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Features of deformation of the «debris – external core apparatus» model in the case of using structures with different structural geometry

O. K. Popsuishapka [1, 2], I. A. Subbota [1]

[1] Sytenko Institute of Spine and Joint Pathology National Academy of Medical Sciences of Ukraine, Kharkiv

[2] National Medical University, Kharkiv. Ukraine

Objective. To study the linear and angular displacements of the "fragments" during their connection with an external rod apparatus manufactured by HB ORTHO (Ukraine) or Orthofix (USA) under different variants of the geometry of the "fragments – apparatus" structure in order to clarify the mechanical principles of its rational construction. Methods. The model was rigidly fixed at one end in a horizontal position, and a transverse force was alternately applied to the opposite end using weights of 1, 2, 3, 4, 5 kg. The experiment involved the study of the magnitude and nature of the displacement of the fragments depending on the following parameters of the rods: the number of rods in the fragment (2 or 3); diameter (5, 6 mm); length of the rod section from the bone to the support (100, 50 mm); length of the bone section between the extreme rods (150, 100 mm); the presence of a multi-plane arrangement of the rods and, in particular, when they formed a 45° angle between them, the number of external supports: one or two, located in parallel or side by side. Results. The first most important parameter that influenced the amount of displacement of the distal "fragment" was the distance from the bone to the support. In the case of a distance of 50 mm, the amount of displacement of the fragment is 2–4 times less than in the case of 100 mm. The second parameter that influenced the displacement of the fragments was the length of the bone section between the extreme rods screwed into the fragment. If it is reduced by 30 %, the displacement increases by 64% and almost does not depend on whether 2 or 3rods were used. It is possible to significantly reduce the displacement of the distal fragment (at least twofold) by inserting rods in different planes, in particular, by positioning the rod so that in the proximal fragment near the fracture in a plane that is 45° to the frontal plane. With a gradual transverse load, the deformation of the structure at the initial stages (1, 2, 3 kg) is elastic in nature and with an increase (up to 4–5 kg), residual deformation occurs due to: movement of the clamp on the cylindrical support; plastic deformation of the rods, which is inherent in HB ORTHO devices (Ukraine).

Мета. Дослідити на фізичній моделі лінійні та кутові переміщення «уламків» під час їхнього з'єднання зовнішнім стрижневим апаратом виробництва «HB ORTHO» (Україна) чи пристроєм «Orthofix» (США) за різних варіантів геометрії конструкції «уламки – апарат» для з'ясування механічних принципів її раціональної побудови. Методи. Модель одним кінцем жорстко закріпляли в горизонтальному положенні, а до протилежного почергово прикладали поперечну силу, використовуючи гирі масою 1, 2, 3, 4, 5 кг. Експеримент передбачав дослідження величини та характеру переміщень уламків залежно від таких параметрів стрижнів: кількість в уламку (2 або 3); діаметр (5, 6 мм); довжина ділянки стрижня від кістки до опори (100, 50 мм); довжина ділянки кістки між крайніми стрижнями (150, 100 мм); наявність різноплощинного розташування стрижнів і зокрема, коли вони утворювали між собою кут 45°, кількість зовнішніх опор: одна або дві, розташовані паралельно чи поряд. Результати. Першим за значущістю параметром, який впливав на величину переміщення дистального «уламка» є відстань від кістки до опори. У разі відстані в 50 мм величина переміщення уламку в 2–4 рази менша, ніж за 100 мм. Другим параметром, який впливав на переміщення уламків є довжина ділянки кістки, що знаходиться між крайніми стрижнями загвинченими в уламок. За зменшення її на 30 % величина переміщення збільшується на 64 % і майже не залежить від того, було заведено 2 чи 3 стрижні. Суттєво зменшити переміщення дистального уламка (мінімум удвічі) можна шляхом різноплощинного заведення стрижнів, зокрема розташувавши стрижень щоб він знаходився в проксимальному уламку поблизу перелома в площині, яка розташована під 45° до фронтальної. За ступеневого поперечного навантаження деформації конструкції на початкових етапах (1, 2, 3 кг) мають пружний характер, зі збільшенням (до 4–5 кг) виникає залишкове викривлення через: переміщення затискача на циліндричній опорі; пластичну деформацію стрижнів, яка притаманна апаратам «HB ORTHO» (Україна). Ключові слова. Перелом стегнової кістки, зовнішній стрижневий апарат, навантаження.

