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# Markerless three-dimensional tracking of masticatory movement

Yuto Tanaka*, Takafumi Yamada, Yoshinobu Maeda, Kazunori Ikebe

*Department of Prosthodontics, Gerodontology and Oral Rehabilitation, Osaka University Graduate School of Dentistry, 1-8 Yamadaoka, Suita, Osaka 565-0871, Japan*

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ABSTRACT

Conventional methods for measuring mandibular movement are expensive and require headgear and a marker attached to the mandibular incisors. These make assessment of normal chewing difficult. The aim of the present study was to test the validity of a markerless three-dimensional system for tracking masticatory movement by comparing it with a conventional method using an incisal marker. The study investigated 100 chewing cycles in 10 participants. The jaw tracking system consisted of a camera capable of recording depth and red, green, and blue data simultaneously, a laptop computer, and data analysis software. Depth data for each participant's face, tracked in real time, produced a computed 3D mask. The most prominent point of the soft tissue under the lip was defined as the chin point. A dental clasp cemented to the labial surface of the mandibular incisors was defined as the incisal point. The movement of these two measuring points was simultaneously recorded during mastication of chewing gum for 20 s. To conduct the same analysis on each cycle from the two measuring points, all cycles were normalized by dividing by the corresponding vertical displacement because of their size variation. The findings showed excellent intramethod correlation for normalized horizontal displacement at every level ( $>0.9$; except for 2 out of 19 levels; 0.896 and 0.898), and a lack of proportional bias. These findings suggest a correlation between the chewing cycles from two measuring points, the incisor and the chin, further suggesting the feasibility of a markerless system for tracking masticatory movement.


## 1. Introduction

Mandibular jaw movement is controlled by a central pattern generator for the coordination of jaw muscle commands during mastication (Türker, 2002; Lund and Kolta, 2006; Westberg and Kolta, 2011), and is modified by sensory inputs such as periodontal mechanoreceptors (Türker et al., 2007; Trulsson and Johansson, 2002), and the muscle spindles of the jaw-closing muscles (Kang et al., 2010; Tsukiboshi et al., 2012).

Orofacial diseases affect sensory inputs. For example, a dental cavity alters the occlusal contact, resulting in a change in the input from the periodontal mechanoreceptors (Watanabe et al., 2011). Missing teeth alter the vertical dimension of the occlusion and the position of the condyle in the jaw, disturbing the input from the muscle spindles of the jaw closing muscle (Yabushita et al., 2005, 2006) and the temporomandibular joint (Nebel et al., 2010), respectively. Therefore, analysis of mandibular movement provides dentists with reliable information for diagnosis of diseases and assessment of the effects of treatment. Indeed, the manner in which mandibular movement during mastication is controlled has been of interest ever since technology was developed to observe the path of the mandibular incisal point.

However, conventional methods for measuring mandibular movement have the following weaknesses. Jaw trackers such as the mandibular kinesiograph require a marker such as a small magnet or light-emitting diode (LED) with a clasp on the mandibular incisor which disturbs lip movement and is unsuitable for patients with a deep overbite and denture wearers; and headgear to track the marker results which makes it difficult to chew normally. In addition, the high expense of these devices does not allow for routine usage for general practitioners or dental clinical researchers. To overcome these limitations, Kinuta et al. previously confirmed that the trajectories of an incisal marker attached to the subject's mandibular incisors by solid wires were able to be recorded by a simple system using a home camcorder with a precision equivalent to that of a conventional jaw tracking system such as the Sirognathograph Analyzing System III, which is one of the gold standard methods for jaw tracking (Kinuta et al., 2003, 2005). In addition, some previous studies used an RGB (red, green, and blue) video camera to track the markers attached on the chin for assessment of the jaw movement (Wiesinger et al., 2014; Zafar et al., 2000). However, a markerless method which requires neither an incisal marker nor headgear to record normal chewing has yet to be developed. If a simple and inexpensive method without

* Corresponding author. Tel.: +81 6 6879 2954; fax: +81 6 6879 2957.
*E-mail address:* yutotanaka.0106@gmail.com (Y. Tanaka).

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any device attached to the body can be established unequivocally, treatment could be standardized, and patients would experience improved prognoses. Similarly, it would facilitate the expansion of knowledge in the dental research field.

The aim of the present study was to test the validity of a markerless three-dimensional system for tracking masticatory movement by comparing it with a conventional method using an incisal marker.

### 1.1. Participants

Ten healthy participants (8 males and 2 females, aged $30.3 \pm 2.2$ years) volunteered to participate in this study. The inclusion criteria were: (1) Class I incisor relationship; and (2) ability to distinguish their habitual chewing side.

The exclusion criteria were: (1) overbite exceeding 2 mm; (2) stomatognathic system dysfunction; (3) history of neuromuscular disorder or injury to the jaw; (4) mobile teeth and/or periodontal symptoms; (5) major dental restorations.

The study was conducted in accordance with the Helsinki Declaration and was approved by the Ethics Committee at our university. Each participant gave informed consent before involvement in the study.

