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An Investigation on Stiffness of the Temporomandibular Joint Under Cyclical Loading

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Abstract - **This research is a continuation of our previous study on temporomandibular joint (TMJ). The aim of the research is to investigate the mechanical behaviour of the TMJ, in response to kinematics/cyclical loading caused through actions of speech and mastication. A set of in-vitro experimental tests have been performed on a fresh sheep jaw bone to examine the hypothesis of the study. 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 is a geometrically complex and extremely mobile joint [2]. The bone of the lower jaw, mandible, is connected by the TMJ to the upper temporal bone of the skull and mediates the regulation of jaw movement. The bi-condylar TMJ contains condyles located at the opposite ends of the mandible which function simultaneously [1]. The condyle is the round upper end of the lower jaw which glides along the articular fossa during opening and closure of the mouth. The condylar movement along the articular fossa is allowed by a disc located between the condyle and the articular fossa functions as a stress absorber [2].

The joint is separated into two compartments by the disc which disperses the stress imposed on the joint through contact of temporomandibular components during jaw movements. A significant feature of the TMJ as a distinguished joint is the fibrocartilage of the disc which covers the articular surfaces of the condyle and the fossa [2].

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The temporomandibular joint is the most frequently used joint in the human body. It opens and closes 1500–2000 times per day during its diverse movements, which include: mastication, speech, deglutition, yawning and snoring. The closure of the mouth is enabled by the masseter muscle, one of the strongest muscles in the human body which plays a key role in mastication [2]. A significant number of the human population is affected by the pathologies of the complex temporomandibular joint (TMJ) [3].

The simulation of the TMJ behaviour during diverse movements can be immensely useful to the understanding of this articulation by physicians contributing to the investigation of prevention and treatment techniques of mandibular issues [2].

B. TemporoMandibular Disorders (TMD)

Temporomandibular disorder (TMD) is a generic term used for clinical conditions of the temporomandibular joint and masticatory muscles [7]. It was reported that that 20–25% of the human population exhibit symptoms of TMD [1]. A higher prevalence in women (6.3–15%) in comparison to men (3.2–10%) was observed among these patients [6]. Key symptoms of TMD include pain in the jaw, restricted jaw movement, grating and clicking sound of the temporomandibular joint, earache and headache. Majority of the conditions of patients with TMD are improved with simple therapies; use of mouth guards and preventive measures such as avoiding extreme jaw movements to minimize aggravation of the conditions. At the end-stage of TMD, surgical therapies such as repairment and reconstruction of TMJ are utilized in the treatment of patients [11]. Parafunctional activities such as grinding or clenching the teeth, presence of osteoarthritis or rheumatoid arthritis in the TMJ and trauma may cause TMD as a result of deformation of TMJ and masseter muscles[10].

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).

The articular disc, a fibrocartilaginous plate which facilitates the movement between the mandible and the temporal bone, is the main constituent of the TMJ. The articular disc functions as a stress absorber and prevent impairment of the articulating surfaces by distribution of the load over greater area of contact . Hence damage of the articular disc may cause temporomandibular disorders (TMD) [4].

Due to limited jaw movements, patients with myofascial TMD pain may have impaired masticatory function and the awareness of muscle pain may also obstruct mastication [6].

Fig 1. The sheep's temporomandibular joint (TMJ)

C. Jaw movement in mastication and speech

Motor functions such as mastication and speech involve the movement of jaw. Anatomy of muscles and biomechanical properties such as reflex, sensory and motor components are shared to a certain extent between masticatory and speech systems [5]. The measurement of rate and amplitude in speech and the formation of bolus in mastication presents a quantitative evaluation of jaw movement. The movement, rate and amplitude of jaw movement were greater in mastication in comparison to that in speech, according to Ostry and Flangan, 1989, as reported in Table I [5]. The process of mastication is composed of three stages including ingestion of food, bolus formation followed by clearance and swallowing. The key masticatory muscles are masseter, temporalis, digastric, lateral pterygoid and medial pterygoid [1]. The masseter muscle, one of the strongest muscles of the human body is the main muscle of mastication [2]. The muscles ensure the mandible is appended to the skull and pivoted at the condyle at both sides of the jaw through the TMJ [1]. The zygomatic bone (cheek bone) on the skull is attached to the mandible through the masseter muscle which controls the opening and closure of the mouth. The temporalis muscle is attached to the temporal bone and regulates elevation of the mandible [1].

