Computer Modeling of Intervertebral Disk Endoprosthesis

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Abstract. The article describes the model of the intervertebral disc endoprosthesis. The algorithm for constructing the geometric model of the intervertebral disc prosthesis is developed in the ANSYS programming language APDL, which allows to automatically rebuilding the shape and size of the prosthesis depending on the size of the vertebrae and the required intervertebral spaces of different parts of the spine of particular individual. The geometric model of the intervertebral disc prosthesis is based on the experimental sample of a ceramic endoprosthesis developed at the Institute of Strength Physics and Materials Science SB RAS.

1. Introduction

One of the most important constructions of the human body is the spine. Its structure allows you to perform the functions of support and movement. The spine is divided into cervical, thoracic, lumbar and sacral regions [1, 2]. An intervertebral disc (IVD) separates each vertebra, except in the upper cervical spine (C1 & C2), and in the sacrum and coccyx, where the vertebrae are fused together [3]. The discs resists spinal compression, permits limited bending, twisting, and sliding between vertebral bodies [2].

Degenerative changes of the intervertebral discs are the major cause of pain in the spine and neck in those of the middle and elder age [4]. A radical method of treatment in such cases is the replacement of the intervertebral disc with an implant. Adequate development and individual selection of implants play a decisive role in the treatment of a person. Improper selection of materials and design of implants can lead to deterioration of the bone tissue and the functioning of the spine as a whole. Ceramics are identical to the inorganic bone matrix in the type of chemical bond. Traditionally, brittleness, low mechanical fracture toughness and low resistance to impact have limited the applications of the ceramic materials. Nevertheless, a strong interest in the use of ceramics for biomedical engineering applications has been developed from the end of the 20th century. New ceramics [5-9], with very improved properties, contributed to increasing the possibilities of using ceramics as osteoimplants.

The problems of mechanics arising in the creation and selection of implants of biological tissues are solved on the basis of studying the structure, mechanical behavior and properties of the biological tissues themselves and their interaction with implants. The use of computer modeling methods makes it possible to more deeply understand the patterns of functioning of the spine in norm, at pathologies, at interaction with the implant, which facilitates the selection of a suitable prosthesis for a particular individual.

The paper considers one of the steps on the way to solving the important scientific problem of choosing the individual intervertebral disc prosthesis which is mechanically compatible with organism,
namely the construction of a geometric model of the intervertebral disk endoprosthesis with the purpose of the subsequent aided study of the prosthesis behavior in the spine segment under physiological loads and the study of its influence on the stress-strain state of segment.

2. Materials and methods

The algorithm for constructing the geometric model of the intervertebral disc prosthesis is developed in the ANSYS programming language APDL. The geometric model of the intervertebral disc prosthesis is based on the experimental sample of a ceramic endoprosthesis developed at the Institute of Strength Physics and Materials Science SB RAS.

Figure 1 shows the geometrical model of the intervertebral disc prosthesis built in the ANSYS. The Z axis is directed along the axis of the prosthesis (spine axis), the Y axis in the anteroposterior direction, the X axis in the lateral direction. Geometrical model includes the two opposing plates: upper plate and lower plate. The upper and lower plates contain elements forming a pair of conjugation (Figure 2). It is assumed that the upper plate of the prosthesis will be attached to the lower surface of the upper vertebra, and the lower one to the upper surface of the lower vertebra respectively.

![Figure 1. Geometrical model of the intervertebral disc prosthesis (front view)](image)

![Figure 2. Geometric models of the structural components of the model prosthesis of the intervertebral disc: (a) the upper plate of the prosthesis, (b) the lower plate of the prosthesis](image)

The developed algorithm allows to automatically rebuilding the shape and size of the prosthesis depending on the size of the vertebrae of different parts of the spine of a particular individual and the size of the required intervertebral spaces. The shape of the upper and lower surfaces of the opposing prosthesis plates accordingly can vary from round to ellipsoidal. Figure 3 shows the geometrical model of the intervertebral disc prosthesis with ellipsoidal shape of the upper and lower planes of the prosthesis plates.

The normal spine has three natural curves, the cervical (neck) curve, the thoracic (middle back) curve, and the lumbar (lower back) curve. The cervical and lumbar sections curve forward (lordosis),
while the thoracic section curves backward (kyphosis). This curvature allows even distribution of weight and the withstanding of the applied loads [2]. The presence of lordosis and kyphosis of the spine provides a different height of the intervertebral space in front and behind, occupied by the intervertebral disc, which must be replaced with an implant.

![Figure 3. Geometrical model of the intervertebral disc prosthesis with ellipsoidal shape of the upper and lower planes of the prosthesis plates](image)

For example, Table 1 and Table 2 present the anterior and posterior heights of the intervertebral disc of the cervical and thoracic spine measured by different authors [3, 10-13] and the ratio of these lengths.

