

Mechanical Properties of Selected Biological Structures

Jan Kovanda , Hedvika Kovandová, and Josef Stingl

ABSTRACT

The mechanisms of injuries are depending on the initial and boundary conditions of the violence and on the basic mechanical properties of body tissues. The tests of mechanical properties of human organs and tissues are complicated from many reasons (ethic, legal, technical, availability, reliability). On the other hand the mathematical simulation requires databases containing data indicating the mechanical properties of the tissues. The presenting method declares the correlation between the stiffness of selected tissues (selected as most vulnerable parts during car accidents) and its histological analysis on the microscopic level. The histological assessment is based on the method called morphometry. It evaluates the substructures from the histological section on the base of the numerical level. These characteristic numbers correlate with the measured and evaluated stiffness of the tissue under study. The stiffness measurements were made of the identical specimens on the tearing machines. Parallel to it the difference between fresh (under 48 hours post mortem) and embalmed specimens was evaluated. The histological data are well available and they can serve as basic tool for injury mechanisms assessment. This methodology can be used during accident reconstruction as well.

The proceeding deals with the special problem in the area of passive safety of vehicles and biomechanics - the analysis of mechanical properties of biological structures and their relation with histological characteristics of tissues. The methodology used covers both experimental and mathematical research. The aim of the research is to understand the mechanisms of injuries from microscopic view. The presented methodology of biological materials evaluation can serve as the amendment to the conventional test. The initial idea of the research is taken from the presumption, that there could be some relations between mechanical properties of biological materials and some quantitative expression of their histological structure. This relation, which should be statistically proved, can be found between the conventionally measured characteristic (stiffness) and histological structure described in numerical characteristics taken from microscopic sections of the same specimen. This method is called Stereology/Morphometry. Measuring of real three-dimensional structures in a microscope is difficult due to flatness of microscopic images as a result of projecting the content of (usually) thin sections onto the image plane of an optical or electron microscope. The image of a spatial object is therefore considerably deformed (the spatial information has been partly lost due to sectioning, and structures in the depth of the section become optically compressed onto the image plane and can therefore not be suitably resolved /at least not in the conventional microscopes/).

A traditional approach to overcome this problem is the reconstruction of three-dimensional structures from serial sections. Even certain measurements can be obtained by this approach, particularly when suitable computer algorithms are used. For the general application, however, this is not the best approach for a number of reasons, but mainly because it is very laborious and thus limits the sample size that can be studied with reasonable effort. The development of stereological methods has overcome these problems by a different approach. These methods exploit the fact that sections are 'samples' of the structure (sometimes even 'random samples') and thus use suitable statistical methods to derive measures of the structure itself from measurements performed on the section. Stereological methods are thus mathematical methods. Their theoretical basis is geometric probability or integral geometry.

The original definition of stereology (Weibel and Elias, 1967) states that: 'Stereology is a body of mathematical methods which relates parameters defining three-dimensional structures to measurements obtainable on two-dimensional sections'. Stereology is a basic method for measuring through the microscope. The general principle is that the structure is 'probed' with a reference or test systems of known geometric properties and known size characteristics, either plane sections, line grids, or point sets, on which the structure is imaged quantitatively with predictable probability, thus resulting in a coherent set of stereological relations. For each of the structure parameters there exists one test system on which the structure parameter can be estimated by simple point counting procedures. This approach has allowed the question of structure-function relationship to be approached in a quantitative sense, leading to new insights into the role of structural design in setting up functional systems. The second side of the relation are conventionally measured mechanical data of tissues under consideration. The tearing machine was used to measure the one-axis stiffness characteristics of tissue taken from dissection.

Due to tight and fragile structures of tested organs, tendons, ligamentous apparatuses, the specimens have to be fixed in the jaws of tearing machine with the special care and good strategy respecting the physiological position and main orientation of external forces, if possible. The special tearing machine jaws were designed with respect of measurements requirements. The materials under tests were used either as the fresh specimens or were taken from fixed resources. The first sets of tests proved the differences between fresh and embalmed specimens to find the relation between the estimated properties of living organs and material destined for anatomical dissection. The embalmed material can be used for statistically valuable numbers of tests.

