CALCULATION OF SYSTEMS FOR SUBFASCIAL BIOLOGICAL OSTEOSYNTHESIS

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Abstract. The necessity of purposeful and scientifically based improvement of the “bone-fixator” system and its properties was substantiated, as well as perspective directions of progress in internal osteosynthesis techniques. The results of studying the subfascial plate for biological osteosynthesis offered by the authors are shown. The engineering methods of determination of number and sizes of elements in a subfascial biomechanical system that will guarantee a reliable fixation of femoral bone fragments are presented. The calculations revealed that two screws (\(d_1 = d_2 = 6\) mm) inserted into the hip’s neck and head are sufficient to provide a reliable fixation of the subfascial plate; however in order to raise the reserves of the whole system’s durability the usage of the upper screw with somewhat greater diameter [the non-standard screw (\(d_1 = 7\) mm) or the standard one (\(d_1 = 8\) mm)] is recommended. The durability parameters for three variants of the main subfascial plate’s cross-section were calculated. The analysis of number and possible locations of the interlocking screws in the diaphyseal part of the subfascial plate shows that at least four screws are necessary to ensure stable fixation; \(d_4 = d_5 = 6\) mm, \(d_6 = d_7 = 8\) mm.

Key words: biological osteosynthesis, subfascial plate, durability of construction elements, calculating methods

Introduction

Improvement of methods and systems for osteosynthesis (fastening bone fragments by means of different fixation devices) remains an important problem of biomechanics.

The empirical approach, which was spread until recently and reduced to the increase of the fixation constructions, their masses and volumes, i.e. the extensive direction of development (the AO plate, Kuntcher’s nail, etc.) is now replaced by the scientifically substantiated intensive direction, which allows increasing the strength and stiffness of the fixation systems and considerably decreasing their masses and dimensions.

The usage of the methods of mathematical modelling, structural mechanics, theory of elasticity and strength of materials in practical projecting of technical systems for osteosynthesis made it possible to improve the properties of the “bone-plate” system [2, 5, 6]. Therefore the current aim of the research is to bring the surgical treatment of bone fractures “from the thickets of naked empiricism to the rails of exact clinicotechnical sciences” [5].

The main principles of the biological osteosynthesis were stated rather recently [7, 8].

The term of “biological osteosynthesis” was introduced in 1985 by O. Trentz and concerned the surgical treatment of comminuted fractures using plates [7]. The primary spelling of the concept of “biological” synthesis had no success [8, 9, 12].
Unlike the old methods of anatomical reposition and strong internal immobilisation of all the bone fragments, the biological osteosynthesis is based on different grounds. Osteosynthesis must minimally interfere in the regeneration process. To do this, some rules listed below should be taken into account.

1. The fracture site must be minimally uncovered, so that the plate’s position does not harm the blood supply of the soft tissues and bone fragments. This means that it is enough just to eliminate the rotational displacements and then to unite the main fragments. In this way the fragments can be repositioned indirectly by means of the distracter.

2. It is expedient to reposition the large fragments only when their connection with the nearby soft tissues can be preserved. Preserving the blood supply of the fragments is more important for fracture treatment than using the mechanical methods for precise fragments repositioning at the fracture site. These fragments must be fixed with minimal damage of the tissues.

3. If two principles are fulfilled, the fracture is consolidated with quick callus formation typical for the secondary consolidation. Auxiliary usage of a bone plate is unnecessary in such cases.

The biological osteosynthesis as a new principle has been accepted into the medical terminology and is widely used as a key word.

The following groups of methods comply with the biological osteosynthesis principles at the current level of traumatology development [8, 10, 11]:

a) osteosynthesis with LC-DCP (Limited Contact Dynamic Compression Plate), PC-Fix (Point - Contact - Fixator);

b) canulated screws transcutaneous insertion;

c) osteosynthesis by means of improved apparatuses for external fixation (Pinless systems, self-threading screws);

d) biologically degradable (resorbable) implants.

e) intramedullary interlocking osteosynthesis without reaming the medullar cavity.

The usage of the latter method in Ukraine is limited due to high costs of imagic intensifier equipment and lack of specialised surgical instruments.

The original intramedullary interlocking nails and instruments were designed, comparative biomechanical researches of stability of the osteosynthesis were carried out using modern inner constructions, clinical experience of using the biological osteosynthesis methods in over 600 cases was accumulated in the Chair of Traumatology and Orthopaedics of the Bukovinian State Medical Academy and in the Research Laboratory of Materials Resistance of Chernivsi National University [1, 3, 4].