During mastication, the movement of the functional condyle occurs towards the direction in which the condyle compresses on the mandibular fossa than the balancing condyle [5].

A cycle of chewing is comprised of three sectors including the opening, closing, and occlusal phase. In biomechanical applications, mandibular displacement, velocities of jaw opening and closing, and masticatory frequency are key features of mastication [1].

The lateral capsule elongates during the mastication and slowly returns to the original formation once the process is completed. Due to the complexity of the human masticatory system, performance of muscular activity includes balance and coordination of the masticatory muscles on both sides during mastication.

In the field of biomechanics, the masticatory system is classified as static, dynamic and kinematic computational models in order to investigate various aspects. The mandibular deformation under muscle forces or loads and its impact on masticatory functions are studied by static models. Different properties of the masticatory system are investigated by the dynamic models through the analysis of muscle forces and directions. Kinematic models are dedicated to the study of mandibular movement [1].

TABLE I
Kinematics of mandible at mastication and speech [8]

	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

The aim of this research is to confirm the hypothesis of the previous study done by authors of this paper [8]. The importance of different factors on speech and mastication on the TMJ has been investigated. In order to do so, the jaw movement during mastication was simulated in the study.

II. Methods

The study uses fresh sheep jaw bones to simulate the mechanical behaviour of the jaw under daily mechanical loading on the TMJ. The study uses the lower jaw which was blasted from the sheep's head.

The sheep's head was stored in the freezer for a few days at a temperature of -20°C. On the day of the experiment it was defrosted in ambient air. The experiment was set by placing the lower jaw on a steel plate which was secured with screws and plastic cable ties.

Table II
Number of sheep's jaw movements per day [7]

Eating	30,008
Ruminating	40,950
Chewing	70,958

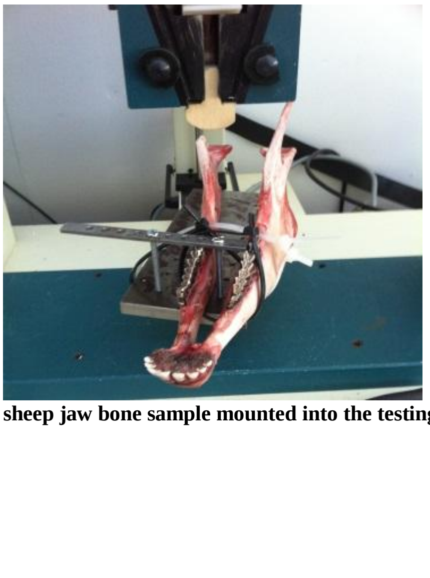

Fig 2. The sheep jaw bone sample mounted into the testing machine

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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.

Table III
The data used for the sheep's jaw bones

Amplitude of the mouth	22.4mm
Amplitude of the TMJ	1.3mm
Frequency	1.57Hz
Density	20 pcf

The study includes 10 tests which utilized polyurethane foam tool (20 pcf) to simulate the action of the temporal bone on the TMJ. The 10 tests were done under the same conditions. A compression-cyclic routine from the QMat database was used to carry on the test.

Table IV
Specification of the ten tests

Load range, N	100
Extension range, mm	5
Speed, mm/min	100
Preload, N	5
Number of the cycles	500

III. Results and Discussion

There are no significant differences between the ten tests. The results show that by increasing the load on TMJ, the displacement of the bone would increase. However, the behaviour of the load-displacement curve was not linear.