During the research the tendons, aorta, kidneys, liver, spleen and lungs were tested. The comment to the measurement and the results are: The stiffness of selected tissues has been tested. The term of maximal stiffness has been substituted by the evaluation of maximal stiffness derived from the unified cross-section used for histological evaluation (MNHONS). It must be more exactly specified for future more precise calculations..

- The graphs show large diffusion of the stiffness of one type of the tissue. This phenomena can be given by the different material properties, inaccuracy of the measurements (measuring scale of the tearing machine) and cross-section area estimation.
- The difference of the results obtained from fresh and embalmed specimens could be affected by side effects like different time of measurement examined by different assistants, etc. The same is valid for the relation between stiffness and the age.
- The most exact results we can find in aorta, this tissue has the lowest stiffness in fact.
- The speed of deformation is about 25 mm per minute. The tests carried out are considered as static ones. The biological materials deformation tolerance is sensitive on the speed of deformation, therefore the speed should be considered in the future.
- The obtained data were compared with published data – see tab.5.

The evaluation of both mechanical properties and stereological data have carried out for aorta and lung tissue, respectively. The measured data are in tables 1 and 2.

Aorta	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Stiffness	1,00	1,53	1,50	0,95	1,87	1,68	1,54	2,10	2,55	2,69	2,78	1,27	0,91	1,18	1,65	1,87

Table 1. – Stiffness of aorta specimens

Lungs	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Stiffness	35,26	27,82	50,00	28,34	24,29	29,30	81,20	85,02	76,92	64,10	31,47	62,27	40,49	46,82	106,23

Lungs	16	17	18	19	20	21	22	23	24	25	26	
Stiffness	76,92	68,38	82,05	133,60	36,63	83,16	18,46	45,25	45,25	36,20	67,31	MPa

Table 2. – Stiffness of lungs specimens

The graph of results for aorta is presented in Figure 1.

Aorta - measured stiffness

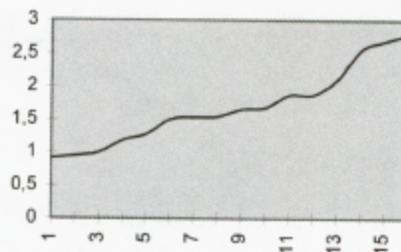


Figure 1. – Data from measurements

The histological evaluation for these tissues gives following results:

Specimen	Section Number	Magnification	Fibrous Component Volume Rate		
			Collagen	Elastic	Total
A I	337	4000 x	0.26	0.07	0.33
A I	338	4000 x	0.22	0.09	0.31
A I	340	4000 x	0.17	0.04	0.21
A I	337,338,340				
A II	342	4000 x	0.32	0.00	0.32
A II	361	4600 x	0.78	0.00	0.78
A II	362	6000 x	0.79	0.00	0.79
A II	363	6000 x	0.88	0.00	0.88
A II	364	8000 x	0.66	0.00	0.66
A II	365	8000 x	0.42	0.00	0.42
A II	366	4600 x	0.79	0.00	0.79
A II	367	4600 x	0.61	0.00	0.61
A II	342,361-367			0.00	
A III	345	4000 x	0.16	0.02	0.18
A III	346	4000 x	0.13	0.15	0.28
A III	347	4000 x	0.18	0.09	0.27
A III	348	6000 x	0.14	0.17	0.31
A III	351	4000 x	0.32	0.14	0.46
A III	345-358,351				
P I	369	2600 x	0.08	0.00	0.08
P I	370	2600 x	0.26	0.00	0.26
P I	371	6000 x	0.07	0.00	0.07
P I	372	3400 x	0.34	0.00	0.34
P I	373	2200 x	0.63	0.00	0.63
P I	374	2200 x	0.59	0.00	0.59
P I	375	4600 x	0.28	0.00	0.28
P I	376	4600 x	0.21	0.00	0.21
P I	377	4600 x	0.19	0.00	0.19
P I	369 - 377			0.00	
P II	378	4600 x	0.33	0.00	0.33
P II	379	4600 x	0.46	0.00	0.46
P II	380	4600 x	0.39	0.00	0.39
P II	381	6000 x	0.42	0.00	0.42
P II	382	1400 x	0.20	0.00	0.20
P II	383	4600 x	0.19	0.00	0.19
P II	378 - 383			0.00	

Note: A = aorta, P = lungs

Table 4. The morphometrical data obtained from selected specimens

The graphical representation of total fibrous component volume rate gives Figure 2.

