EXAMINATION OF STRENGTH PROPERTIES OF THE TEMPOROMANDIBULAR JOINT DISC

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Abstract

The purpose of this research was to determine selected biomechanical properties of the temporomandibular disc. After endurance tests and once the load-displacement characteristics were determined, the susceptibility and dimensionless energy dissipation coefficient were determined. The research was carried out on ten discs (six fresh and four frozen) taken from five young pigs. Endurance tests were conducted in the laboratory of Wrocław University of Science and Technology, using the INSTRON 5944 machine. All tested discs were kept in a NaCl solution heated to 37.5ºC during the experiment. A recurring difference of 1 mm in the height of the fresh and frozen discs was observed. In contrast, the strength of the discs was similar regardless of the method of storing the preparation. The material susceptibility values ranged from 0.4 to 1.4 millimetre per Newton, and the dimensionless energy dissipation factor oscillated between 0.27 and 0.87.

The aim of these experimental investigations was to determine the compressive force at predefined strain levels and to elucidate the loading characteristics corresponding to displacement. Due to the observed variability in these characteristics across consecutive measurement cycles, the analysis in this paper is restricted to the results obtained from the first measurement series.

Keywords: *temporomandibular joint disc, biomechanical properties, dimensionless energy dissipation factor, susceptibility*

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Introduction

The temporomandibular joint is considered the most complex joint in the human body both functionally and anatomically. The temporomandibular joint is the only paired joint and the only mobile joint, a true joint, in the craniofacial region. Therefore, the functional anatomy and biomechanics of this joint are extremely complex. The disc in the temporomandibular joint is classified as a hinge position joint, which means that it allows hinged movement in one plane and translational movements. With this combination of movements, it is possible to open and close the mouth and move the mandible in different directions [1].

The functional and anatomical complexity of the temporomandibular joint often results in various dysfunctions. These are congenital, developmental, and acquired as a result of conditions such as neck muscle contractures, postural defects, or malocclusion, for example. As a result of these dysfunctions and damage from trauma, disc damage and inflammatory or degenerative conditions can occur [2-5].

Despite the important role of the temporomandibular joint in anatomy and function, many questions about its biomechanics and adaptation in different conditions remain unclear. Most studies are based on research material collected from animals, and, in particular, pigs [6-11]. Porcine anatomy has a high convergence with human anatomy, making it a suitable model for the study of the temporomandibular joint and other anatomical structures [12]. Taking this into account, the authors of this thesis decided to conduct an experimental strength study using pig temporomandibular joint discs.

Materials and Methods

The study material consisted of the temporomandibular joint of pigs aged between 4 and 6 months. The discs were collected immediately after the head of the pig was delivered to the laboratory. After the discs were taken from the pig's head, the biological material was tested for strength, or frozen until testing (FIG. 1). Each time before the strength tests, the discs were visually assessed for mechanical damage or other defects that would disqualify the testing value of the sampled material. The dimensions of the discs were then measured.

Based on thickness measurements, the amount of strain understood as the change in disc height at the central point of the surface was determined (FIG. 2) [9]. Thanks to these measurements, it was possible to properly adjust the strength test conditions to the specific parameters of the biological material tested, which was crucial to the correctness and precision of the tests carried out.

After taking all the necessary measurements, the temporomandibular joint discs were subjected to a compression test. The test was carried out using the INSTRON 5944 testing machine, equipped with a 2 kN actuator (FIG. 3). The tests were carried out in an aqueous environment - 90% NaCl heated to 37.5°C, using a vessel for this solution. The discs were subjected to a compression test, loading the centre of the disc with force, resulting in a change in height corresponding to a relative deformation of 80% of the height.

