Original

Assessment of Mandibular Kinematic Variables using a Motion Analysis System and a Regular Mobile Phone

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ABSTRACT

Background: The development of a standard motion capture system is needed since the measurement of temporomandibular disorders is time-consuming and costly using laboratory tools.

Objective: The current study aimed to investigate the mandibular kinematic variables using a regular mobile phone and the motion analysis system.

Material and Methods: In this quasi-laboratory and comparative study, ten healthy individuals participated, and three mobile cameras, nine red markers, and Kinovea software were also used to investigate the mandibular kinematic variables. Nine light reflective markers were used to check the sensitivity, accuracy, and reliability of the proposed system. The motion was analyzed using seven motion analysis infrared cameras and Qualisys Track Manager (QTM) software. Two other raters analyzed the kinematic variables obtained from the mobile to measure intra- and inter-rater reliability.

Results: Pearson's correlation coefficient was obtained at 0.98, 0.75, 0.98, and 0.96, showing a high correlation. The accuracy and reliability validation tests showed an average error and an accuracy of 0.156 mm and 95%, respectively, with a mobile phone. The Intra Class Correlation coefficient showed a high internal correlation in the mentioned confidence interval (0.98 and 0.81, and 0.96 and 0.97). The intraclass correlation coefficient method also showed 97% inter-raster reliability.

Conclusion: Mobile phones as a new system can evaluate the kinematic variables of mandibular disorders with appropriate accuracy and reliability.

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Keywords

Mandibular Movements; Kinematic Variables; Range of Motion; Motion Analysis System; Regular Mobile Phone; Biomechanical Phenomena; Temporomandibular Joint Disorders; Software

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Introduction

Neuromusculoskeletal injuries, caused by facial diseases, and their treatments are favorable due to the effect of facial muscle activity and jaw joint function on the expression of emotions and some vital human actions, such as sucking, swallowing, and chewing [1]. Some methods, including questionnaires, dynamic imaging, radiography, computer tomography, magnetic resonance, Electromyography (EMG), Magnetic Resonance Imaging (MRI), and arthroscopy are used for diagnosing temporomandibular (TMJ) disorders [2,3]. In the clinical studies of the temporomandibular joint, maximal mouth opening, closing movement, right and left lateral, and protrusive movements are used as a functional evaluation of the mandible [4]. The characteristic of the mandible movements can be used as a reference for the investigation of its morphology, restoration of artificial teeth, and coordination of joint function to regulate joint cramps and injuries [5].

For the first time in the mid-1960s, three-dimensional mandibular movements were recorded using a bulky and complex device that was similar to the jaw joint. However, it could only detect 70% of the occlusal point of the mandibular movement [6]. A new type of capturing system was presented, consisting of electronic and ultrasonic sensors and circuits, with advantages, such as low invasiveness, easy operation, and high accuracy [7]. In this technique, the ultrasonic sensors were connected to the facial arch and fixed on the people's heads instead of directly fixing the sensors on the skull. Therefore, the face morphology may affect the accuracy of the measurement system. Further, other problems should be addressed, such as technical characteristics and the unavailability of the system [7]. The effect of external environment temperature and noise on the results is considered a disadvantage of sonography techniques [8]. The accuracy of the electromagnetic tracking system is easily affected by external factors, such as metal blocks and mobile phones. However, a new technique was introduced to record temporomandibular joint kinematics using an electromagnetic system and dental devices, the tool measuring head frame or facial arch may inaccurately record the mandibular trajectory and cause abnormal feelings in patients [9-10].