Keywords. Femoral fracture, external fixation device, loading

Introduction

The prevalence of numerous gunshot fractures in the extremities has shifted the priority of methods for fragment fixation, with the use of external rod devices (ERDs) emerging as a prominent area of focus for new theoretical concepts and practical applications. When connecting ERDs, a non-rigid structure is created, allowing for certain movements. This differs from structures that use a plate or an intramedullary locked rod. Studies on experimental models and patients have shown that during the connection of ERDs, the linear movement of their ends was within 0.6–16 mm [1, 3, 11], and with bone osteosynthesis 0.017–0.07 mm [2]. The difference was one or two orders of magnitude. We have already drawn attention to the fact that the presence of movement of the fragment(s) under load is not a sign of an unstable state of the structure, provided that it is elastic (temporary). Accordingly, it was proposed to use the terms "rigid structure" in relation to the connection of fragments with a plate or a blocked rod and "elastic structure" for those connected by an external rod (spoke) apparatus. In both cases, these will be stable structures [4].

As our previous studies have shown, elastic deformations of the fractured segment with the specified movements of the ends of the fragments at the first stages of hardware treatment of diaphyseal fractures do not disrupt the process of union, but on the contrary, lead to the formation of periosteal bone regenerate. The mechanisms of its formation under conditions of elastic movements of fragments are given in our publications [5]. However, as practice shows, there is a risk of their re-displacement during the use of the ERD [7]. It is expected and can be largely prevented with the appropriate knowledge, experience and technical capabilities.

In the modern scientific literature there is a lack of information on the substantiation of mechanically and geometrically rational designs of "fragments – ERD" for fractures of a certain localization. Attention is focused on the selection of places for insertion of rods taking into account the anatomical and topographic features of vessels, nerves and tendon-muscle formations [9, 10] as well as on the study of the strength of devices or their elements using different materials [6, 14].

The works confirm the principle of expediency of using multi-plane rod insertion to achieve more reliable fixation of fragments [12, 13].

Our clinical data [7] indicates that from 2022 to 2024, external rod devices manufactured by "HB ORTHO" (Ukraine) and the "Orthofix" device (USA) were commonly used in treating gunshot fractures of the extremities. Moreover, in 87.5 % of patients, these devices were used as the main method of fixing fragments (without replacing them with submerged osteosynthesis).

Purpose: to study on a physical model the linear and angular movements of "fragments" during their connection by an external rod device manufactured by "HB ORTHO" (Ukraine) and the "Orthofix" device (USA) for different variants of the geometry of the "fragments – device" structure to clarify the mechanical principles of its rational construction.

Material and methods

We studied models using the Ukrainian-made "HB ORTHO" and foreign-made "Orthofix" (Galaxy Fixation Gemini model) [8], which were most often used to treat gunshot fractures in Ukraine in the period 2022–2024 [7]. Although these devices are structurally different, they are related in functional purpose; they are commonly used for temporary fixation of fragments in the case of open fractures for the period until the wound heals. Their characteristic feature is that they provide for the possibility of creating different geometry of the structure depending on the localization of the fracture, soft tissue damage, as well as the surgeon's ideas about its mechanical reliability.

The situation of a femur fracture was chosen as the basis, when the fragments were fixed with a rod apparatus. Clinical practice shows that in this case, a condition always arises when the damaged limb is horizontal and at the same time the distal fragment is subjected to a transverse force of the limb mass, and the proximal fragment may be subjected to a force in the opposite direction as a result of tension of the *m. iliopsoas* (Fig. 1). The force acting downwards is of considerable magnitude, especially if the tibia is in an extended position, since the extension of the lever increases the moment of force. This situation is extremely dangerous due to the possibility of repeated displacement of the fragments if they are fixed with a rod apparatus. Recent experience in the treatment of gunshot fractures shows that it is most difficult to hold the fragments with the apparatus when the fracture is localized in the upper half of the femur [7]. If the tibia is bent to a right angle, the moment of force will significantly decrease. When the injured limb is in a vertical position, the load vector coincides with the axis of the femur, and the foot interacts with the supporting surface (which neutralizes the force of the mass of the distal fragment), the situation becomes less dangerous. Biomechanical studies on a physical model have shown that in the case of axial loading, the fragments connected by the ERD move significantly less than in the case of transverse loading [3].