Aorta - morphometry

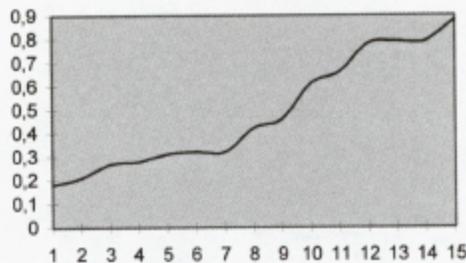


Figure 2. – Data from morphometry

The correlation data between data presented in Graph 1 and 2 respectively can be calculated. Nevertheless the low number of tested specimens and the morphometrical analysis of random histological sections can not be statistically conclusive. Therefore we stated only the feeling of possible relations from the graph and the serious evidence will be done in the frame of future works.

CONCLUSION

The problem under study is very complex and requires deep analysis in both laboratory conditions and computer modelling. Nevertheless available database of morphometrical data can provide the first approximation to the real biological properties which enables the quite realistic simulation of human body under crash condition including the individual deviations. The value of the method for the crash reconstruction is selfevident. The loading forces are taken from mathematical models developed in the environment of well-know software packages. The motivation of the presented research in to provide these packages with good background for human body simulation, beyond the simulation of crash-test dummies during the crash conditions. The future activities should be aimed to the biomechanical criteria derivation and more complex and real human behavior analysis.

Note:

Comparison of obtained data with literature resources.

Values presented in MPa.

Tissue	A	B	C
Aorta	1,74	0,75 ± 0,3	1,88 ± 0,29
Liver	2,72	-	-
Kidney	7,89	2,67 ± 0,36	-
Lungs	48,96	-	-
Spleen	9,45	0,02 ± 0,005	-
Tendons	About 25	67 ± 2	67 ± 2

Table 5. - Comparison of obtained results with some data from publications.

REFERENCES:

- Stingl, J. - Altschul, J. - Gruber, V. - Kostal, J. - Koudela, K. - Marecek M.: To the diagnosis of injuries of the external collateral ligament of the ankle joint. Pilsen Med. Report 43: 37-42, 1976
- Stingl, J.: Contribution to the investigation of the vascular supply of the Achilles tendon. Acta Chir.orthop.Traum. czech. 48: 163-168, 1981
- Kovanda, J. - Stingl, J.: Critical tension by injury. Report IRCOBI International Conference, Berlin 1991
- Stingl, J. - Kovanda J.: Measurement of Resistance of Internal Organs to Tension during Barrier Test(in Czech). Motor Veh. Research Inst. Ref.542/3/89, Praha 1989

- Kovanda,J., - Holy,S.- Stingl,J. : Some aspects of passive safety of the vehicles. Czech-German symposium, Academy of Sciences of CR, Liblice 1995
- Kovanda,J.: Design of vehicles - Passive safety. Czech Technical University. Prague (1994)
- Vogelova,H.: Analysis of the special cases in the passive safety of vehicles. Czech Technical University. Prague (1998)
- Kovanda,J., Stingl,J.: Reports for grant agency GACR. Prague (1996, 1997)
- Cruz-Orive,L.M. Stereology: Recent solutions to old problems and a glimpse into the future. Acta Stereol. 6, 3. (1987)
- Cruz-Orive,L.M. & Weibel,E.R. Sampling designs for stereology. J.Microsc. 122, 235. (1981)
- Gundersen,H.J.G. & Jensen,E.B. The efficiency of systematic sampling in stereology and its prediction. J.Microsc. 147, 229. (1987)
- Gundersen,H.J.G. & Osterby,R. Optimizing sampling efficiency of stereological studies in biology: or "Do more less well!" . J.Microsc. 121, 65. (1981)
- Hoppeler,H. et al. The use of small computer systems for stereology. Mikroskopie, 37, 408. (1980)
- Mathieu,O. et al. Measuring error and sampling variation in stereology: Comparison of the efficiency of various methods for planar image analysis. J.Microsc. 121, 75. (1981)
- Weibel,E.R. Stereological Methods Practical Methods for Biological Morphometry. Vol.1. Academic Press, London. (1979)
- Weibel,E.R. & Elias,H. Quantitative Methods in Morphology. Springer Verlag, Berlin. (1967)