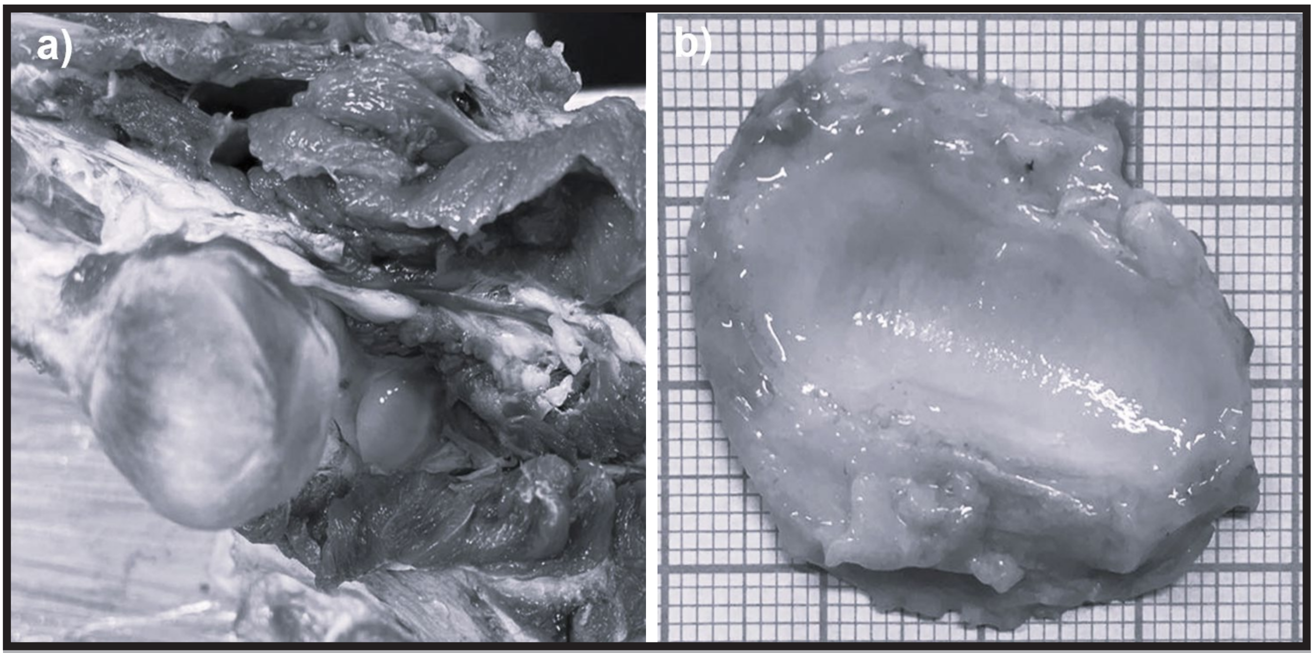

FIG. 1. a) Process of preparing the material for the endurance testing disc in the porcine temporomandibular joint before preparation, b) prepared test specimen - the temporomandibular joint disc.