The physical model (Fig. 2) was a cylindrical wooden (beech) bar 400 mm long, 35 mm in diameter, corresponding to the average anthropometric dimensions of the femur. In the middle, the bar was sawn transversely and the ERD was connected using geometrically different schemes in accordance with the experimental plan. The "fragment – ERD" model thus obtained was rigidly fixed at one end in a horizontal position and a transverse force was applied to the opposite end in stages using weights weighing 1, 2, 3, 4, 5 kg. The movement of the fragments was recorded photometrically, with a camera fixed on a tripod, while the model was located on graph paper. The linear displacement of the distal (a) "fragment" of the model between standardly selected points was measured with a metal ruler and its angular displacement (b). The measurements were performed under load and after removal of the corresponding weight. If there was a residual displacement (a1), it was also recorded and measured. For each variant of the construction of the study structure, the average value of the displacement values was taken as a basis. After each experiment, the connection of the rods with the external support was renewed, the nuts were tightened as much as possible.

The experiment involved studying the magnitude and nature of the displacements of the fragments depending on a number of key (in our opinion) geometric parameters of the "fragments – ERD" structure. We were interested in the dependence of the magnitude of the displacements of the fragments on the following parameters (Fig. 3):

– the number of rods in the fragment (N) — 2 or 3;

– the diameter of the rods (D) — 5 or 6 mm;

– the length of the rod section from the bone to the support (L) — 100 or 50 mm;

– the length of the bone section between the extreme rods (H) — 150 or 100 mm;

– the presence of a multi-planar arrangement of the rods and when they formed an angle (G) of 45°;

– number of external supports: one or two, located parallel to each other.

In total, an experiment was conducted on the movements of the distal fragment using 15 variants of the "fragment – ERD" design configurations using the "HB ORTHO" (10) and "Orthofix" (9) apparatus (Table 1).

The studies were performed in the biomechanics laboratory of the State Establishment "Professor M. I. Sytenko Institute of Spine and Joint Pathology of the National Academy of Medical Sciences of Ukraine" (head of the laboratory, Doctor of Medical Sciences O. A. Tyazhelov).

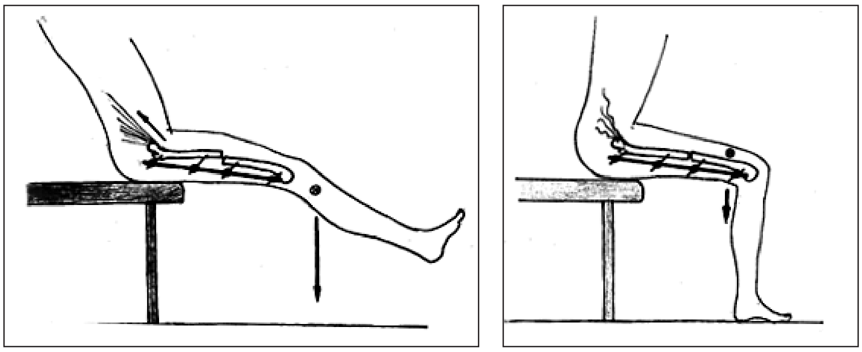

Fig. 1. Schemes illustrating the mechanics of displacement of femoral fragments in different limb positions