Material and Method

Figure 1 shows (A) the subfascial plate for biological osteosynthesis of femoral fractures, (B) a native preparation of the femoral bone synthesised with the subfascial plate; (C) an roentgenogram of the naive preparation of the femoral bone synthesised with the subfascial plate.

The calculation of the subfascial plate’s construction can be divided into three stages (Fig. 2): A) calculation of the fixing screws 1 and 2; B) calculation of the plate 3; C) calculation of the interlocking screws 4, 5, 6, 7.

A. For calculation of the fixing screws 1 and 2 (Fig. 2) the bending force applied to the screws must be found by considering the latter as whole system of two cantilever rods [1]. Then

\[ P_{\text{bend}} = P \cdot \cos 40^\circ, \]

where \( P \) is the patient’s weight.

The location of the system’s gravity centre, i.e. the location of the neutral axis for bending may be determined as

The resultant axial moment of inertia of the system's section equals

$$y_i = \frac{\sum_{i=1}^{n} S_{i} y_i}{\sum_{i=1}^{n} F_i} \quad (n = 2).$$

The resultant axial moment of inertia of the system's section equals

$$I_{x_0} = \sum_{i=1}^{n} I_{x_i} = (I_{x_1} + a_1^2 F_1) + (I_{x_2} + a_2^2 F_2) =$$

$$= \left(\frac{\pi d_1^4}{64} + a_1^2 \frac{\pi d_1^2}{4}\right) + \left(\frac{\pi d_2^4}{64} + a_2^2 \frac{\pi d_2^2}{4}\right) =$$

$$= \pi \left[\frac{d_1^4}{4} \left(\frac{d_1^2}{16} + a_1^2\right) + d_2^4 \left(\frac{d_2^2}{16} + a_2^2\right)\right].$$

Here $a_1$ and $a_2$ are the distances from the gravity centres of the screws 1 and 2 to the neutral axis of the section, respectively; $d_1$ and $d_2$ are the diameters of the screws 1 and 2, respectively; $F_1$ and $F_2$ are the cross-section areas of these screws, respectively.

The axial moment of bending resistance of the system's section is

$$W_{x_0} = \frac{I_{x_0}}{y_{\text{max}}}. $$

Fig. 1. A – appearance of the subfascial plate for biological osteosynthesis of femoral fractures; B – native preparation of a femoral bone synthesized with the subfascial plate; C – an roentgenogram of the native preparation of a femoral bone synthesized.
Given the diameters of the fixing screws $d_i$, their lengths and the distance between them, we can evaluate the screws’ durability from the condition of bending resistance using the equation

$$\sigma_{\text{max}} = \frac{M_{\text{bend}}}{W_{N}} \leq [\sigma],$$  \hspace{1cm} (4)

where the bending moment is $M_{\text{bend}} = P_{\text{bend}} l$ ($l$ is the length of the screw’s working part); $[\sigma]$ is the allowed bending stress).

B. The carrying plate 3 (Fig. 2) can be analyzed by the scheme of a hyperstatic constrained beam using the theorem about 3 moments as an equation of combined strains

$$M_0 l_1 + 2M_1 (l_1 + l_2) + M_2 l_2 = -6 \left( \frac{\omega_1 a_1}{l_1} + \frac{\omega_2 a_2}{l_2} \right),$$  \hspace{1cm} (5)

where $M_0, M_1, M_2$ are the support-bearing bending moments, $l_1; l_2; a_1; a_2; \omega_1; \omega_2$ are the geometric parameters of diagrams of bending moments.

One can evaluate the durability of different fixation systems from the durability condition (4) by using equation (5) to determine $M_{\text{max}}$ and choosing the shape and area of the cross-section.

C. To consider the interlocking screws 4, 5, 6, 7 (Fig. 2) we used the method of forces, i.e. the general method for calculation of statically undetermined systems (Fig. 3a).

Getting rid of auxiliary bindings (Fig. 3b) gives the system of equations to determine the unknown reactions ($X_1 \ldots X_9$)

$$\sum_{j=1}^{9} \delta_{y} x_i + \Delta_{lp} = 0, \hspace{1cm} i = 1, 9.$$  \hspace{1cm} (6)
The coefficients $\delta_{ij}$ can be found by multiplying the corresponding single diagrams; note that according to the theorem of mutual displacements $\delta_{ij} = \delta_{ji}$.

