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Investigation of the mechanical properties of a composite material of chitosan-vancomycin-nanocellulose nanoparticles of bacterial origin to close dura mater defects

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INTRODUCTION

Dura mater (DM) is a thick, dense, irregularly shaped connective tissue that surrounds the brain and spinal cord. In the case of injuries, oncological processes of the brain and spinal cord, as well as during neurosurgical interventions, the dura mater can be damaged, dissected or removed to provide access to and underneath the nerve structures. Effective closure of dura mater defect helps to minimize CSF leakage and ensure proper wound healing. DM defects can be closed in various ways, and among them there are those that involve the use of DM substitutes available on the market. However, an ideal material for dura mater plastics has not yet been created.

AIM

The aim of this work is to compare the mechanical properties of samples of bacterial cellulose grown using Novochizol™ (BNC + C) with bacterial cellulose grown without it (BNC) and to assess the possibility of controlling the mechanical properties of the material by varying thickness. To validate the obtained results, we also compared samples of grown tissues with samples of fresh and cadaveric dura mater obtained on the basis of project participants.

RESULTS

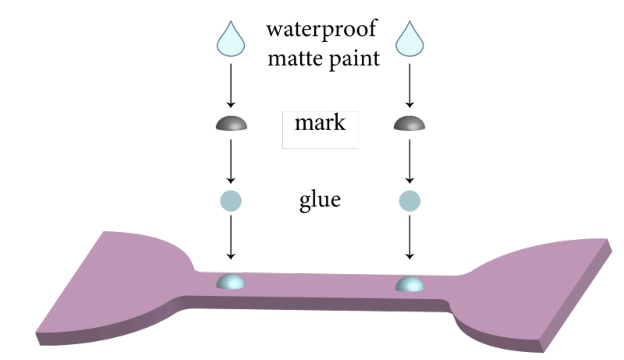
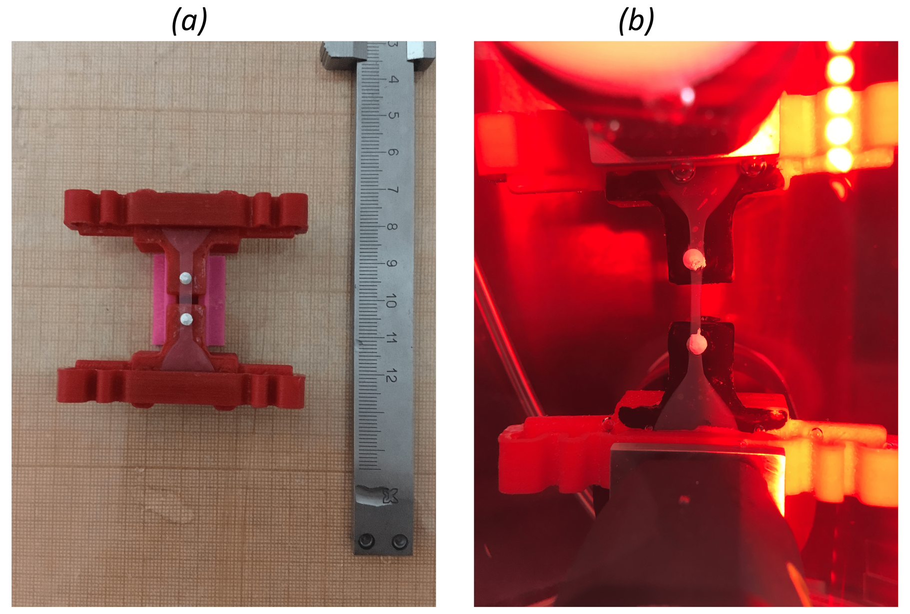


Fig. 1. The technique of attaching marks to the specimen for the extensometer.

Fig.2 (a) – preparation of the specimens, (b) – specimen in the tensile machine.

(a) (b)



Overall 43 experiments on uniaxial mechanical loading of BNC specimens and 22 BNC + Novochizol specimens were carried out. In addition, the dura mater tissues (2 specimens) of healthy patients and cadaveric dura mater specimens (13 specimens) were tested using the same technique.

In the course of the study, we have shown that the ultimate strength of the new composite is similar and slightly exceeds the ultimate strength of the material grown according to the standard technique: 0.75 Vs 0.58 MPa(± 29.31%). Statistical analysis of the dependency between the thickness of the samples, and their ultimate values of stress and strain, as well as Young's modulus at small deformations showed that there are no significant differences between the two types of material (BNC vs BNC + Novochizol) for Young's modulus. Regarding the relationship between ultimate stress and deformation, the relationship for the standard BNC cultivation method is more linear (R=0.305807), at the same time, this only indicates that this relationship is less linear for BNC + Novochizol material.

Analyzing the relationship between the thickness of the material and its ultimate stress, we see (Fig. 4) that this relationship is more linear for the new material, and in this case, this indicates more predictable strength characteristics of the material during its growth. As in in this case it is enough to carry out the measurements of the material thickness at the same definite time intervals rather than building a complex polynomial or recursive model for measuring the thickness of the grown material, which is an undoubted technological advantage of such a material.

