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Effect of Cyclic Loading on the Temporomandibular Joint

Janith Muhandiram, Bin Wang, Mahmoud Chizari

***Abstract*— This research is aiming to investigate the mechanical behaviour of the temporomandibular joint (TMJ), in response to kinematics/cyclical loading caused through actions of speech and mastication. A set of in-vitro experimental tests has been performed in three different groups on a fresh sheep jaw bone to examine the hypothesis of the study. No failure was monitored during the cyclical test. The study was concluded that the amount of loading is effective on the displacement of the TMJ.**

***Index Terms*— cyclic loading, mastication, speech, temporomandibular joint**

I. Introduction

A. Temporomandibular Joint (TMJ)

THE temporomandibular joint (TMJ) is the region which connects the bone of lower jaw, mandible, to the upper temporal bone of the skull as shown in Fig 1. The TMJ is the most constantly used joint in the human body [2]. The flexibility of these joints allows the movement of the lower jaw, enabling the actions of speech, chews and yawn [1].

The TMJ is composed of a mobile segment known as condyle, the round upper end of the lower jaw and a joint socket of the temporal bone called the articular fossa [2] (Fig 1). The condyle glide along the articular fossa, when the mouth opens and returns to the original position as the mouth is closed [1]. A disc composed of cartilage is located between the condyle and the articular fossa to ensure a smooth motion of the condyle. The disc functions through the absorption of stress to the jaw caused by chewing and other actions [2].

The significant character of hinge and slide movements along with the unique composition of the TMJ imposes many challenges to the study of this complex [1]. The function of the TMJ maybe obstructed by a variety of conditions and those conditions may lead the TMJ to a joint disorder [3].

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Janith Muhandiram is with the School of Design and Engineering, Brunel University West London, UK

Bin Wang is with the School of Design and Engineering, Brunel University West London, UK

Mahmoud Chizari is with the School of Mechanical Engineering, Sharif University of Technology, Tehran, Iran

Mahmoud Chizari is with Orthopaedic Learning and Research Center at Brunel University West London, UK, (corresponding author: Mahmoud Chizari. Phone: +447886454320; e-mail: mahmoudchizari@yahoo.com)

B. Temporomandibular Disorders (TMD)

Due to the dynamic nature of the mandible and its constant movement during functions, issues may occur at the temporomandibular joint. Varying degrees of force is applied on to the mandible during functions of mastication and speech, and force overload leads to the rise of temporomandibular disorders (TMD). Temporomandibular disorders are also termed as temporomandibular joint dysfunction (TMJD) and temporomandibular joint pain dysfunction syndrome (TMJPDS) [3], [4]. TMD is a group of conditions in the temporomandibular joint and the muscles of mastication [4].

Temporomandibular disorder is a benign condition and has a variety of symptoms including the ongoing pain in the jaw, pain on jaw movement, restricted jaw movement, earache and headache [3]. These conditions are also characterized by clicking or grating sounds in the temporomandibular joint and pain on the opening and closing of the mouth [1].

TMD falls into key subtypes including myofacial pain, arthralgia and internal derangement of the joint involving replacement of the disc [4]. A key cause of the TMD is arthritis as joint disorders affects the TMJ [1]. TMD may also be caused by injury to the TMJ due to grinding teeth at night, clenching teeth together or habitual movements that cause stress to muscles of the jaw [3]. An additional cause of TMD is the disc displacement in the TMJ due to internal derangement which may result in the clicking and popping sound, pain on opening and closing the mouth and restricted jaw movement. A grating sound on movement of the jaw maybe produced due to perforation of the disc. Rheumatoid Arthritis and trauma is capable of fusing components of the TMJ preventing jaw movement which also leads to TMD [2].

There has been no cure found for TMD and the condition of majority of patients with the TMD have been reported to be improved with simple and effective treatments such as avoiding extreme jaw movements, avoiding chewing of hard food, application of hot or cold packs on the face, jaw and face exercises [1]. Also the use of the hard bite guard is a treatment of the TMD, which reduces tension of jaw muscles, preventing further injury to the TMJ as a result of teeth grinding or clenching of the jaw at night [3]. Anti-inflammatory medication is used at times to reduce the swelling of the jaw and aid the relaxation of the jaw [2]. Jaw joint surgery is an unusual treatment of the TMD [3]. Further investigation of the complex and unique nature of the temporomandibular joint is required to discover a cure for temporomandibular disorders.

