly oversimplified. The three-dimensional geometry of the occlusal surfaces, combined with the complex and varying movement of the mandible results in a large variation of occlusal contact areas, over which forces act. This is further complicated by the large inter-subject variability of tooth morphologies and mandibular movements.

An alternate approach to define the occlusal loads in the virtual environment is to use biomechanically driven models of the masticatory system (e.g., [39–43]). By accurately modelling the underlying biomechanical constituents, i.e., the materials, geometries and movements, the predicted occlusal loads may be assumed to be within the physiological range. Simulations have the advantage of providing detailed information, over an infinite variety of anatomy and load configurations, where obtaining such detail experimentally may be difficult, expensive or impossible to obtain.

Within the literature, there exists a large quantity of different methodologies to evaluate forces acting on the teeth during biting and clenching. Due to their importance in the design of dental materials, tooth restoration and implants, this review aims to provide an overview of the development and state-of-the-art methods for determining bite force using experimental and computational techniques. Section 2.1 focuses on experimentally measured resultant bite forces, with a focus on three-dimensional bite force measurement given in Section 2.1.5. Section 2.2 provides an overview on how biomechanical models can be used within computer simulations to predict occlusal loads. Section 3 summarises the different bite forces reported in the literature. The overview on different methodologies to determine bite forces concludes with a simulation, highlighting the importance of realistic and physiological bite forces through comparison of stress distributions within the mandible using a point load and a spherical ball load in Section 4. Furthermore, recent trends and challenges facing the field of bite force measurement and computational force predictions are discussed.

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