EFFECT OF COMBINING MUSCLE SUB-GROUPS IN THE MANDIBLE DURING MASTICATION: A FINITE ELEMENT STUDY

Samrat Sagar (1), Rupesh Ghyar (1), B. Ravi (1) and Darshan Shah (1)

1. Department of Mechanical Engineering, Indian Institute of Technology Bombay, India

Introduction

Defects in the mandible arising from infection, tumour or trauma need to be reconstructed for facial aesthetics and oral functions. Custom implants have recently gained popularity over stock implants owing to superior biomechanical outcomes. 3D printed custom implants need to go through standardised verification and validation protocols checking design efficacy [1]. Although finite element analysis is widely used for computational verification, it requires experimental validation for meaningful interpretation of results. Appropriate replication of the anatomy and functionality of the muscles of mastication is a challenge owing to the presence of multiple muscle sub-groups, resulting in complex lines of action. Mechanical testing of implant prototypes often simplify specimen loading during *in vitro* validation, overlooking the anatomical arrangement and physiological function of masticatory muscles [2]. In contrast, replicating all muscle sub-groups experimentally is often expensive and practically infeasible. This finite element study aimed to quantify the effects of combining sub-groups of mastication muscles on the stress distribution in the mandible during mastication, with the hypothesis that combining muscle sub-groups would not affect stress distribution.

Methods

A finite element analysis was conducted on an edentulous intact mandible model, assumed to be homogeneous and isotropic cortical bone, subjected to loading conditions experienced during mastication using Ansys Workbench 2020 R2 (Ansys Inc., USA).

Jaw-closing muscles – masseter, temporalis and medial pterygoid – were simulated in four configurations varying in force magnitude, lines of action, and regions of muscle insertion. In the first configuration ($M_{sep}T_{sep}$), the masseter was simulated as two separate muscle sub-groups (superficial and deep), the temporalis as three sub-groups (anterior, middle and posterior), and the medial pterygoid as one [3]. In the second ($M_{sep}T_{com}$) and third ($M_{com}T_{sep}$) configurations, sub-groups of the temporalis and the masseter were individually combined, respectively. In the fourth configuration ($M_{com}T_{com}$), sub-groups of both the temporalis and the masseter were individually combined.

Mastication was simulated on each of the four configurations using loads for six unilateral clenching tasks – intercuspal (ICP), incisal (INC), canine (CAN), molar (MOL), left group (LGC) and left group with molar balancing (LGC+MB) – and one molar chewing task (MOL chew) [4]. The condyles of the mandible were rigidly fixed [3]. Magnitudes and regions of maximum stress were identified and compared across muscle configurations and mastication tasks.

Results

When configurations combining muscle sub-groups were compared to the baseline configuration $M_{sep}T_{sep}$ across mastication tasks, the maximum stress increased the most during MOL chew, and decreased the most during ICP (Table 1). For all tasks in $M_{sep}T_{sep}$, regions of maximum stress were observed around their respective clenching points, except for LGC and LGC+MB, wherein these regions were found on the anterior aspect of ipsilateral coronoid process and balancing side, respectively. For all tasks in the remaining combinational configurations, the maximum stress was found in similar regions as those in $M_{sep}T_{sep}$, but differed in magnitude.

Tasks	$M_{sep}T_{sep}$	$M_{sep}T_{com}$	$M_{com}T_{sep}$	$M_{com}T_{com}$
MOL	25.1	25.3	26.7	26.9
chew	-	(+0.8%)	(+6.4%)	(+7.2%)
ICP	48.4	47.8	45.1	44.5
	-	(-1.2%)	(-6.8%)	(-8.0%)

Table 1: Maximum stress (MPa) in the mandible during select mastication tasks across muscle configurations.

Discussion

Regions of maximum stress found similar across muscle configurations could be attributed to the principle of vector addition, where combining muscle sub-groups produced a force comparable to their individual effects. Although the magnitude of maximum stress was hypothesized to remain unchanged across muscle configurations, computational approximations in the software could have potentially resulted in the observed variations; however, it must be noted that the maximum variations were <10% (Table 1). Results from this study vouch for a combination of muscle sub-groups for quasi-static computational testing of an intact mandible or mandibular implant designs. This could also result in potential simplification of experimental setups designed for quantification of native and/or altered mandibular biomechanics. However, the effect of combining muscle sub-groups should not be overlooked for dynamic simulations, wherein biomechanical parameters, such as kinematics and occlusion forces, need to be quantified.

References

1. Morrison et al, Clin Trans Sci, 8:594-600, 2015.
2. Merema et al, Oral Diseases, 27:42-51, 2021.
3. Korioth et al, J Dent Res, 73:56-66, 1994.
4. Nelson G.J., MSc Thesis, 1986.