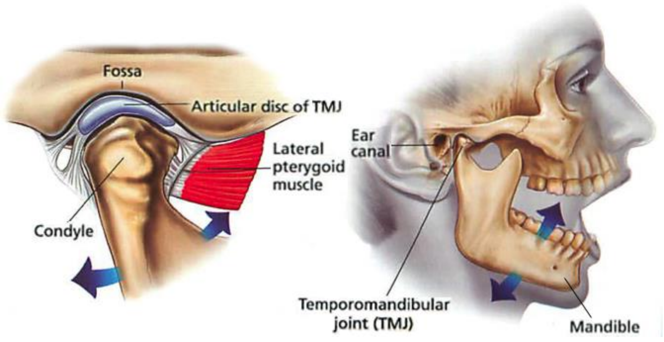

Fig 1. Schematic of a Temporomandibular Joint. The image has been reproduced from reference [3]

C. *Jaw movement in mastication and speech*

The jaw movements are involved in primitive motor functions such as mastication and speech. A communal muscle architecture and histochemistry as well as sensory, motor and reflex components are shared between the functions of mastication and speech to a certain degree [5]. During these functions, varying amounts of force is applied on to the temporomandibular joint, depending on the behaviour of the jaw movement.

The movement of jaw has been investigated through the measurements of movement, rate and amplitude in speech and the compliance of the bolus in mastication. In 1989 it was reported by Ostry and Flangan [5] that in mastication, the movement, rate and amplitude of jaw movement was greater in comparison to that in speech, as reported in Table I. However, the normalized functions were similar in jaw-closing movements in contrast to the movement, rate and amplitude values in both mastication and speech. The functions for mastication and speech were similar in jaw-opening movements although the amplitude and compliance values were significantly different. The duration of acceleration and deceleration of fast movements were approximately equivalent, whereas the deceleration duration was significantly longer than that of acceleration duration of slower movements.

Due to the dynamic nature of the mandible and its constant movement during functions, complications may occur at the temporomandibular joint. Varying degrees of force is applied on to the mandible during functions of mastication and speech and force overload leads to the rise of temporomandibular disorders.

TABLE I
KINEMATICS OF MANDIBLE AT MASTICATION AND SPEECH

	Normal Opening		Normal Closing	
	Mastication	Speech	Mastication	Speech
Amplitude, cm	0.63	0.26	0.64	0.26
Duration, ms	318	234	356	267
Acceleration, ms	110	69	99	94
Deceleration, ms	208	163	257	133
*V_{max}, cm/s	6.82	2.93	5.38	2.82
	Fast Opening		Fast Closing	
	Mastication	Speech	Mastication	Speech
Amplitude, cm	0.45	0.24	0.44	0.24
Duration, ms	132	110	143	342
Acceleration, ms	74	49	145	148
Deceleration, ms	58	61	95	64
*V_{max}, cm/s	7.21	4.06	6.76	4.00

*V_{max} is the maximum instantaneous velocity

D. *Objective of the study*

Simulation of the dynamics loading applied on the TMJ of a healthy human jaw during functions of speech and mastication is the key focus of this research. The study is aiming to model a cyclical load applied on TMJ and assesses its mechanical behavior. Investigating possible modes of failure, while the loading is applied, is also an interest of the study.

II. METHODS

A. *Input data*

The study uses fresh sheep jaw bones to simulate the mechanical behaviour of the jaw under daily mechanical loading on the TMJ. In order to simplify the problem and make the test possible using our available testing facility, an assumption was made and the input data was defined. The assumptions made for the use of sheep jaw specimens are reported in Table II.

TABLE II
THE ASSUMED DATA FOR SHEEP'S JAW SPECIMEN

Chews per day	3750 ± 50 cycles
Frequency	1.57 Hz
Amplitude at the mouth	22.4 mm
Amplitude at TMJ	1.3 mm

B. *Testing setup*

Fresh sheep jaw bones were used for the experimental examination of this study. Sheep head samples were obtained from an authorized farm and the mandible jaw bone of the heads was carefully harvested by an experienced person. The jaw bone was then cleaned off from all the meat, muscles and ligaments, only the hard bone as shown in Fig 2 was kept for experimental investigation of the study. The harvested mandible jaw bones were packed in a zip plastic bag and then stored in a freezer at temperature of -20^{o}C. On the day of the experiment, the specimen was removed from the freezer and kept for 3 hours at room temperature to be thawed. The specimen was kept moist by spraying pure water during thawing and the experimental setup.

A custom made fixture was utilized to mount the specimen into the testing machine as shown in Fig 3. The specimen was adjusted on the testing rig to make sure the TMJ of the jaw bone is in front of the loading bar which was attached to the crosshead. The size of contact zone at the loading bar was about the size of TMJ. Before applying the load, the distance between the loading bar and the TMJ was controlled. The specimen was then fixed using metal bridges on the metal rig.

A computer drive Hounsfield hydraulic testing machine was used to carry out the test. The machine was armed with a 1000 N load-cell on its crosshead. The machine was controlled with the QMat V5.3 software (Tinius Olsen, UK). The software enabled the user to introduce the input data to the testing machine. A compression-cyclic routine from the QMat database was used to carry on the test.