The requirements for the design of the material used to close the dura mater defect are that it should not induce an immunological or inflammatory response, should not be neurotoxic, should be degradable for the growth of endogenous indolence, should provide a hermetic closure, should retain its shape after use, and must be durable. An ideal substitute for dura mater should not pose a risk of transmission of viral and prion infections and should be of reasonable cost and free of infectious complications after implantation.

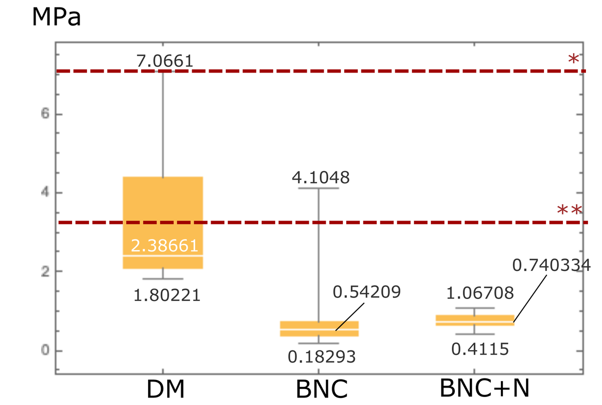
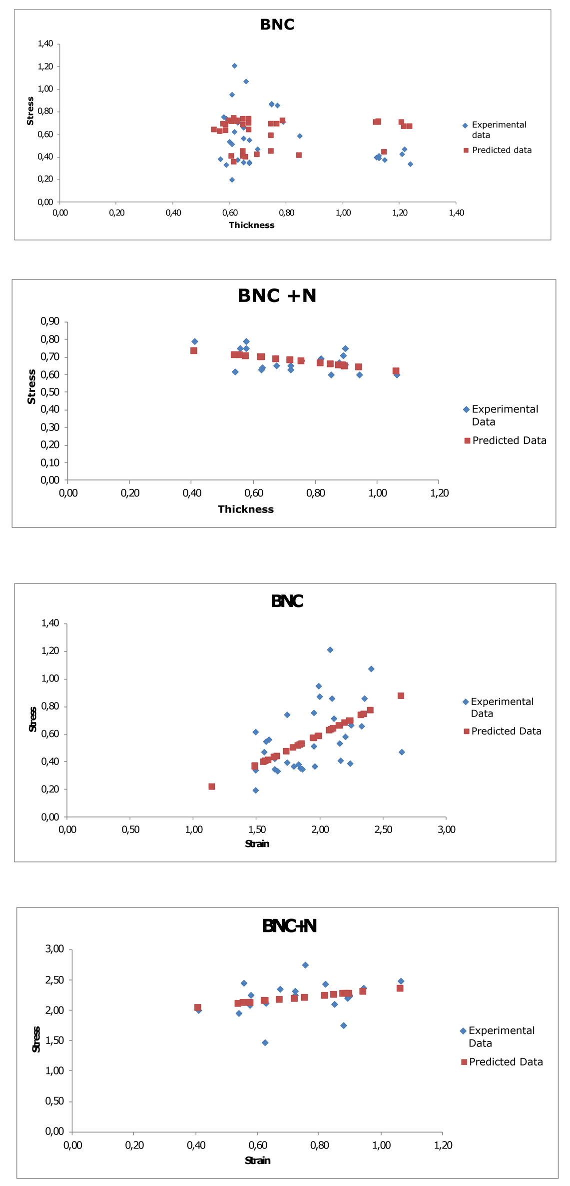


Fig. 3. (above)
The technique of attaching marks to the specimen for the extensometer.
Fig.4 (on the right)
Linear regression for BNC (1) and BNC + Novochizol (2) samples for stress-thickness relationship.
Linear regression for BNC (3) and BNC + Novochizol (4) samples for stress-strain relationship.



METHOD

Native bacterial cellulose was grown at the Institute of Chemical Biology and Fundamental Medicine SB RAS, then transferred to N.N. Vorozhtsov Novosibirsk Institute of Organic Chemistry SB RAS for Novochizol treatment. Samples were cut using a laboratory apparatus for cutting biological tissue "Melaz Cardio" at the Institute of Laser Physics SB RAS.

Samples of fresh dura mater were obtained during neurosurgeries as described above. This part of research was carried out in cooperation with Federal Neurosurgical Centre of Novosibirsk. The obtained tissue was preserved with saline 0.9% at 2◦C-5◦C during transportation(12-48h).

An uniaxial tensile machine Instron 5944 was used for mechanical testing of the dura matter. After being delivered to the laboratory, rectangular shape is cut from the specimen. Then the sample was fastened in tensile machine Instron 5944 and a series of experiments was performed. From the cadaveric material the dog-bone shape was cut, with the same parameters as for the BNC. For fresh DM samples obtained during neurosurgery we used a rectangular shape of the sample for testing, mainly due to the small and irregular shape of the initial samples, and also to simplify the processing of data. Video extensometer (lens from Fujifilm) was used to measure the local deformation in some of the samples.

CONCLUSIONS

Mechanical tests were performed on samples of bacterial nanocellulose and live and cadaveric samples of dure mater. It was established, that the mechanical properties of the BC are in the range of those of other substitutes of dura mater which are currently used in the surgical practice. An addition of Novochizol™ can allow to control the thickness of the material and improve the healing properties of the graft.

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