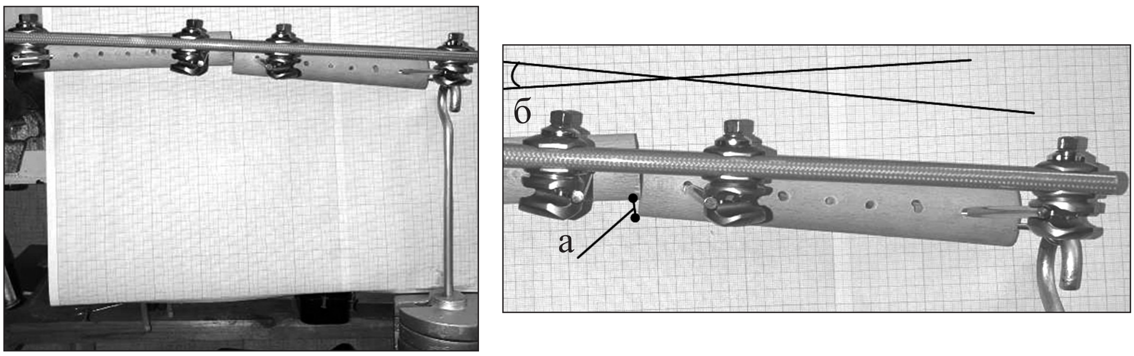

Fig. 2. General view of the model under load and deformation: a — linear displacement of the distal "fragment"; b — angular displacement of the distal "fragment"

Results

In the case of transverse loading of the model, the distal fragment was found to move uniformly in space in the sagittal plane. Its longitudinal axis moved at an angle and in width, as shown in Fig. 2.

The magnitudes of the displacement of the distal "fragment" under the action of the maximum (5 kg) transverse load for different geometric parameters of the model are given in Table 1.

The experiment showed that both linear and angular displacements of the distal fragment relative to the proximal one under the action of a step load correlate with each other in their magnitudes. Therefore, the magnitudes of the linear displacement (a) of the fragment under a step load were chosen as the main criterion, by which the deformation of the structures can be compared with each other.

At the beginning, we will consider the linear displacements (a) in the case of fixation of the fragments with the "HB ORTHO" apparatus in the geometric parameters indicated in ordinal numbers 1–4 of Table 1 (Fig. 4).

This series of experiments demonstrated the behavior of the model in the case of using rods with a diameter of 5 mm and a length of 200 mm, which were included in the specified apparatus. With a rod section length of 100 mm (from the support to the bone), there was a significant movement (a) of the distal fragment, up to 33.8 mm in the case of inserting 2 rods into each fragment and 41.7 mm when inserting 3. With a reduction in the length of the rod section between

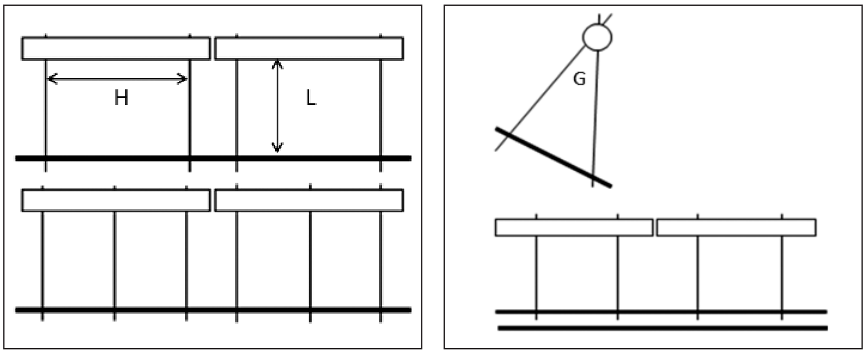

Fig. 3. Some basic schemes illustrating the geometric parameters of the "fragment – ERD" structure

Table 1

Displacement of the distal "fragment" under the action of the maximum (5 kg) transverse load of the model with different geometric parameters of the "fragment – ERD" design

