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# DEVELOPMENT OF CUSTOMIZED COMPOSITE MOUTHGUARDS TO IMPROVE ATHLETES SAFETY AND COMPLIANCE

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**Summary:** Athletes of competitive sports are at risk of contact induced injuries such as dental and cranial tissues damages. From a biomechanical perspective, a shock to the jaw can directly introduce destructive stress on the tooth-bone complex and indirectly cause traumatic cerebral tissue deformation due to the consequent head kinematical response. Mouthguards (MGs) can be beneficial in reducing the injury risk by changing the dynamics of an impact to the jaw as well as enhancing head stability. Despite availability of three types of MGs (e.g., off-the-shelf, mouth-formed and custom-made), literature findings suggest that only well-designed customized MGs can provide trauma-protective effect and athletes comfort simultaneously. Indeed, not only mechanical properties of materials could have an impact on MG performance, but also the geometrical/structural attributes are contributing factor in the MG design. To study the effect of MG thickness, materials and structural design, an anatomical human head finite element model was developed including skull, teeth, and periodontal ligament. We then evaluated the role of different design variables in the performance of customized MGs by simulation of a Hockey puck impact (using LS-DYNA explicit solver) and analysis of protected teeth response with different MG configurations. We consistently observed that the larger MG thickness is more efficient in reducing the risk of injury in all examined configurations. However, athletes are reluctant to use bulky MGs due to the perceived discomfort, despite being aware of their protective advantage. Additionally, we found that space inclusion is only effective when a hard insert is employed in the composite MG arrangement to distribute the load. Moreover, combination of hard and soft layers could not significantly change the protective performance of MG compared to conventional design when the teeth are in full contact with the MG. The best configuration was obtained when we employed a stiff thermoplastic layer in conjunction with hard and soft rubbery layers in a composite MG with space inclusion in front of incisors. Specifically, it was found that the thickness reduction of a composite and spaced MG from 4 mm to 3 mm is not significantly altering its protective capability. However, it was not possible to find a compromise between protective performance and athletes comfort when the MG thickness was further decreased to 2.5 mm. It was also shown that by controlling the thermoplastic layer's geometry and degrees of hardness, the protective performance of the composite and spaced MG could be tuned. Collectively, the high cost, long lead time and rare availability of expert orthodontists for fabrication of spaced and composite MG designs with specific structural and material properties could restrict their usage among athletes. However, the operational difficulties in the traditional fabrication process (thermoforming technique) could be by-passed by emerging digital based additive manufacturing technologies. In particular, multi-material 3d printing could present important potential to enhance the design details and the final product's geometrical accuracy. We therefore envision the future with printable composite custom-mouthguard with distinct attributes that are adaptable by the user based on the level/type of competition and associated harshness of the impact incidences.