MUSCLE FORCES DURING MASTICATION

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INTRODUCTION

In order to perform true loading of temporo-mandibular joint and dental replacements, the loading of masticatory muscles during bolus processing was investigated. Input kinematic variables and mastication force were experimentally examined. The inverse dynamics approach and static optimization technique were used for solution of the redundant mechanism.

METHODS

First was the creation of mathematical 3D model of mandible and skull including 16 actuators for two temporo-mandibular (TM) joints. These actuators included two parts of masseter (deep and surface), two parts of temporalis (anterior and posterior), two parts of pterygoideus medialis (anterior and posterior) and two parts of pterygoideus lateralis (inferior and superior) for each left and right side. The model consist of mandible, skull and muscle attachments positions, and was symmetrical according to the medial plane. The mandible can move with 6 degrees of freedom against the skull and distance between both of TM joints is assumed invariable. Muscle attachments and muscle parameters as physiological cross-sectional area, pennation angle, muscle mass, optimum muscle lengths etc. were taken from literature [1].

The 3D mandible and skull motion was experimentally analyzed by three cameras and processed with APAS software (Ariel Dynamics Inc.) during bolus processing. Simultaneously with an experimental measurement of kinematic parameters was investigated a chewing force (Figure 1) during soft bolus mastication. The chewing force was measured by developed 3D force micro sensor. Force sensor was implanted into the specimen bolus side.
For the mandible were derived six equations of equilibrium. In these equations perform 16 unknowns of actuators forces and 2 unknown reactions in TM joints, each in three directions.

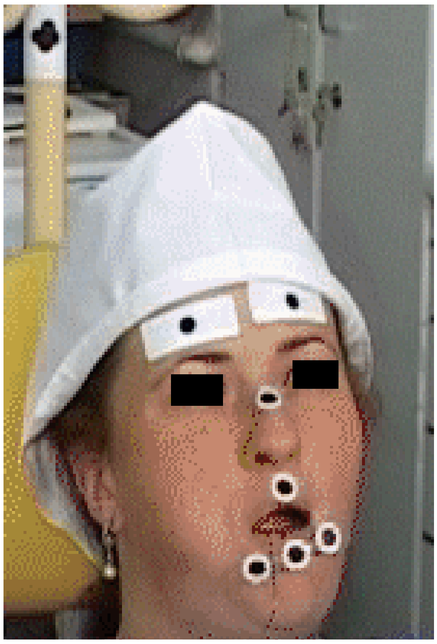

Figure 1: Experimental kinematic data and chewing force collection.

A representation of the musculotendon complex (Hill type model) using idealized mechanical objects is expressed in eq. (1). Disadvantages of these types of models include the assumptions associated with the input data, such as kinematic measurement of actuator length, and the muscle parameters of the model.

$$F = F_0^M \left[f_l^{act} \cdot f_v \cdot a(t) + f_l^{p} \right] \cos(\alpha(t)) \qquad (1)$$

Here is the basis for the physiological EMG-driven model [2,3] and it considers factors related to force-velocity f_v, force-length f_l^{act} and activation level $a(t)$ of the contractile muscle component, force-length relation of passive muscle component f_l^p, maximum isometric muscle force F_0^M, and pennation angle

$\alpha(t)$. This model corresponds with a full Hill type musculotendon complex.

EMG recording for activation signal estimation of all single and deep muscles is practically impossible. One potential method of addressing these discrepancies is to use an optimization scheme which assumes that EMGs are inherently imperfect, and the driven activation signal *a(t)* (normalized EMG) is calculated by optimization method. So, in place of actuators forces the unknown variable is now activation (for each muscle).

This problem was solved with constrained static optimization technique. Optimization criteria were minimization of muscle activation, eq. (2), and minimization of TM joint reactions, eq. (3).

$$J = \sum_{i=1}^{n} a_i^2 , \qquad (2)$$

$$J = \sum_{i=1}^{n} R_i^2 , \qquad (3)$$

The function (1) was constrained so that all of the musculotendon forces were positive $F_i \geq 0$, because muscles can not produce compressive force. Next inequality constraints were $1 \geq a_i \geq 0$, for limitation of activation level.

RESULTS AND DISCUSSION

Chewing force (Figure 2) was measured only in one place, the most loaded tooth, on specimen bolus side even if in real situations the mandibles are contacting in multiple points. Has been examined, that chewing forces in both left-right and anterior-posterior directions are not insignificant.

The calculated TM joint forces are higher on the specimen balance side and smaller on the bolus side which is in conformity with [4]. By contrast, the calculated muscle forces are higher on the bolus side, for example masseter forces are shown on Figure 3. Inertia and mass properties of mandible have not significant influence in results because the mandible accelerations during our investigation was very small. The TM joint forces were investigated with smaller values than was published [5,6]. In our experiment was masticated soft bolus (bread), probably from this reason these force are smaller than published.

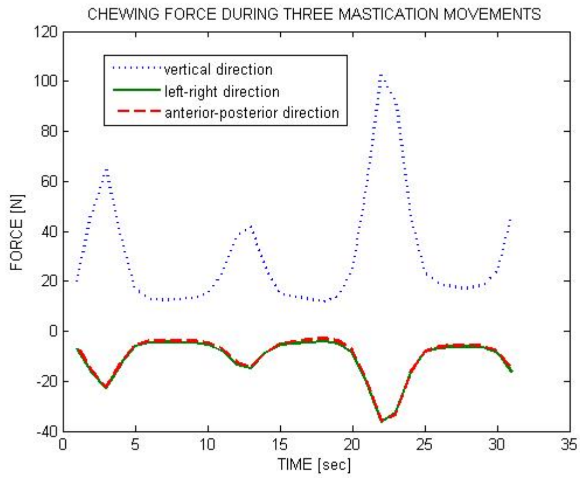

Figure 1: Experimentally collected chewing force on balance side.

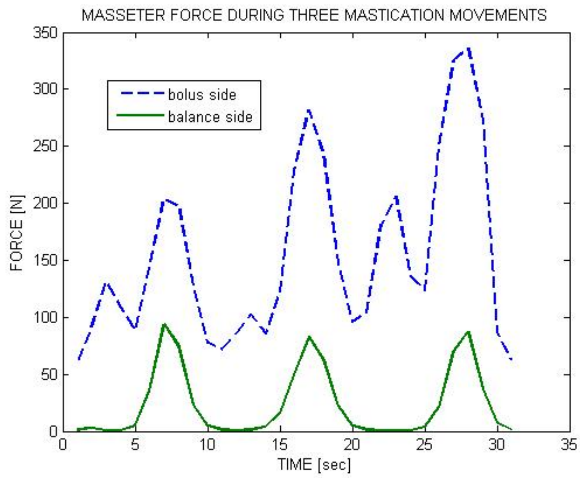

Figure 1: Calculated masseter forces on balance and bolus side.

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