At least three non-linear markers for the head and mandible are needed to measure the three-dimensional mandibular movement with an optical-electronic motion tracking system based on the skin marker. Anatomical positions with minimal soft tissue artifacts (STAs) should be selected to place the markers since the skin markers may move relative to the underlying bone, leading to the error of STAs [11]. The nasal bridge markers are more preferred than the maxilla [12-14]. The researchers presented a practical method for reconstructing the three-dimensional model of the mandibular movement and evaluated occlusion for crown restoration using a charged coupled device camera, which can show the natural occlusion behavior of an individual by the simultaneous effects of rotation and translational movements [15-16]. A compact, portable, low-cost, and simple planar-fiducial-marker-based motion-capturing system (PFMS) was developed to capture mandibular spatial motion using two general webcams [17]. However, PFMS can obtain accurate mandibular trajectory, it captures mandibular trajectory in three two-dimensional planes, which is incompatible with real motion analysis [17].

A Bionic Jaw Motion (BMJ) system consists of a jaw motion analyzer and a robotic joint [18]. However, the use of simulators may reduce preventable medical errors, their design has one major drawback, completely lacking real facial expressions [19]. Some scientists reported a method for three-dimensional measurement inside the body using single-plane fluoroscopy [20] and three-dimensional tracking of masticatory movement [21,22].

Kinematic evaluation of TMJ can be useful in diagnosis [23], prevention of side effects, and treatment planning since TMJ disorders cause changes in the mandibular kinematics due to neurological, articular, and muscular reasons [24]. However, motion capture is an accurate method, it is expensive and time-consuming [25]. Therefore, the current study aimed to evaluate the mandibular kinematic variables using a regular mobile phone and the motion analysis system with a validation and reliability approach.

Material and Methods

In this quasi-laboratory and comparative research, ten individuals participated to compute using G*Power version 3, 1, 2 (Heinrich Heine University Düsseldorf, Germany) statistical power=0.88, effect size=0.7 and *P*-value<0.05 (using Cohen's criterion).

The participants were healthy volunteers, including three men and seven women, aged between 22 and 58.7 years with a mean and standard deviation of 41±19 years, 58±11 kg, and of height 155±14 cm, who referred to the Laboratory of Musculoskeletal Disorders research center of Isfahan University of Medical Sciences. After examining their clinical conditions, eligible participants were included in the study.

The participants completed the consent form after knowing the research objectives and implementation method. In addition, the protocols related to the data collection process were approved by the Specialized Ethics Committee in Biomedical Research of Kharazmi University with the code (IR.KHU.REC. 2019.029). Finally, ten healthy people were randomly selected from among 25 healthy volunteers based on the inclusion criteria, as follows: 1) no complaints or medical diagnosis of facial paralysis, 2) no history of facial trauma or surgery on the face or neck, and 3) no use of partial or complete dental prosthesis [26-29].

Data collection instrument

Three regular mobile cameras, three fixed bases, a short adjustable seat, nine-color markers (diameter of 14 mm), and Kinovea software (version 0.8.27-x64) were used. Also, nine-light reflective markers were placed on mandibular anatomical points, and mandibular movements were tracked using seven-motion analysis infrared cameras with a trademark (Qualisys). The collected data were then analyzed in X, Y, and Z axes using Qualisys Track Manager (QTM) software. The data related to kinematic variables were analyzed by two other raters to check the inter-rater agreement.

Unlike the current commercial systems, the innovative method of motion capturing system proposed in the present study includes three-simple video cameras of regular mobile phones with video-recorded mandibular movements of healthy individuals for 120 s. The cameras were placed on fixed bases from three directions: frontal, right, and left at an angle of 90° and a 50-cm distance (Figure 1). Nine colored markers (diameter of 14 mm) were placed on the face to show the key points and increase the visibility of the mandibular movement.

