# Quantifying Changes in Mouthguard–Dentition Fit to Support Head Impact Measurement Validity

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## Introduction / Objective

- Mild traumatic brain injury (mTBI) is a major concern in contact and collision sports [1,2].
- Measuring head kinematics during impacts is critical for understanding injury risk and improving player safety [3,4].
- Wearable sensors are widely used to collect real-world head impact data [3,5].
- However, measurement accuracy depends heavily on how well the sensor is coupled to the skull.
- The relationship between instrumented mouthguard (iMG) fit and measurement accuracy is not well understood [5,6]

**Objective:** Establish a workflow to quantify changes in mouthguard (MG) fit associated with repeated use over time.

## Background

- Many wearable systems, such as helmet- or skin-mounted sensors, suffer from poor skull coupling, reducing measurement accuracy [4,7].
- iMGs improve skull coupling by attaching directly to the dentition, enabling more accurate measurement of head motion during impacts [6,8].

**https://www.bikeradar.com/**

**Figure 1:** Example of a helmet-mounted sensor. The helmet's independent movement from the skull during impact leads to reduced skull coupling and decreased measurement accuracy.


**https://preventbiometrics.com/**

**Figure 2:** Instrumented mouthguard (iMG) designed to measure head kinematics. Direct coupling to the teeth enables more accurate tracking of skull motion compared to helmet- or skin-mounted sensors. Contains accelerometers and gyroscopes.

- Despite this advantage, repeated use can deform the MG and degrade its fit over time [9].
- Reduced coupling may introduce measurement error, limiting the reliability of collected data [4,5].

## Methods and Materials

**1. Mouthguard and Dental Modeling:** A boil-and-bite MG was custom-fit to the participant. Dental stone casts were generated from high-resolution impressions of the participant's dentition. The cast were produced using Type IV gypsum and digitized using micro-CT to create an accurate 3D model for the dentition.

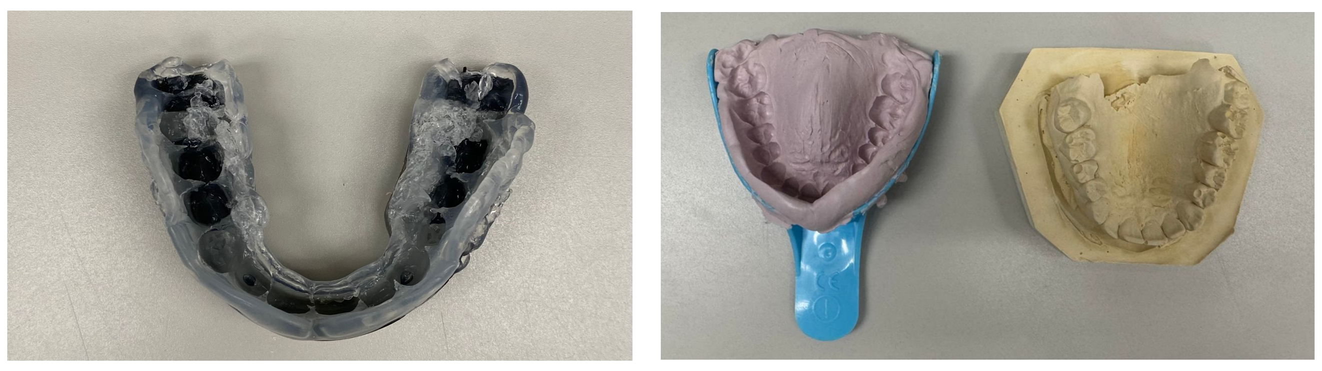

**Figure 3-4:** Custom-fitted Under Armour Mouthguard, Dental Impression, and Dental Stone Cast

**2. Micro-CT Imaging:** A Nikon XT H 225 ST was used to obtain high-resolution micro-CT scans to capture the geometry of the dentition–MG system, at both the baseline and deformed fit from two hours of wearing. Scan parameters (voxel size <55 μm) enabled detailed visualization of fit and internal gaps.