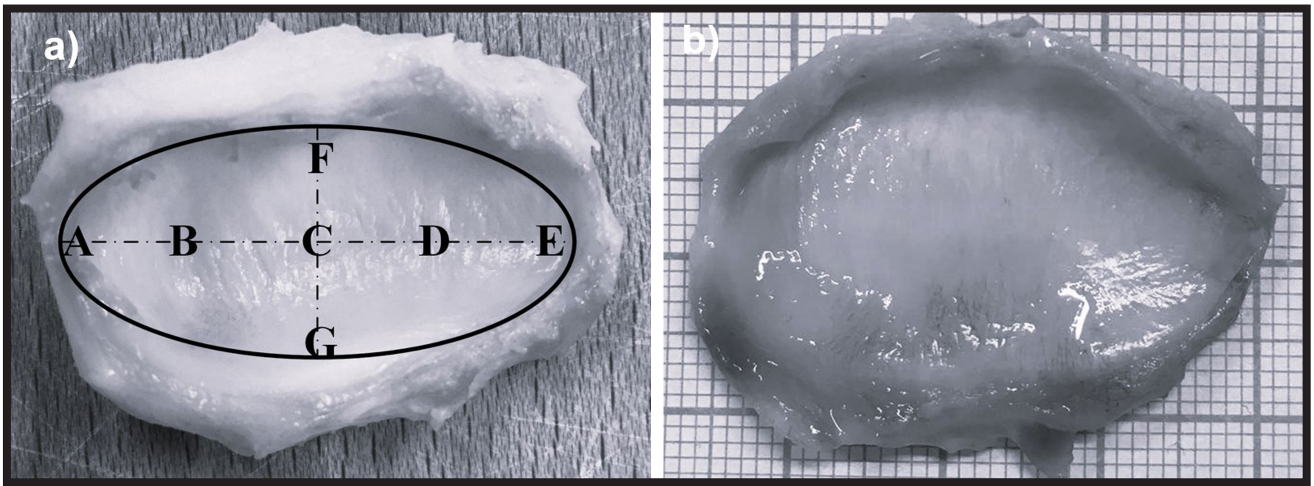

FIG. 2. a) Diagram with marked zones for measuring the thickness of the temporomandibular joint disc from the cranial side - before examination, b) the temporomandibular joint disc from the mandibular side - before examination.

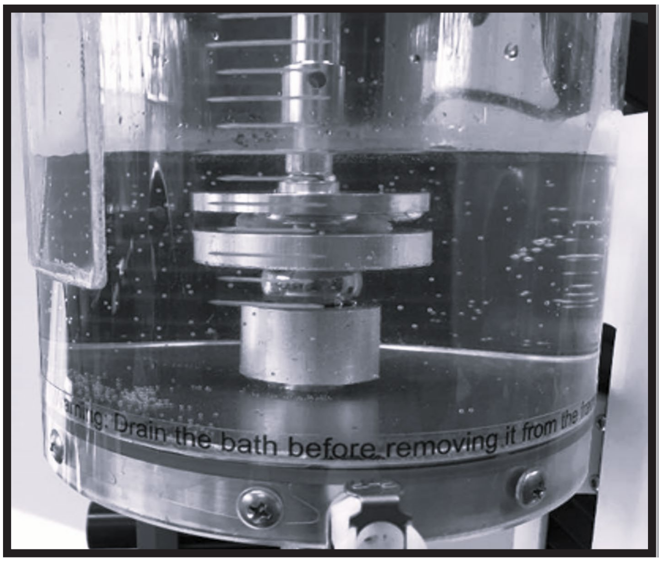

FIG. 3. Test stand for endurance tests, with the temporomandibular joint disc preparation to be tested, in holding wraps, in a saline bath at 37.5°C.

All tests were carried out under the same conditions, using the following procedure: in the first minute, the temporomandibular joint disc was loaded with a force to reach 80% of its height; in the second minute of measurements, the disc was compressed by the testing machine at a constant displacement of the actuator in the last minute of each measurement series, the disc was relaxed, i.e. relieved of load (each test consisted of three series of measurement) [12] - after the experiment was performed, the load-displacement characteristics were obtained. Subsequently, a strength test analysis was carried out to determine the compressive deformation susceptibility of the material (the compressive stiffness of the puck was not determined because the governing formula is applied using Hooke's law, which does not apply when testing on biological material). The susceptibility was determined from the first measurement test.

$$S_c = u/F_c \text{ [mm/N]}$$

u - displacement [mm],
F_c - compressive force [N].

On the basis of the results obtained, hysteresis loops were determined (based on the approximation of the diagram) to determine the dimensionless energy dissipation factor. The dimensionless energy dissipation factor was determined on the basis of the first measurement attempt.

$$\Psi = A_H/A_S$$

A_S - field under the graph,
A_H - hysteresis surface area.

After the strength test, the geometry of each disc was re-measured.