Nine reflective markers were placed on the key points of the face of the same individuals to compare the proposed system with the motion analysis camera system. The mandibular

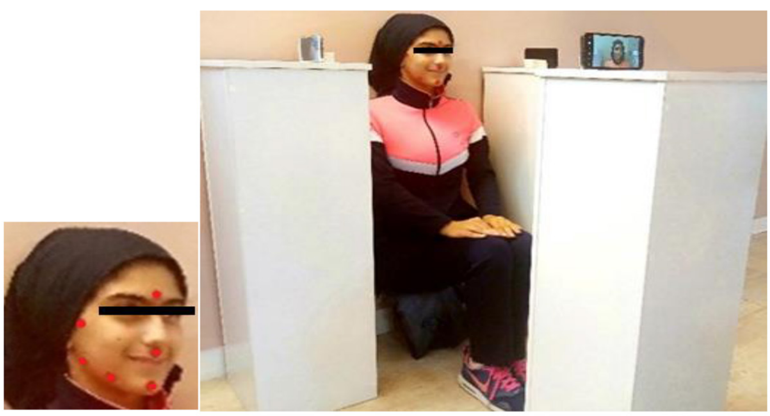


Figure 1: Adjusting and preparing the mandibular movement capturing system using three mobile cameras

movement tracking was recorded using seven-infrared motion analysis cameras.

After collecting the mandibular kinematic variables with the Qualisys motion analysis system, the collected data were analyzed using QTM software in X, Y, and Z vectors (Figure 2).

Subjects

The participants completed and signed the consent form, which was accompanied by the protocols related to the data collection process.

The individual sat in a completely straight and standard position on a normal adjustable chair with his feet on the floor and leaned his head against the wall. Nine-color markers in the first stage and nine-infrared reflective markers in the second stage were placed on the individuals' faces to increase the visibility of the mandibular movements by the regular mobile phone and the motion analysis camera.

Data collection

International parameters and TMJ physical examination were used to evaluate the displacement and movements of the lower jaw. Likewise, these parameters included maximal mouth opening, right and left lateral, and protrusive movements of the mandible as follows:

a) midline: while the teeth are in occlusion, the lines are checked to be in the same line between the maxillary and mandibular central incisors; deviation from the midline was measured and checked when these lines do not match (measure the distance of one line horizontally from the other line), b) maximal mouth opening: measuring the distance between the edges of the maxillary and mandibular teeth (Figure 3), c) maximal lateralization of the mandible: measuring the horizontal distance between the midline of mandibular central incisors and the midline of the maxillary central incisors, after a right mandibular movement; the corresponding settings were used providing a midline deviation, d) maximal left lateralization of the mandible: measuring the horizontal distance of the line between the mandibular central incisors and between the maxillary central incisors, after a left mandibular movement (Figure 4), and f) maximal mandibular protrusive movement: measuring the forward movement and maximal horizontal change of the mandible.

Data Analysis

Kinovea software (version 0.8.27-x64) was used to collect information from three-mobile cameras and evaluate maximal mouth opening, protrusion, and left and right lateral movements of the mandible. QTM software was also used to collect the data from motion analysis cameras; the collected data were analyzed in three-movement axes, including the maximal opening of the mandible on the Z axis, right and left lateral movements on the X axis, and the maximal protrusive movements