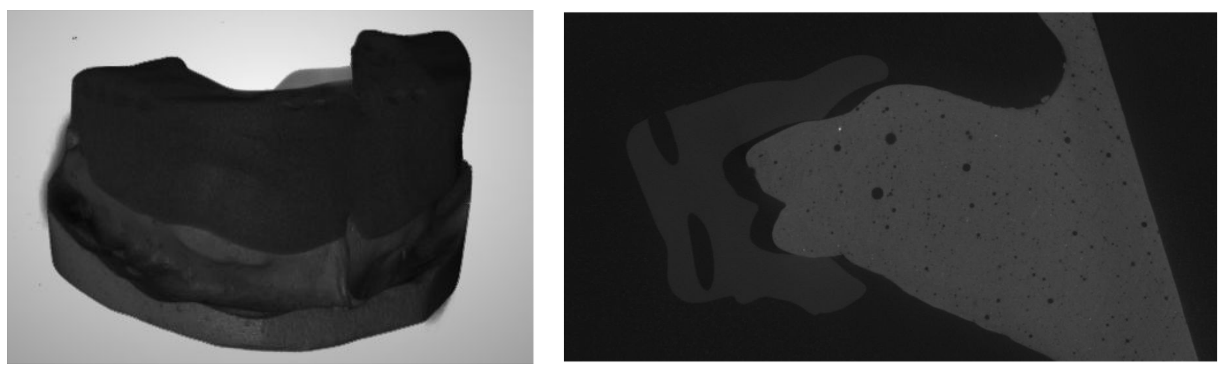

**Figure 5-6:** 3D Reconstruction of Dental Stone with Custom-Fit Mouthguard (baseline) and a cross-sectional view

**3. Image Processing:** CT scans were processed using Dragonfly ORS 3D software. TIFF image stacks were imported, cropped, and segmented to isolate the dentition and MG. The MG was then subdivided into three anatomical regions (incisors/canines, premolars, and molars) to enable region-specific analysis of MG fit.

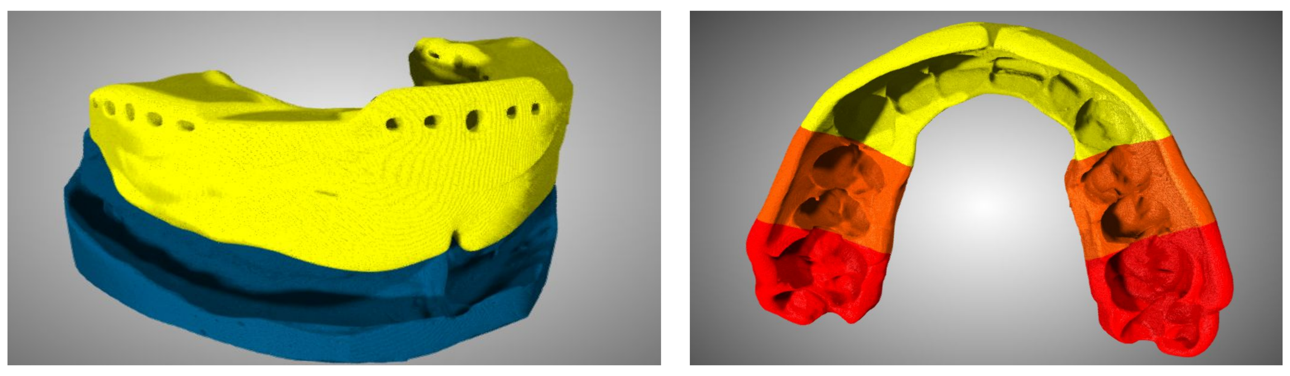

**Figure 7-8:** 3D View of the segmented dentition-MG system and the MG subdivided into anatomical regions

**4. Fit Quantification:** MG fit was evaluated using regional MG-dentition contact surface area, normalized by the total inner surface area of the MG in each region at baseline. Contact area was calculated in Dragonfly using interpolated 3D interfacial surface analysis between the segmented dentition and MG surfaces.

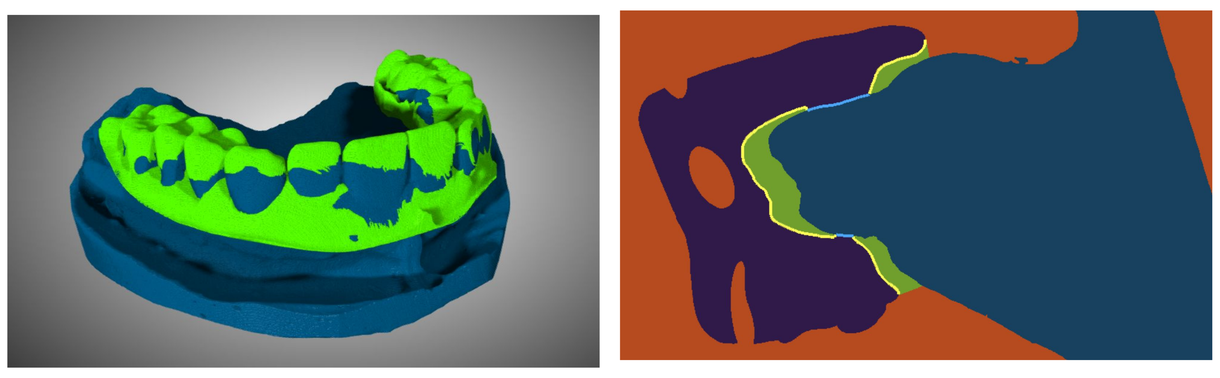

**Figure 9-10:** Visuals of MG fit quantification, showing air gaps between the dentition and MG and contact surface contours