Results and Discussions

Six discs were selected for the analysis of the results, four of which were fresh and two of which had undergone a freezing process. This decision was made in order to eliminate incorrect measurement data, raising doubts about the other materials collected. The designations of the test samples are summarized in TABLE 1.

Before and after the compressive strength test, the width and height of the discs were measured to observe the geometric changes of the test material. The results of the geometric disc measurements are shown in TABLE 2 and in FIGs 4 and 5.

TABLE 1. Designation of test samples.

Sample	Temporomandibular joint disc
k.1	frozen
k.2	fresh
k.3	fresh
k.4	frozen
k.5	fresh
k.6	fresh

TABLE 2. Geometric dimensions of the articular disc from the cranial side before and after examination.

Sample	width of the temporomandibular joint disc [mm]		height of the temporomandibular joint disc [mm]	
	before the test	after the test	before the test	after the test
k.1	27.9	28.2	17.4	16.9
k.2	28.2	28.7	17.9	17.1
k.3	30.5	30.9	17.9	17.2
k.4	31.8	31.2	18.5	18.3
k.5	28.8	29.2	21.0	19.8
k.6	26.1	27.1	18.4	15.6
results	(28.9±2.0)	(29.2±1.6)	(18.5±1.3)	(17.5±1.4)

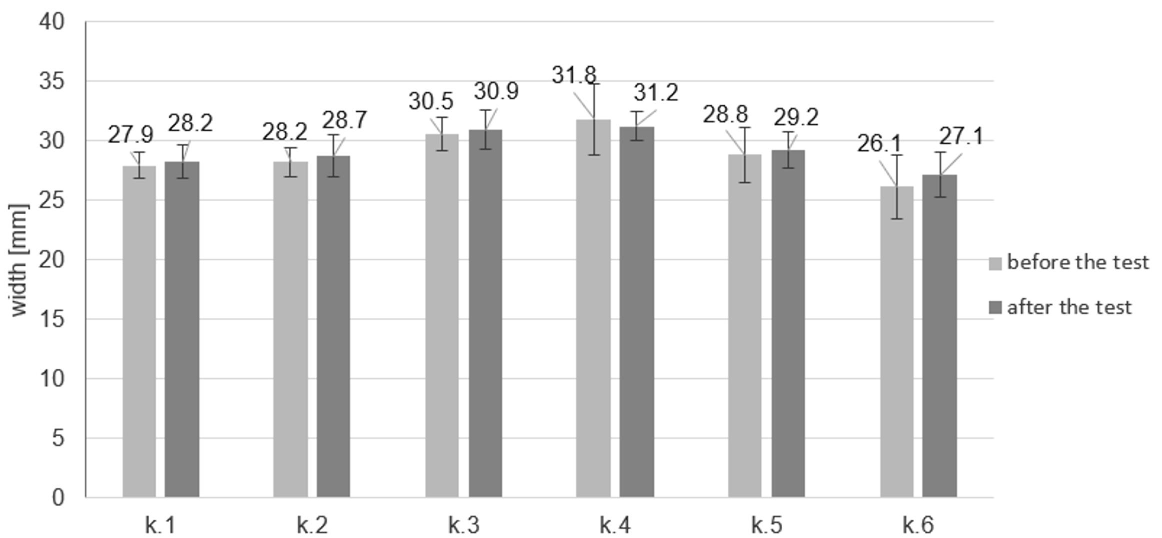

FIG. 4. Width of the temporomandibular joint disc before and after the test.