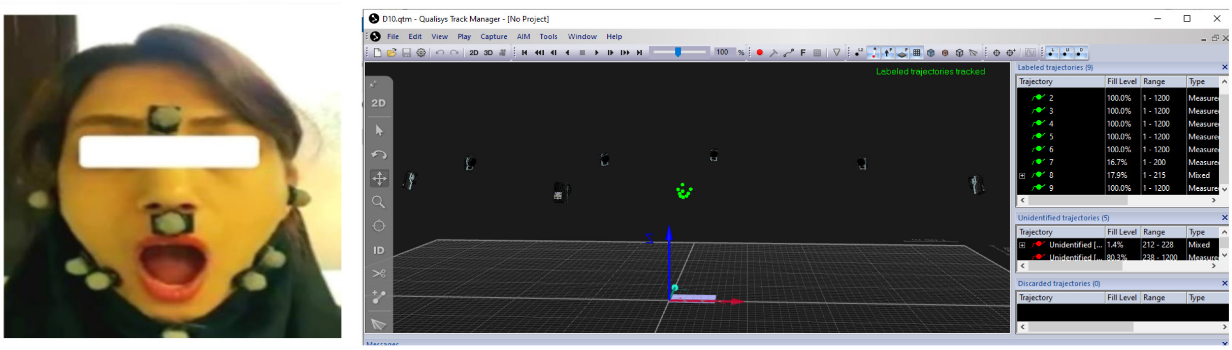


Figure 2: Setting up and preparing the mandibular movement capturing system using seven-motion analysis cameras and nine-light reflective markers in Qualisys track manager (QTM) software

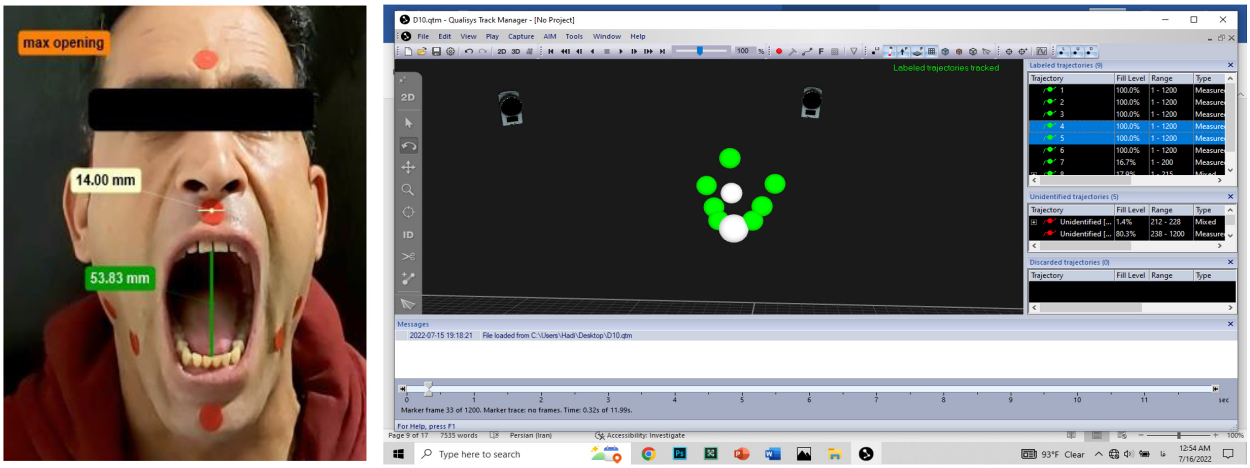


Figure 3: The mandibular displacement, range of motion a healthy subject, and maximal mouth opening using motion analysis and a mobile phone

Figure 4: The maximal lateral movement of the mandible of a healthy individual to collect kinematic variables using motion analysis and a mobile phone

on the Y axis (Figure 5).