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Fig 2. The sheep jaw bone sample was mounted into the testing machine

C. Biomechanical testing

In order to determine the mechanical behaviour of the TMJ under a cyclical load that was applied on to the specimen, the data was recorded and possible mode of failure was visually monitored [6].

The multiplication of daily chews by the number of days of a given period of time, determines the amount of mechanical load applied on to the jaw during a specific life time. Fig 3 shows the experimental setup and the position of the specimen in relation to the tensile machine.

The specimens were tested in three different groups. Table III shows the specification of each testing groups. The specimen was kept moist whilst it was attached to the testing machine.

TABLE III
SPECIFICATION OF THE THREE TESTING GROUPS

	Group 1	Group 2	Group 3
Load range, N	10	20	50
Extension range, mm	0.5	10	10
Speed, mm/min	1000	1000	1000
Sample height, mm	5	5	5
Load target, N	10	10	10
Number of Cycle	100	100	100
Preload, N	2	5	5

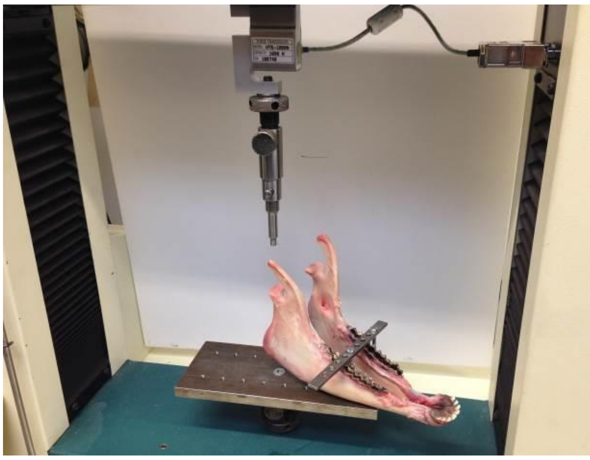

Fig 3. The mounted specimen in a Hounsfield testing machine. The specimen was mounted into the machine using a custom made fixture.

III. Results and Discussion

Experimental measurements were carried out using Hounsfield testing machine and QMat V5.3 software on a sheep jaw bone specimen. The cyclical load and its correspondence displacement were recorded for all three groups. The load displacement results of the three groups are illustrated in Fig 4. No significant difference was monitored between the three groups. However the effect of the applied load on TMJ was obvious. The results show that by increasing the load on TMJ, the displacement of the bone would increase. However, the behavior of the load-displacement curve was not linear.

The maximum displacement after a full cyclical test for group 1 was 2.1 mm. This displacement was in correspondence with 14.6 N loads which was applied onto the TMJ. For group 2 and 3, maximum displacement was 2.9 mm and 3.4 mm which were in correspondence with 16.2 N and 13.6 N loads respectively.

A difficulty was experienced on the fixation of sheep jaw bone on the testing rig which may have caused a minor movement while the specimen was under loading. This unexpected movement may impact accuracy of the recorded data.

The study was trying to show that the cyclic loading on the TMJ is effective on its mechanical behaviour but the result obtained here are preliminary and further investigation is needed to complete the hypothesis of the study.

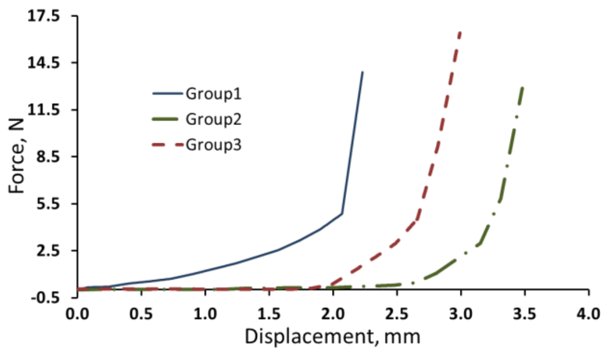

Fig 4. Load and displacement result of the three groups applied on a sheep jaw bone sample

IV. Conclusion

This research focuses on the kinematics loading applied on the temporomandibular joint during speech and mastication. A set of in-vitro tests were performed to examine the hypothesis of the study. A fresh sheep jaw bone was used to investigate the mechanical properties of the TMJ in response to cyclical loading caused through actions of speech and mastication. The data was recorded and possible mode of failure was screened. The study examined three different methods of input loading and concluded that the amount of kinematic loading may be effective on the deformation of the TMJ. No significant difference was monitored between the three groups and there was no failure on the specimen during the test.

This study is still under research and outcome has not yet finalized. However, the concept of the study may be used to improve the treatment of TMJ.

The hypothesis of the study may need further investigation with more jaw bone specimens. The utilization of an improved testing rig to mount the specimen into the testing machine may increase the accuracy of the future experiments. In addition the replacement of the contact point of the loading bar with an actual TMJ may enhance the results of further investigations.

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