### 1.2. Equipment

The jaw tracking system in this study consisted of a camera (Microsoft Kinect V1 for Windows, Microsoft Corp., Bellevue, Washington, USA) which can obtain depth data and RGB data of the object simultaneously, a laptop computer (PCLL750TS, NEC Corp., Tokyo, Japan) and Faceshift software for data analysis and reconstruction of the participant'' face (Faceshift Corp., USA). Twenty eight points as virtual markers were determined based on the facial profile for the individuals according to the default setting. The user can add other arbitrarily chosen virtual markers on the face. The system tracks 28 or more markers in real time. Therefore, the computed three-dimensional (3D) mask fits a participant's face and is deformed based on facial movements.

The participants were seated comfortably in an office chair so that their Frankfort plane was parallel to the floor. They were asked to look at the Kinect camera located 1 m from their eyes during the scan so that the quality of the input was constant and the reconstructed profile was accurate.

A dental clasp, which was bent to ensure minimal inhibition of jaw and lip movement, was cemented to the labial surface of the mandibular incisors with polycarboxylate cement (HY-Bond Temporary Cement Hard, Shofu, Japan), so that the rounded tip was defined as the incisal point. The end of the tip was colored black so that the RGB sensor in the Kinect camera could detect and track it. The participants were instructed to complete certain movements (rolling the lips in, moving the lips towards the nose, and putting the lips together and forward) during the scan, so that the software could detect the profile of the lips and soft tissue under the lip, and thereafter, the most prominent point of the soft tissue region under the lip was defined as the chin point. Similarly, the most prominent point in the midface was defined as the nose tip point to compensate for the movement of the head posture. These scanning procedures to determine the measuring points were conducted automatically by the system, and the system tracked the measuring points in real time during the measurement.

We compared the data obtained from the marked incisal point with those obtained simultaneously from the markerless chin point. The method for recording the incisal point reported by Kinuta et al. (Kinuta et al., 2003, 2005) was used as a proxy for the gold standard.

### 1.3. Measurements

Our study followed the measurement protocol and analysis first described by Shiga et al. (Shiga et al., 2001, 2012)

A single researcher set up the experiments in all cases.

The movement of two measuring points of the chin and incisor was simultaneously recorded during mastication of chewing gum for 20 s on the habitual side at a 30 Hz sampling rate. From the recorded cycles, 10 cycles after the fifth cycle (fifth to fourteenth cycle) were used for analysis. A piece of chewing gum (Trident, Cadbury Adams, Parsippany, NJ, USA) was used as the test food. The chewing gum was softened prior to the recording.

### 1.4. Mathematical procedure for coordinates

The origin of the coordinate axes was the camera ($O=(x_0, y_0, z_0)$). The $x$-axis is a left-to-right line, the $y$-axis is a vertical line and $z$-axis is anterior-posterior line. First, the coordinates of the nose tip ($Nose=(x_{nose}, y_{nose}, z_{nose})$) and two measuring points ($Inc=(x_{inc}, y_{inc}, z_{inc})$ and $Chin=(x_{chin}, y_{chin}, z_{chin})$) were calculated from the depth data obtained from the camera and then the distance between the nose tip and the measuring points of the incisor and chin ($Y_{Inc}$ and $Y_{Chin}$, respectively) were calculated using the following equations.

$$Y_{inc} = |\overrightarrow{\text{Nose Inc}}| = \sqrt{(x_{inc}-x_{nose})^2+(y_{inc}-y_{nose})^2+(z_{inc}-z_{nose})^2}$$

$$Y_{chin} = |\overrightarrow{\text{Nose Chin}}|$$

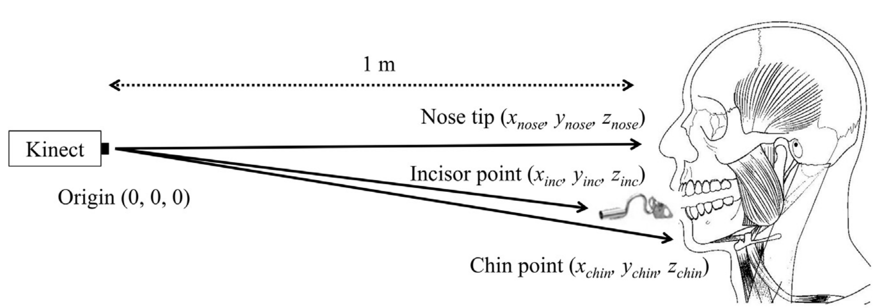


**Fig. 1.** Schematic illustration of the experimental set-up. The origin of the coordinate axes was the camera ($O=(0, 0, 0)$). The distance between nose tip ($Nose=(x_{nose}, y_{nose}, z_{nose})$) and two measuring points ($Inc=(x_{inc}, y_{inc}, z_{inc})$ and $Chin=(x_{chin}, y_{chin}, z_{chin})$) were calculated by following equations. $|\overrightarrow{\text{Nose Inc}}| = \sqrt{(x_{inc}-x_{nose})^2+(y_{inc}-y_{nose})^2+(z_{inc}-z_{nose})^2}$ $|\overrightarrow{\text{Nose Chin}}| = \sqrt{(x_{chin}-x_{nose})^2+(y_{chin}-y_{nose})^2+(z_{inc}-z_{nose})^2}$.