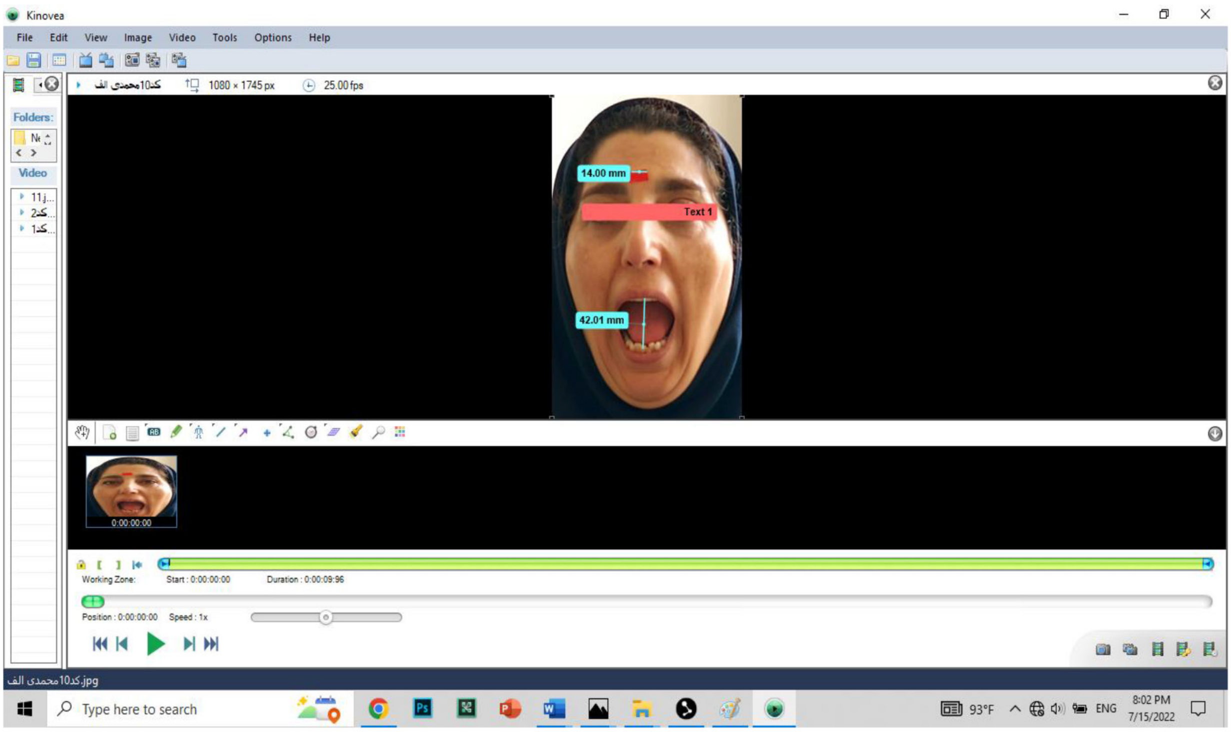
Statistical Methods

Data were analyzed based on Pearson's correlation test using the software SPSS 20 to validate the accuracy and reliability of the system. ICC coefficient was used to determine the intra- and inter-rater reliability.

Results

Table 1 shows the mean value of motion and mobile procedures for the data obtained from the maximal mouth opening, protrusion, and left and right lateral movements of the mandible. Pearson's correlation coefficient was used to determine the relationship between jaw movements of healthy individuals. Further, Table 1 shows the results of the average range of mandible motion, including the maximal mouth opening, right and left lateral, and protrusive movements for mobile phones and motion analysis devices (mm), respectively. Also, Pearson's correlation coefficient and the degree of intra- and inter-correlation of the individuals' mandibular movements are presented using the motion and mobile analysis system.

According to Pearson's correlation coefficient, the relation of the maximal mouth opening, right and left lateral, and protrusive



