Chapter 2
Robotic Models of the Masticatory System*

Abstract. In order to quantitatively evaluate the dynamic changes in the texture of foods during chewing in humans, a robotic device is required to enable the reproduction of human chewing behaviour. The first step in designing such a device requires the jaw mechanism to be modeled and analysed through simulations. Following a biological examination of the muscles used in the process of mastication, it was determined that those responsible for chewing movements can be represented by a set of linear actuators. By placing these actuators between the mandible and the skull, according to human biological structure and functionality, a robotic model of parallel mechanism was identified. The physical dimensions and properties of the mechanism were measured from a model replica of the human skull. Simulations for the mandible movements with respect to given muscular actuations, and for the muscular actuations required for actual human chewing patterns, were conducted using the Matlab/SimMechanics toolbox and the SolidWorks/CosmosMotion, respectively.

2.1 A Mechanism Model of the Masticatory System

2.1.1 Jaw Muscles and Movements

More than twenty muscles are involved in the process of human mastication [1, 2]. The temporalis muscle (as shown in Fig. 2.1a) is a large, flat muscle. Its fibres can be divided into two parts: firstly, the anterior fibres that elevate the mandible (lower jaw) and close the mouth and secondly, the posterior fibres that contribute to the complex grinding movement by retraction of the mandible. The pterygoid (as shown in Fig. 2.1b) consists of a family of muscles including the lateral and medial pterygoids. The lateral pterygoids work to protract the mandible and open the mouth, and the medial pterygoids are mostly used to protract the mandible.

The masseter (as shown in Fig. 1c) is a flat, quadrilateral muscle with both deep and superficial component parts. It contributes mostly to the elevation of the mandible (i.e. mouth closing), but also plays a role in protracting the mandible. Underneath the mandible, the hyoid bone supports a muscle set referred to as the suprahyoid muscles (Fig. 2.1d). Among them, the digastric, stylohyoid, mylohyoid, geniohyoid and platysma muscles are involved in mouth opening and subsequently the depression of the mandible.

![Fig. 2.1](image)

**Fig. 2.1** Muscles for mastication (a) left temporalis muscles, (b) left pterygoids muscles, (c) right masseter muscles and (d) suprahyoid muscles. (©1918 Lea & Febiger, Reprinted from [2] with permission).

The mandible, or the lower jaw, is attached to the rest of the skull by muscles by the so-called temporo-mandibular joint or TMJ (as shown in Fig. 2.1b). The mandible therefore, cannot move as a free body in space, as it is biologically constrained by both joints and muscles.

Human chewing behaviour can be described by way of two basic mandibular movements: namely clenching and grinding movements (Fig. 2.2). Clenching consists of the successive elevation and depression of the mandible and uses a variety of muscles, but mostly the masseter and temporalis anterior muscles. Grinding involves almost all of the jaw muscles together with the incisal point (the point between the two lower incisors) with the resulting movement tracing a circle within the horizontal plane. Thus, complex human mastication can be regarded as an aggregate of both clenching and grinding movements.