Mechanics of external fixation device of spine: reducing the mounting stress

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Abstract. During the installation of the external fixation device on the spine, there is an occurrence of mounting stress due to misalignment of the rod-screws. To determine the magnitude of the mounting stresses, mathematical dependencies are sometimes used. The proposed technical solution is to reduce stress in the external fixation device.

1. Introduction
One of the most common diseases of the spine of children and adolescents is scoliosis – curvature of the spine in the frontal plane. In the treatment of this disease, along with prevention of the actual scientific problem, methods of treatment and technical devices for their implementation are developed, as the mechanical effect on the spine is the most effective part [1-12].

The device for mechanical impact on the spine is used when there is an injury in the spine. Lately preference is given to devices that provide anterior fixation of the spine [13-16]. During the installation, rods-screws are introduced in the vertebrae. Corrective effect on the vertebrae is provided by means of external fixation device in which the rods-screws are connected in a unitary structure by means of controlled mechanical linkages.

There is a deviation of the arrangement of some parts of the external fixation device after installation. During the installation, rods-screws are introduced in the vertebrae on, all sorts of gaps, distortions and misalignment are usually eliminated using a set of flat and conical washers and hinges. These distortions increase the time in operation and do not provide the necessary accuracy and rigidity of the assembled device.

To increase the bearing capacity of the device for external fixation of the spine, the mounting stress effect was evaluated on the bearing capacity of the device.

2. Materials and methods
Anatomical requirements for the details of the device for external fixation and the results of processing the statistical characteristics of geometric, medical-biological parameters, taking into account the individual characteristics of patients, are given in [15-19].

When installing the external fixation device, due to misalignment of individual parts, there may be significant mounting stresses. One of the main reasons for this is the deviation of the rod-screw from...
the vertical plane when it is installed in the vertebra. Figure 1 shows a vertebra with fasteners in the frontal plane.

Considering the deflection of a rod-screw with a diameter of 6 mm, when it joins the plate, a gap of, for example, 3 mm appears (Figure 2). The force method is used to analyse the stress-strain state [20]. The appearance of a gap of 3 mm is equivalent to turning the support at the point A by an angle $\alpha$ (Figure 2, diagram "a"), providing the same gap.

In this case, only the torque moment $M_{tor}$ will appear in the transverse plane of the section of plate 2 in Figure 1 before tightening the bolted connection. Considering the basic systematic method of forces of the circuit shown in Figure 3 (diagram "a"), the moment diagrams for unit factor $X_1$ are shown in Figure 3 (diagram "b").

The canonical equation of the force method takes the form:

$$\delta_{11} \cdot X_1 + \Delta_{1p} = 0,$$

where $\delta_{11}$ – movement from the external load $P$; $X_1$ – external force; $\Delta_{1p}$ – movement in the direction of the force.

To determine coefficient $\Delta_{1p}$, the actual rotation of the rod-screw is determined by angle $\alpha$ as a result of the displacement of the support.

$$\Delta_{1p} = \frac{3}{0.06 \cdot \cos 28^\circ} = 0.057.$$

The coefficient $\delta_{11}$ is determined by the method of graphical multiplication of the diagrams:

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**Figure 1.** Vertebra with fasteners in the frontal plane: 1 - rod-screw; 2 - plate; 3 - vertebra.

**Figure 2.** Wiring diagram (sagittal plane): 1 - rod-screw; 2 - plate; 3 – vertebra; $P$ - force on the rod-screw, which occurs when it deviates from the vertical.
\[ \delta_{11} = \frac{L_1 \cdot \cos^2 \alpha}{E_1 \cdot J_{lx}} + \frac{L_2}{G_2 \cdot J_{2p}} + \frac{L_1 \cdot \sin^2 \alpha}{G_1 \cdot J_{1p}}, \]  

where \( E_1 \cdot J_{lx} \) is stiffness of the rod-screw during bending; \( G_1 \cdot J_{1p} \) is the stiffness of the rod-screw during torsion; \( G_2 \cdot J_{2p} \) - rigidity of the plate when torsion.