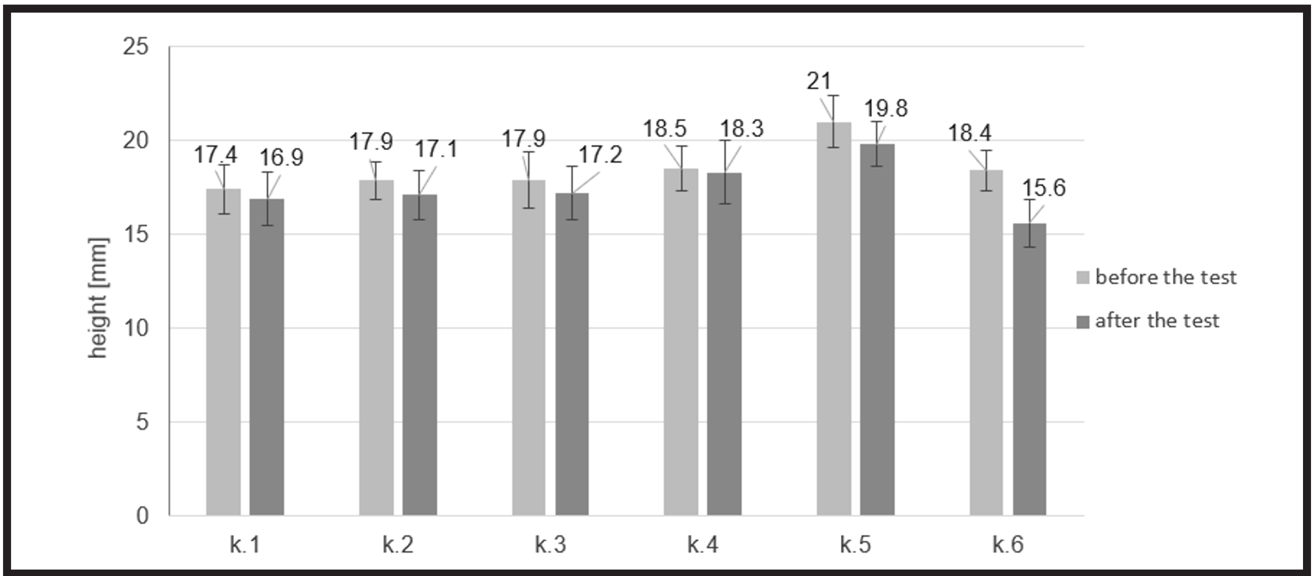

FIG. 5. Height of the temporomandibular joint disc before and after the test.

The results of the pre- and post-test disc thickness measurements were collected as mean values along with the standard deviation (TABLE 3). The key measurement was the central area, marked C, which was subjected to further strength testing. The thickness of the discs was also measured after the experiments to observe any differences.

The results of the maximum temporomandibular joint disc load measurements for each first measurement trial were collected and presented in TABLE 4. Load-displacement characteristics was determined for each temporomandibular disc tested (FIG. 6).

The results of the maximum susceptibility values of the discs for the first measurement test are summarized in TABLE 5.

A dimensionless energy dissipation coefficient was then determined, understood as a measure of energy loss during cyclic loading, which reflects the material's ability to absorb energy during deformation and resist fracture. Analysis of this coefficient allows the strength of the material and its behaviour under dynamic conditions to be assessed.

TABLE 3. Measurement of the thickness of the temporomandibular joint disc.