№ з/п	Geometrical parameter of the design						Distal fragment displacement at maximum load (5 kg)			
							«HB ORTHO»		«Orthofix»	
	number of rods in fragments N	rod diameter D (mm)	rod section length L (mm)	bone section length H (mm)	angle between planes G (deg.	number of external supports	linear A (mm)	angular B (deg.)	linear A (mm)	angular B (deg.)
1	2	5	100	150	—	1	33.8	14.0	—	—
2	3	5	100	150	—	1	41.7	17.1	—	—
3	2	5	50	150	—	1	6.8	4.0	—	—
4	3	5	50	150	—	1	10.0	6.0	—	—
5	2	6	100	150	—	1	23.9	14.0	13.8	11.0
6	3	6	100	150	—	1	18.2	12.0	11.0	13.0
7	2	6	50	150	—	1	4.0	7.9	4.0	6.0
8	3	6	50	150	—	1	4.7	3.0	3.0	5.0
9	2	6	100	100	—	1	—	—	23.1	9.9
10	3	6	100	100	—	1	—	—	18.8	15.0
11	2	6	50	100	—	1	—	—	9.0	4.0
12	3	6	50	100	—	1	—	—	9.0	5.0
13	2	6	100	150	10	1	25.2	13.0	—	—
14	2	6	100	150	45	1	—	—	10.0	12.0
15	2	5	100	150	—	2	17.0	14.0	—	—

the support and the bone to 50 mm, the movement decreased, compared to the previous situation, by 4–5 times, to 6.8 mm and 10 mm, respectively. We draw attention to the fact that the magnitude of the movement did not significantly depend on whether 2 or 3 rods were inserted into each of the fragments. It was not possible to compare the obtained data with those obtained when using the Orthofix device, since its equipment did not include rods with a diameter

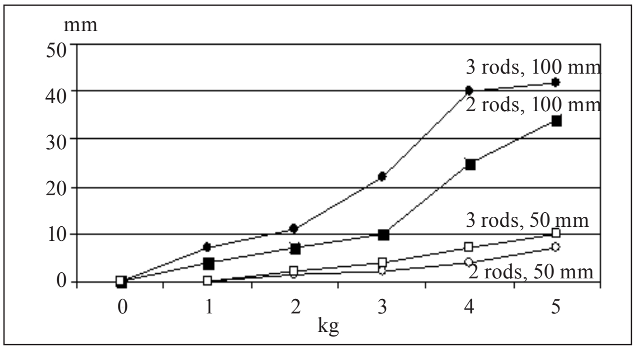

Fig. 4. Linear displacements (a) in the case of stepwise loading of the model with geometric parameters indicated under numbers 1–4 of the Table

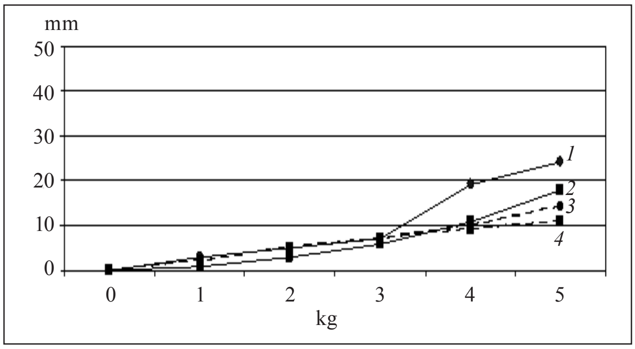

Fig. 5. Linear displacements during stepwise loading of the models with geometric parameters indicated under numbers 5 and 6 of the table using the devices "HB ORTHO" (*1* — 3 rods,100 mm; *2* — 3 rods, 100 mm) and "Orthofix" (*3* — 3 rods, 100 mm; *4* — 3 rods, 100 mm)

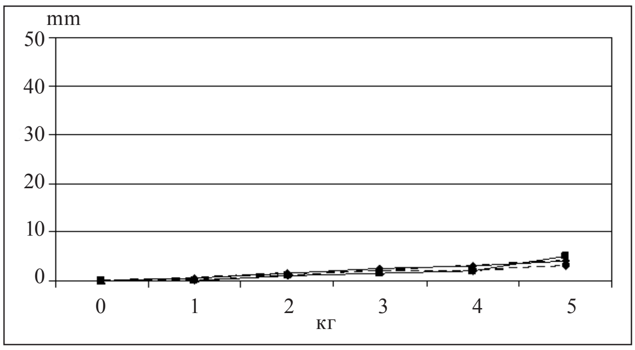

Fig. 6. Linear displacements during stepwise loading of the models with geometric parameters indicated under numbers 7 and 8 of the table using the devices "HB ORTHO" and "Orthofix"

of 5 mm and a length of more than 100 mm. This was done in a series of experiments, where rods with a diameter of 6 mm were provided and used.