\( E_1 = 1128.15 \cdot 10^8 \text{ N/m}^2 \) – modulus of elasticity at tension of tungsten-titanium alloy VT-6;
\( G_1 = 4.5 \cdot 10^{10} \text{ N/m}^2 \) – modulus of elasticity in the shear of a tungsten-titanium alloy VT-6; \( J_{1x} = \pi \cdot d^4/64 \) - axial moment of inertia of the rod-screw section.

\( J_{2p} = \pi \cdot d^4/32 \) - polar moment of inertia of the rod-screw; \( G_2 = 8 \cdot 10^{10} \text{ N/m}^2 \) – the shear modulus of steel 20X13 (plate); \( J_{2p} = \beta \cdot b^3 \cdot \alpha \) - polar moment of inertia of the plate (\( b \) - thickness of plate; \( b = 0.003 \text{ m} \); \( \alpha = 0.31 \) – coefficient; \( \beta = 0.31 \) – coefficient.

\[ \sigma = \frac{M_{\text{ben}}}{W_{lx}} + \frac{M_{\text{tor}}}{W_{lx}} = 3 \cdot 10^8 \text{ N/m}^2, \]  

where \( W_{lx} \) - the axial moment of resistance of a core-screw at a bend.

**Figure 3.** Calculating the equations for determining the mounting forces:

(a) basic system; (b) diagrams of single moments; \( X_1 \) - unit factor; \( \cos \alpha, \sin \alpha \) - the value of the maximum moments from a single factor; \( A \) is the point at which the rigidly clamped rod-screw attachment is located.

3. **Results and Discussions**

When solving these equations, the value for \( X_1 = 6.33 \) (N·m). Moments in the fitting (point A) will be:

\[ M_{\text{ben}} = X_1 \cdot \cos \alpha, \quad M_{\text{tor}} = X_1 \cdot \sin \alpha. \]  

Stress in the insecure section (point A) is given by:

\[ \sigma_B = \frac{\sqrt{M_{\text{ben}}^2 + M_{\text{tor}}^2}}{W_{lx}} = 3 \cdot 10^8 \text{ N/m}^2, \]  

where \( W_{lx} \) - the axial moment of resistance of a core-screw at a bend.
Figure 4 shows the dependence of mounting stresses in the insecure section of the rod-screw when it deviates from the plate.

![Graph showing the dependence of mounting stresses in the insecure section of the rod-screw.](image)

Figure 4. Shows the dependence of installation stresses ($\sigma$) in the insecure section of the rod-screw from its actual deflection angle ($\alpha$): 1 - when the rod-screw is deflected by 5 mm; 2 - when the rod-screw is deflected by 10 mm; $[\sigma]$ is the allowable stress.

It is established that in case of mismatch when mounting the plate and the screw rod by 3 mm, the resulting mounting stresses in the dangerous section of the rod-screw make up 25-30% of the permissible ones.

On the basis of the data obtained, technical solutions were proposed for by reducing installation stresses (the use of washers in the form of spherical and conical elements, the installation of a hinged joint in the middle of the plate 2 in Figure 1, which provides a selection of the mounting gap due to rotation of the plate parts).

Based on the studies carried out, a correcting device for the spinal cored was developed which is protected by the Russian Federation patent [21]. The manufactured construction of this device is used in medical practice (Figure 5). Reduction of installation stresses allows us to carry out the process of correcting the deformation of the spine with large values of controlling force factors, which ultimately provides a reduction of correction time by 15-20%.
4. Conclusion

Assuming that the value of the safety factor in terms of the tensile strength of the material (titanium alloy VT-6) equals 2, then in the example considered, the mounting stresses reach the values of permissible stresses, and further loading of the rod-screws is impossible.

One of the technical solutions to the problem considered in the installation is when the middle plate of a fixed hinge $M_{rot}$ value is equal to zero, no mounting forces are observed.

The conducted studies justify the need to take into account installation stresses in the design and installation of external fixation devices. The technical solution of the parts of the carrier plate [21], developed as a result of the research, makes it possible to use it in medical technology in the manufacture of these devices.

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Figure 5. The general view of a plate consisting of two halves connected articulately: 1- the right side of the plate; 2- hinged joint; 3- left side of the plate.
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