## Results

| Region | Baseline MG Inner Surface Area (mm²) | Baseline Contact Area (mm²) | Deformed Contact Area (mm²) | Change in Contact Area (mm²) | % Change in Contact Area |
|---|---|---|---|---|---|
| Total | 3167.11 | 601.61 | 390.28 | −211.33 | −35.13% |
| Incisors/Canine | 1053.77 | 311.10 | 114.70 | −196.40 | −63.13% |
| Premolars | 912.42 | 218.17 | 188.87 | −29.30 | −13.43% |
| Molars | 1200.92 | 72.34 | 86.72 | +14.38 | +19.88% |

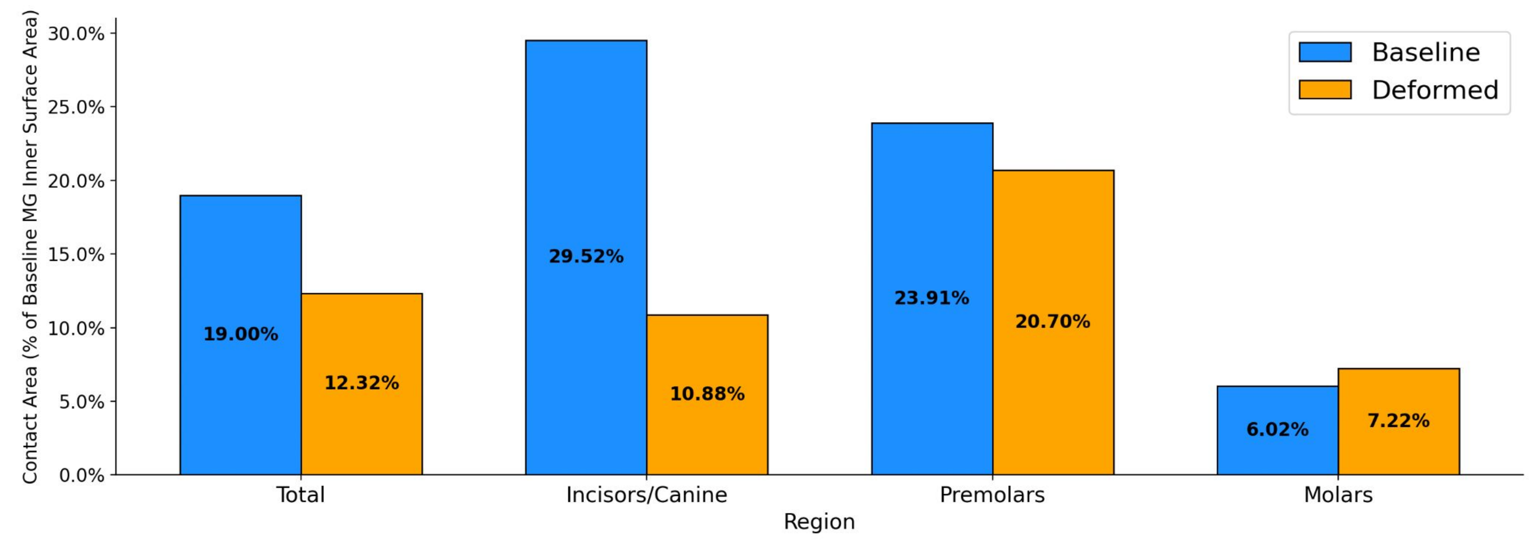


**Figure 11–12:** Comparison of baseline and deformed MG fit across regions. The table summarizes regional contact area changes following deformation, while the bar plot shows contact area normalized to baseline iMG inner surface area.

## Discussion

- Reduced overall MG-dentition contact area suggests degradation of mouthguard fit over time.
- The largest reduction occurred in the incisors/canine region, possibly due to thinner anterior regions being more susceptible to repeated deformation.
- Smaller premolar and molar changes may reflect greater posterior structural stability of MG.
- As the anterior portion of the MG loses fit and deforms outward, the material may shift posteriorly, increasing compression and contact in the molar region.

## Conclusions / Ongoing Work

- Reduced and redistributed contact area may weaken skull coupling and affect the accuracy and consistency of measured head kinematics.
- These findings highlight the importance of monitoring MG fit degradation during long-term use.
- Developing a reproducible method for consistent regional segmentation across participants remains as a future task.

## Reference / Acknowledgments


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