The second series of work consisted of comparing the displacements in the case of using the "HB ORTHO" and "Orthofix" devices with similar geometric parameters and using rods with a diameter of 6 mm (numbers 5–8 in the Table) (Fig. 5).

The first thing that was found was that when fixed with the "Orthofix" device, the displacements A were significantly smaller — by 40 %, compared to the "HB ORTHO" device — 23.9 mm, 18.2 mm and 13.8 mm, 11 mm, respectively, for a rod section length of 100 mm. But after reducing the rod sections to 50 mm, there was no difference in the magnitude of the displacements and at the same time they were 2–4 times smaller than for a rod section length of 100 mm. It is also clear that the displacement magnitude was not significantly affected by the number of rods in each of the fragments (2 or 3).

The study of the deformation of the structure identified a significant feature. During the initial stages of loading (1, 2, 3 kg), the deformation was elastic; meaning that after the load was removed, the "fragments" returned to their original position. In the case of the following stages of loading (4 and 5 kg), after its removal, a residual deformation of the structure appeared, which in mechanics is characterized as plastic. Therefore, it can be stated that the "fragments – ERD" structure during stepwise transverse loading deforms according to the elastic-plastic type. When comparing the magnitude of the residual deformation at the maximum load (5 kg) with the use of the "Orthofix" apparatus, it was 43 %, and with the "HB ORTHO" apparatus — 76.5 %. We present graphs that reflect the linear movements of the ends of the "fragments" during stepwise loading of models using the "HB ORTHO" and "Orthofix" apparatuses with similar geometric parameters and the use of rods with a diameter of 6 mm (Fig. 6).

An examination of the deformed structures revealed that the residual deformation of the "fragment – ERD" structure arose due to the rotation of the clamps on the cylindrical external support, which are located near the fracture, as well as due to the plastic deformation of the rods in this zone (Fig. 7).

To prevent the movement of the clamp with the rod on the cylindrical support, an additional support can be used, which was fixed on the same rods. The effectiveness of such a structure was tested in an experiment on a model. When using two supports in the structure of the "HB ORTHO" apparatus, the linear movement of the "fragment" was reduced by half (17 mm),

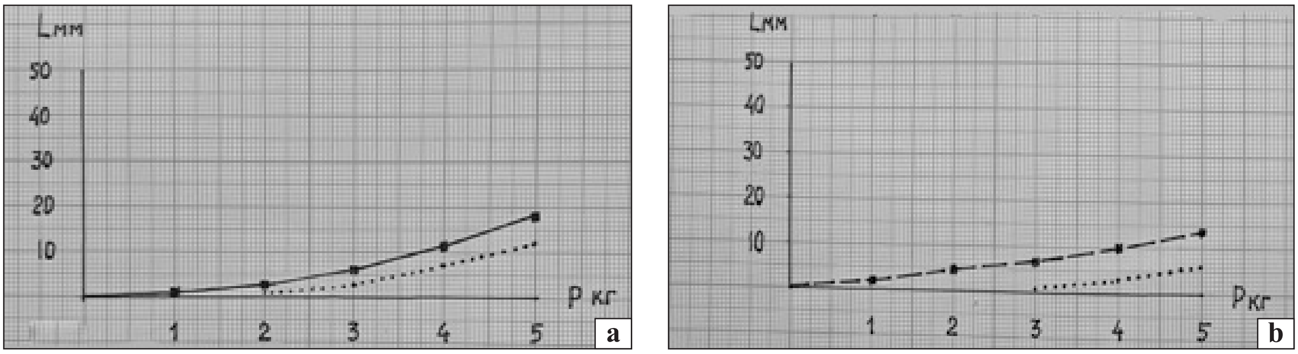

Fig. 6. Graphs showing linear displacements of the ends of the "fragments" during stepwise loading of the models and using the devices "HB ORTHO" (a) and "Orthofix" (b)

Fig. 7. General view of the deformed "fragment – ERD" structure with a demonstration of the connecting node and the rod, in which residual deformation occurs

compared to the structure with one support (33.8 mm). But the main thing was that with two attachment points for each rod, the occurrence of residual deformations was significantly reduced — 2 and 22 mm.