Sample	before the strength test [mm]						
	A	B	C	D	E	F	G
k.1	0.09±0.02	0.97±0.01	0.86 ±0.01	0.94 ±0.01	0.93±0.02	1.31±0.04	2.63±0.01
k.2	0.64±0.01	1.00±0.02	1.06 ±0.01	0.89±0.01	1.10±0.02	3.40±0.01	2.35±0.02
k.3	0.94±0.04	0.74±0.01	0.76±0.01	0.59±0.01	1.20 ±0.01	3.90±0.01	3.33±0.01
k.4	1.17±0.02	1.14±0.03	1.06 ±0.02	1.31±0.02	1.07±0.02	3.13±0.04	4.5±0.02
k.5	0.79±0.01	0.61±0.01	0.92±0.01	0.91±0.02	0.86±0.01	2.01±0.03	2.09±0.01
k.6	1.01±0.01	0.76±0.01	1.00±0.01	0.82±0.01	0.82±0.01	3.72±0.03	3.44±0.01
	after the strength test [mm]						
k.1	1.56±0.03	1.06±0.02	0.99±0.02	1.21±0.01	0.99 ±0.03	1.13±0.02	3.20±0.08
k.2	1.01±0.02	1.04±0.01	1.19±0.02	1.03±0.02	0.87±0.02	2.59±0.01	1.74±0.03
k.3	1.36±0.02	1.68±0.01	1.75±0.01	0.93±0.02	1.18±0.01	2.94±0.02	3.46±0.02
k.4	1.16±0.13	0.96±0.02	1.25±0.02	1.21±0.01	1.12±0.02	3.70±0.04	3.09±0.02
k.5	0.97±0.01	1.01±0.01	0.71±0.01	0.55±0.01	0.82±0.02	1.96±0.06	2.96±0.02
k.6	1.08±0.02	0.84±0.01	1.11±0.01	1.17±0.04	0.92±0.01	3.85±0.01	3.88±0.02

TABLE 4. Maximum load values.

Measurement series	k.1	k.2	k.3	k.4	k.5	k.6
	F_{cmax} [N]					
I	2.14	1.2	2.44	0.56	1.99	1.91
II	0.67	0.87	1.52	0.25	2.21	0.35
III	0.50	0.76	1.46	0.24	2.04	0.26

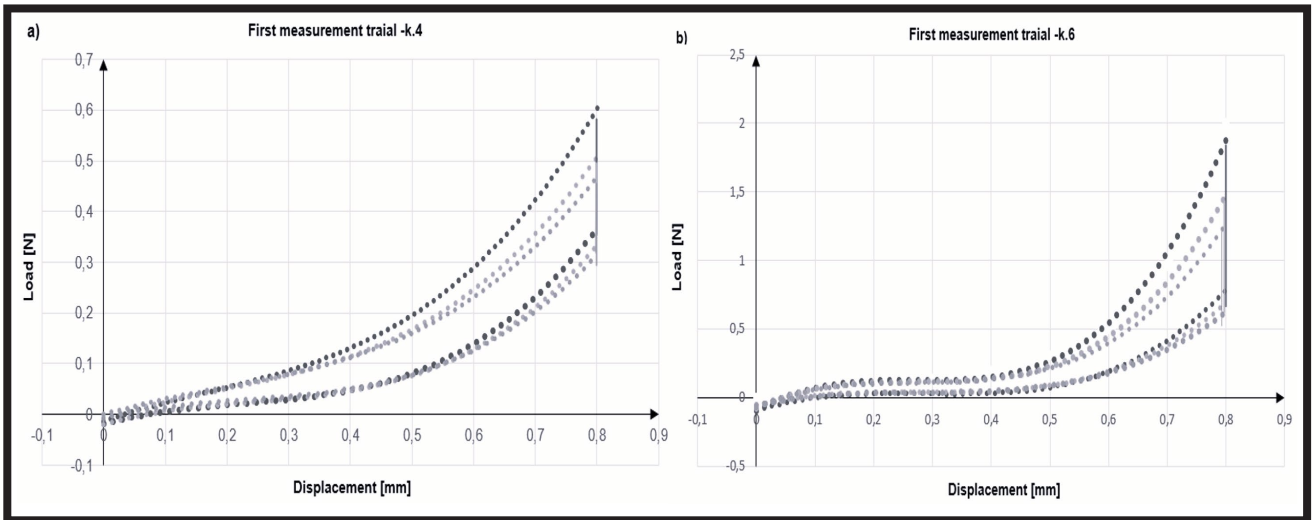

FIG. 6. Temporomandibular joint disc strength test: a) frozen disc, b) fresh disc.

TABLE 5. Maximum values for temporomandibular joint disc compliance.