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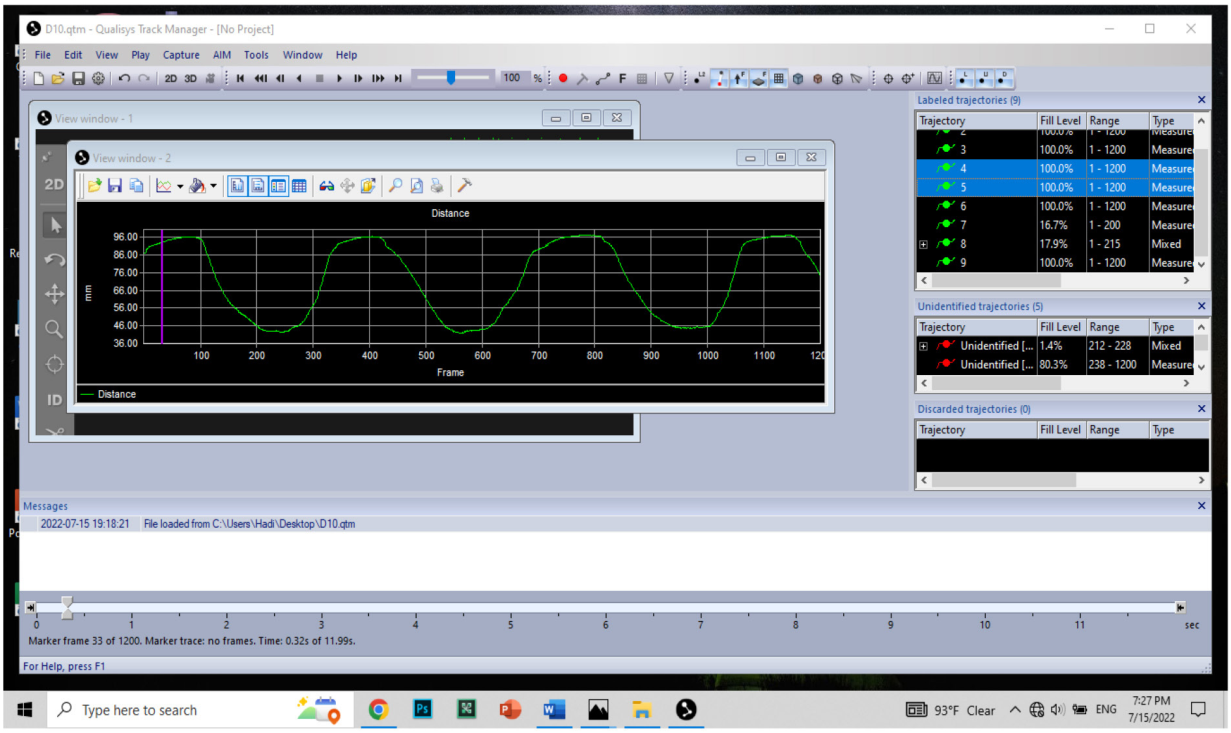

B

Figure 5: A: The maximal opening of the mouth according to the approach of the current research in Kinovea software and B: The maximal opening of the mandible using motion analysis and diagrams in different Qualisys track manager (QTM) axes.

Table 1: Correlation of the individuals' mandibular movement using the motion analysis system and the mobile motion analysis system

Variable	Mea±SD	Pearson correlation coefficient	*P*-value	ICC
Opening motion	36.05±6.38	*0.98	<0.001	0.98 (0.92-0.99)
Opening mobile	34.52±5.30			
protrusion motion	6.95±3.15	*0.75	0.012	0.81 (0.22-0.95)
protrusion mobile	6.73±1.95			
Lateral L motion	9.43±3.51	*0.96	<0.001	0.96 (0.83-0.99)
Lateral L mobile	9.41±2.61			
Lateral R motion	8.92±2.92	*0.98	<0.001	0.97 (0.89-0.99)
Lateral R mobile	8.91±2.20			

SD: Standard Deviation, ICC: Intra Class Correlation, *: Significant Differences

movements were 0.98, 0.75, 0.98, and 0.96, respectively, showing the high correlation between mandibular kinematic variables of the mandible using a mobile camera and motion analysis systems (Table 1). ICC confirmed the strong internal correlation between the two variables, which is 0.98, 0.81, 0.96, and 0.97 in the mentioned confidence interval for the above four movements, respectively. Moreover, the results showed very little change between the mean values of the variables after six repetitions.

The intraclass correlation coefficient was used to determine inter-rater reliability, and the results showed a high ICC (Table 2).

Discussion

The present study aimed to evaluate the mandibular kinematic variables using a regular mobile phone and motion analysis system and develop a standard and accessible motion-capturing system for the kinematic analysis of this joint.