The maximum displacement is 1.6 mm and the average of the displacement is 1.4 mm.

A difficulty was experienced on the fixation of the 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 jaw bone was insufficiently dampened with water and cracked slightly, this may have an impact on the results.

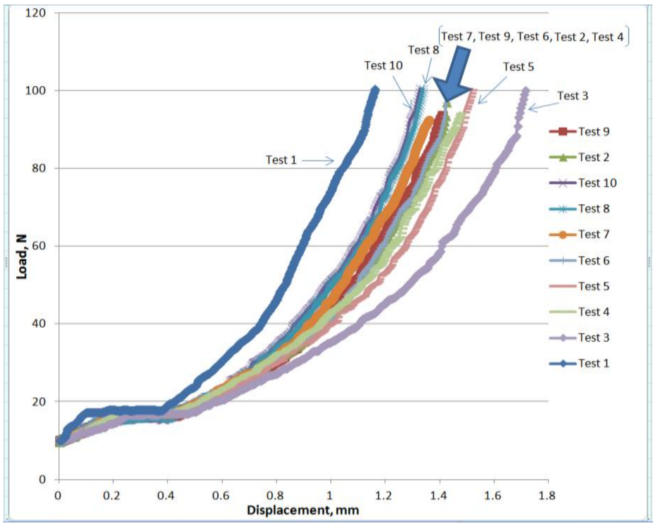

Fig 4. Load and displacement result of the ten tests applied on a sheep jaw bone sample

Table V
Results of the study

Maximum of displacement	1.6 mm
Minimum of displacement	1 mm
Maximum of stiffness	880 N/mm for 0mm
Minimum of stiffness	25 N/mm for 1.4mm
Maximum of stress	0.62 N/mm^2 for 1.2mm/mm
Minimum of stress	0.08N/mm^2 for 0 mm/mm

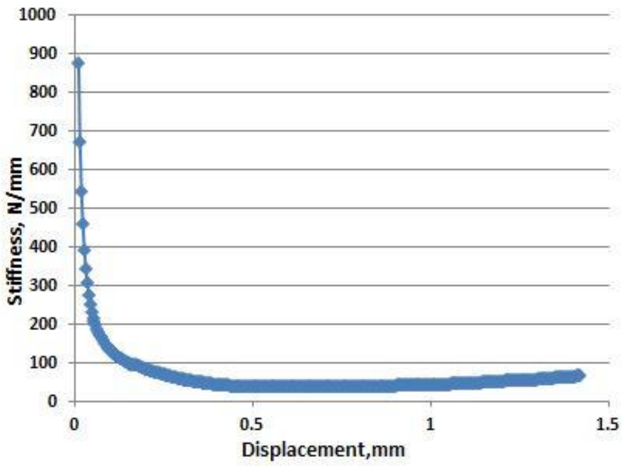

Fig 5. The stiffness and the displacement

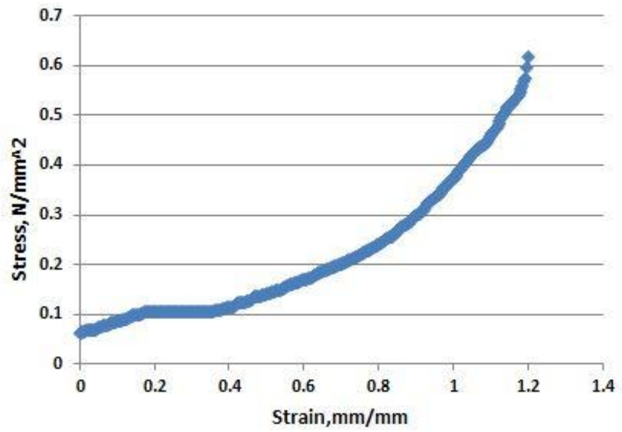

Fig 6. The stress and the strain

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 study examined a method 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 ten tests.

This study is still under investigation and the outcome has not yet been 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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