### Table 1. Intervertebral disc heights of the cervical spine

| Disk location | Anterior $l_1$ (mm) | Posterior $l_2$ (mm) | $l_1/l_2$ | Anterior $l_1$ (mm) | Posterior $l_2$ (mm) | $l_1/l_2$ | References |
|---------------|---------------------|----------------------|-----------|---------------------|----------------------|-----------|------------|
| C2-3          | 4.8                 | 5.3                  | 1.0       | 3.96                | 3.20                 | 1.24      | [3, 10]    |
| C3-4          | 4.5                 | 4.5                  | 1.05      | 3.69                | 3.04                 | 1.21      |            |
| C4-5          | 3.4                 | 3.5                  | 0.97      | 3.23                | 1.95                 | 1.66      |            |
| C5-6          | 3.3                 | 3.2                  | 1.03      | 3.07                | 2.09                 | 1.47      |            |
| C6-7          | 3.0                 | 3.3                  | 0.9       | 2.85                | 2.06                 | 1.38      |            |
| C7-T1         | 3.5                 | 3.6                  | 0.97      | 3.36                | 2.10                 | 1.6       | [12]       |
| T1-2          | 4.1                 | 4.1                  | 1.0       | 3.7                 | 2.18                 | 1.69      |            |
| T2-3          | 4.2                 | 3.6                  | 1.16      | 4.06                | 2.47                 | 1.64      |            |
| T3-4          | 5.6                 | 5.0                  | 1.12      | 4.52                | 2.49                 | 1.82      |            |
| T4-5          | 5.4                 | 4.2                  | 1.29      | 4.88                | 2.97                 | 1.64      |            |
| T5-6          | 7.2                 | 5.8                  | 1.24      | 5.91                | 3.66                 | 1.61      |            |
| T6-7          | 6.0                 | 4.8                  | 1.25      | 5.9                 | 3.23                 | 1.83      |            |

### Table 2. Intervertebral disc heights of the thoracic spine [13]

| Disk location | Anatomical measurements | Radiographic measurements |
|---------------|-------------------------|--------------------------|
|               | Anterior $l_1$ (mm)     | Posterior $l_2$ (mm)     | $l_1/l_2$ | Anterior $l_1$ (mm) | Posterior $l_2$ (mm) | $l_1/l_2$ |
| C7-T1         | 4.5                     | 4.5                      | 1.0       | 3.96                | 3.20                 | 1.24      |
| T1-2          | 4.5                     | 4.3                      | 1.05      | 3.69                | 3.04                 | 1.21      |
| T2-3          | 3.4                     | 3.5                      | 0.97      | 3.23                | 1.95                 | 1.66      |
| T3-4          | 3.3                     | 3.2                      | 1.03      | 3.07                | 2.09                 | 1.47      |
| T4-5          | 3.0                     | 3.3                      | 0.9       | 2.85                | 2.06                 | 1.38      |
| T5-6          | 3.5                     | 3.6                      | 0.97      | 3.36                | 2.10                 | 1.6       |
| T6-7          | 4.1                     | 4.1                      | 1.0       | 3.7                 | 2.18                 | 1.69      |
| T7-8          | 4.2                     | 3.6                      | 1.16      | 4.06                | 2.47                 | 1.64      |
| T8-9          | 5.6                     | 5.0                      | 1.12      | 4.52                | 2.49                 | 1.82      |
| T9-10         | 5.4                     | 4.2                      | 1.29      | 4.88                | 2.97                 | 1.64      |
| T10-11        | 7.2                     | 5.8                      | 1.24      | 5.91                | 3.66                 | 1.61      |
| T11-12        | 6.0                     | 4.8                      | 1.25      | 5.9                 | 3.23                 | 1.83      |
The developed algorithm for constructing the geometric model of the intervertebral disc prosthesis allows to take into account the ratio of the anterior and posterior heights of the intervertebral space. Figure 4 shows the geometrical model of the intervertebral disc prosthesis with $l_1/l_2=1.5$.

![Geometrical model of the intervertebral disc prosthesis](image)

**Figure 4.** Geometrical model of the intervertebral disc prosthesis with various anterior height $l_1$ and posterior height $l_2$ (side view, $l_1/l_2=1.5$)

### 3. Conclusion

An algorithm for constructing the geometric model of intervertebral disk prosthesis in the ANSYS programming language APDL is developed. The algorithm allows to automatically rebuild the shape and size of the prosthesis depending on the sizes of the vertebrae of different parts of the spine of a particular individual and the size of the required intervertebral spaces. The geometric model of the intervertebral disc prosthesis is based on the experimental sample of a ceramic endoprosthesis developed at the Institute of Strength Physics and Materials Science SB RAS.

The constructed computer model is designed to study the behavior of the prosthesis in the segment of the spine under physiological loads and to study its effect on the stress-strain state of the spinal segment.

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