Temporomandibular joint disc	S_c [mm/N]
k.1	0.37
k.2	0.67
k.3	0.33
k.4	1.43
k.5	0.40
k.6	0.42

TABLE 6. Dimensionless energy dissipation factor.

Sample	A_H	A_S	Ψ
k.1	0.18	0.24	0.76
k.2	0.18	0.38	0.48
k.3	0.25	0.29	0.87
k.4	0.02	0.10	0.21
k.5	0.08	0.15	0.56
k.6	0.06	0.23	0.27

The A_H parameter was determined by calculating the hysteresis area (TABLE 6). This analysis focuses on various aspects of the behaviour of the temporomandibular joint disc under load and the interpretation of the data obtained in terms of their clinical and biomechanical significance.

Geometric measurements of the temporomandibular joint discs from the cranial side were taken before strength testing. It was observed that frozen discs appeared slightly thicker than those freshly collected from pigs. However, it should be noted that this difference is not significant. The results of these measurements are shown in TABLE 2, where the values obtained differed by approximately ±1 mm.

When compression tests were carried out on the discs, slight changes were observed in the thickness of the discs. After the test, the width of the discs increased, while the height of the discs decreased. After three measurement series on a given disc, the second and third series were characterized by lower maximum load values, confirming the thesis of geometric changes in the disc. These differences are described in detail in TABLE 3. The width of the discs marked in FIG. 2a at points (A, B, D, E) increases, while their height at points (F and G) decreases. This is a predictable effect of the compression tests, which results in a flatter disc. The largest geometric changes have been observed for disc k.1, which is a frozen disc, and the smallest changes have been observed for the fresh disc, k.6. However, these differences are not relatively high between fresh and frozen discs.

In addition, based on geometry measurements, great similarity in the size of the human temporomandibular joint disc was observed - the thickness of the pig disc at point C of the disc k.1 is 0.86 mm, while the human disc according to [12] is 0.9 mm. This observation provides further confirmation of the validity of subletting experimental studies on pig discs.

Hysteresis plots were obtained for all samples tested, as described in this article. To correctly visualize the measurement data, a polynomial approximation of the trend line (3^{rd} order) was used. Thus, it should be noted that the ‘moduli’ of the measurement series carried out grew non-linearly, clearly demonstrating the non-linear nature of the material. It has been observed that excessive compression of the disc is associated with permanent, invariant geometric changes [7].

In addition, the susceptibility of the discs was determined for each of the first measurement trials, the values obtained for which are shown in TABLE 5. The susceptibility values of the material ranged from ±0.4-1.4 mm/N. The relatively low susceptibility values may be due to the collection of material from young pigs between 4 and 6 months of age.

Subsequently, the dimensionless energy dissipation factor was determined for each first measurement sample. This ratio, which is the ratio of the area of the hysteresis loop to the area under the graph, reached values oscillating between ±0.27 and 0.87, consistent with the data available in the literature [13]. It was found that the area under the hysteresis plot is related to the geometry of the temporomandibular joint disc and its storage method, i.e., whether it is fresh or frozen. The highest energy damping coefficient was recorded for the fresh disc marked k.3.

Conclusions

The experimental studies of the temporomandibular joint discs described in this work are pilot studies to determine how to proceed in strength testing for uniformity in the origin of biological material. The most important objective of these experimental studies was to determine the compressive force at a given strain and to determine and describe the characteristics of loading from displacement. Due to the variability of characteristics during successive measurement cycles, in this paper, the analysis of the results is presented only for the first measurement series [12]. During the strength tests, the values of the susceptibility Sc of the tested biological material and the dimensionless energy dissipation coefficient Ψ were determined. The results obtained do not differ from the typical results observed for tests on temporomandibular joint discs [13]. In the future, the overarching research objective for the authors is to present for a wider research sample the strength properties of the discs, which can serve as a source for both further experimental and analytical (FEM) studies.

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