The constant terms $\Delta_{ip}$ of the system (6) can be calculated by multiplying the force diagram of the bending moments by the corresponding single diagram with number $i$.

The system (6) can be solved by means of one of the numerical methods (the Gauss's method, the square root method, the method of orthogonalization with system and vectors, etc.). By analysing different combinations of interlocking the system for subfascial biological osteosynthesis with 2 or 3 screws, we can calculate the loads acting on the interlocking screws and evaluate their durability for each variant of fixation. For this, the system (6) is reduced to six or three equations, respectively, and the corresponding coefficients $\delta_{ij}$ are calculated for each case.

**Results and discussion**

According to the calculations two screws ($d_1 = d_2 = 6$ mm) are sufficient to provide a reliable fixation of the subfascial plate; however in order to raise the reserves of the whole system’s durability the usage of the upper screw with a greater diameter (the non-standard screw ($d_1 = 7$ mm) or the standard one ($d_1 = 8$ mm)) is recommended. The calculations described in point B give the variants of the subfascial plate’s cross-section (see Fig. 4) to provide its durability [1].

Figure 4 also presents the dimensions of the subfascial plate’s section at the level of its inflection (Fig. 2) which experiences the highest loadings and is therefore the most dangerous. The plate’s section may gradually decrease toward its lower end, because the bending moments acting on it decreases, it makes possible using a bayonet-shaped plate (Fig. 5).

The analysis of number and possible locations of the interlocking screws in accordance with point C shows that at least four screws are necessary to ensure stable fixation, $d_4 = d_5 = 6$ mm, $d_6 = d_7 = 8$ mm [1].
Conclusions

1. A method of calculation of the durability parameters for the “bone-subfascial plate” system and its elements with the usage of methods of strength of materials was proposed.
2. The calculations revealed that two screws ($d_1 = d_2 = 6$ mm) are sufficient to provide a reliable fixation of the subfascial plate; however in order to raise the reserves of the whole

Fig. 4. Variants of cross-section of the subfascial plate for biological osteosynthesis.

Fig. 5. Possible variants of shape of the subfascial plate for biological osteosynthesis.
system’s durability the usage of the upper screw with somewhat greater diameter [the non-standard screw \((d_1 = 7 \text{ mm})\) or the standard one \((d_1 = 8 \text{ mm})\)] is recommended.

3. The durability parameters for three variants of the main subfascial plate’s cross-section were calculated.

4. The analysis of number and possible locations of the interlocking screws in the diaphyseal part of the subfascial plate showed that at least 4 screws are necessary to ensure stable fixation, \(d_4 = d_5 = 6 \text{ mm}, d_6 = d_7 = 8 \text{ mm}\).

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РАСЧЕТ СИСТЕМ СУБФАСЦИАЛЬНОГО БИОЛОГИЧЕСКОГО ОСТЕОСИНТЕЗА

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Дано обоснование необходимости целенаправленного научно обоснованного совершенствования свойств системы “кость–фиксатор”, перспективные пути развития погружного остеосинтеза. Приведены результаты исследования предложенного авторами субфасциального фиксатора для биологического остеосинтеза, приведены расчетные инженерные методики выбора размеров и количества элементов субфасциальной биомеханической системы, обеспечивающей надежную фиксацию отломков бедренной кости.

Приведенные расчеты показывают, что для надежной фиксации в шейку и головку бедра достаточно ввести два винта \((d_1 = d_2 = 6 \text{ mm})\), однако с целью повышения запаса прочности и повышения надежности всей системы проксиимальный винт
желательно использовать с диаметром несколько большим [нестандартный винт \( d_1 = 7 \text{ мм} \) или стандартный винт \( d_1 = 8 \text{ мм} \)].

Рассчитаны прочностные характеристики трех вариантов форм поперечного сечения пластины субфасциального фиксатора.

Расчеты количества блокирующих винтов диафизарной части субфасциального фиксатора и оценка вариантов их расположения показали, что для обеспечения надежной фиксации необходимо наличие четырех блокирующих винтов, при этом \( d_4 = d_5 = 6 \text{ мм} \) и \( d_6 = d_7 = 8 \text{ мм} \). Библ. 12.

Ключевые слова: остеосинтез, субфациальный фиксатор, прочность элементов конструкции, расчетные методы

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