Table 2: Intra Class Correlation (ICC) of variables measured in inter-rater mode

Variable	ICC	95% confidence interval	
		Lower limit	Upper limit
Opening	0.95	0.86	0.99
L_ Lateral	0.99	0.97	0.99
R_ Lateral	0.99	0.97	0.99
Protrusion	0.96	0.89	0.99

ICC: Intra Class Correlation

In recent years, various tools are presented to investigate mandibular movement limitations, improved and developed based on the performance and quality with the development of optics, electromagnetics, and computers [2,3]. Many types of mandibular movement-capturing devices are known, which are mainly complicated and expensive [6]. Head and body vibrations are not important when tracking mandibular movements in most equipment and methods [7,30]. The tool measuring the head frame or facial arch may record the mandibular trajectory inaccurately and cause abnormal feelings in patients [10]. At least three non-linear markers are needed for the head and mandible to measure the three-dimensional mandibular movement with an optical-electronic motion tracking system based on the skin marker. The skin markers may move relative to the underlying bone, leading to the STA error [11].

Despite other mandibular movement evaluation systems, the current study analyzes mandibular movements without the need to install complex mechanical devices on the head and face. Moreover, an accurate calibration software (mm-accuracy) can be used to analyze the mobile video-recorded data, the mandibular movements by tracking the anatomical points of the face, and the examination of the displacement of kinematic variables from selected images at the best angle and the right time.

However, the use of simulators may reduce preventable medical errors, the main drawback was their design, which completely lacked real facial expressions [19]. Tanaka et al. also developed a three-dimensional marker-free system, but the measurement errors of these systems are higher than 1.00 mm and almost impossible to use in clinical applications in dynamic conditions [21].

Movement observation, analysis, and management as essential elements to examine and diagnose movement system disorders, and the use of two-dimensional a slow-motion mobile video. Although Kinovea can facilitate this process, the technique of using a mobile camera, and Kinovea is used less frequently.

However, the limitations of motion analysis to analyze movements, forces, and tension, resulting from joint components, the occlusion of markers, unwanted reflections, and the noise in the paths with filtering, must accurately be calibrated [25]. Motion capture is an accurate method, but is expensive and time-consuming [12].

The current study can observe every movement frame by frame in detail. The ability to slow down and freeze the movement at key moments increases the power, accuracy, and reliability of observation. The inclusion of two-dimensional mobile motion analysis can help the interaction between the therapist as well as the patient and facilitate the decision-making process. Two-dimensional mobile motion analysis also yields better results with lower costs and more favorable levels of satisfaction. Incremental self-awareness can increase acceptance and help the patient and healthcare provider to see a different perspective on movements, understand what movement direction causes symptoms, and thus know how to change those movements to reduce or even eliminate those symptoms.

It was difficult to investigate the mandibular movements in individuals whose teeth needed orthodontics or whose maxilla was noticeably forward. Also, only normal subjects were recruited.

Conclusion

Due to the high-cost and time-consuming specialized laboratory tools, it is recommended that mobile phones are used as a new method for recording and evaluating mandibular kinematic variables in different planes. Further, it is expected due to the high accuracy and reliability of the proposed method in the present study, this method can investigate the kinematic variables of the mandible.

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I appreciate all the subjects who participated in this research.

Authors' Contribution

M. Ziaiee initiated the idea, gather the images and the related literature and also help with the writing of the original draft. H. Sadeghi, reviewing & editing the manuscript, as well as implementation the method. MT. Karimi, conceived the idea and reviewed the manuscript. M. Rafiaei participated in data collection. All the authors read, modified, and approved the final version of the manuscript.

Ethical Approval

Ethical approval was obtained from Committee for Ethics in Biomedical Research of Kharazmi University with the code (IR.KHU.REC.1399.029).

Informed consent

All individuals were provided with informed consent to participate in this scientific project and informed about the purpose of the research and its implementation stages. They were also assured about the confidentiality of their information and were free to leave the study whenever they wished, and if desired, the research results would be available to them.

Conflict of Interest

None

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