Thus, the results obtained in the above part of the experiment revealed that the most vulnerable to deformation is the structure in which all the rods are located in the frontal plane and the external support is located at a distance of 100 mm from the bone. The experiment allowed us to identify the key zone of deformation of the structure — the rod with the clamp, which is located in the proximal "fragment" near the fracture (Fig. 7). There is an assumption that this is caused by the torque of the force on the rod lever. The larger the lever, the greater the force that deforms. The torque can be counteracted by changing the location of the specified rod in such a way that the vector of the deforming force coincides with its axis. The ideal option would be to bring it into the sagittal plane, in which the deforming force acts. But considering that this is not desirable when fixing femoral fragments, a compromise option can be used, to place it in a plane that is located at an angle of 45° to the sagittal and frontal planes. The experiment showed that with such a construction of the geometry of the "fragment – ERD" structure, the displacement is reduced by half, unlike the structure when all the rods are located in the frontal plane (Fig. 8).

Fig. 9 shows graphs that display the magnitude of the displacement of the distal "fragment" during step loading depending on the length of the bone section located between the extreme rods of each of the fragments (the parameters are indicated in points 5 and 9 of the table). It can be seen that it moves nonlinearly, the distance between the fragments begins to increase in the case of a load of 4 and 5 kg. With a decrease in the distance between the rods in each of the "fragments" by one third (from 150 to 100 mm), the magnitude of the displacement at maximum load increased by 64% (14 and 23 mm, respectively). In addition, we performed mathematical calculations of the magnitude and directions of the forces that arise in the places of attachment of the rods to the external support and in the zone of their contact with the bone under the action of an external force in the sagittal plane (according to the experimental conditions). 4 options were selected, when the "fragments" are connected by the "Orthofix" apparatus using two rods in each "fragment", the distance between the rods is 150 or 100 mm, and the distance from the "fragment" to the external support is 100 or 50 mm (items 5, 7, 9, 11, Table 1).

First, we will determine the magnitude of the forces in the rods at the point of their contact with the distal "fragment". To do this, we will represent it as a beam on two supports, where the function of the supports is performed by the rods (Fig. 10).

To determine the support reactions, it is assumed that the body is in a static position (without movement, in a state of equilibrium), and at the same time the sum of all forces and moments of forces acting on the body is zero. Thus:

$$R1 = \frac{P*(H1 + H2)}{H2}, \quad (1)$$

$$R2 = -\frac{P*H1}{H2}. \quad (2)$$

When transferring these loads to the external support at the location of the clamps, we have, in addition to the action of bending forces R1 R2, R3, R4 in the sagittal plane, the appearance of an additional one, which twists the external support. This torque is determined by formula (3):

$$MR = L*R, \quad (3)$$

where L is the distance between the distal "fragment" and the external support (the length of the rod), R is the load on the rod at the point of its contact with the distal fragment.

Now we can calculate the magnitude of the stresses that arise in the external support at the points of attachment of the rods (Fig. 11).

Similarly, we find the reactions of the support R3 and R4.

$$R3 = \frac{R1*(H1 + H2 + H3 + H4) - R2*(H3 + H4)}{H4}. \quad (4)$$

$$R4 = \frac{R1*(H2 + H3) - R2*H3}{H4}. \quad (5)$$

Based on the formulas and actual geometric dimensions, we calculate all the forces and torques acting on the external support at the places of attachment of the rods under the action of an external load of 5 kg (Table 2).

Having all the forces and moments of forces acting on the external support, we can construct diagrams that characterize the distribution of stress in its various areas (Fig. 12).

The obtained digital data revealed the following patterns:

1) in the case of a transversely directed force acting on the end of the distal "fragment" in the "fragment – ERD" design model, the highest level of loads occurs on the external support, directly at the nodes of connection of the rods with it. For example, for option number 5: if at the point of connection of rod 1 with the bone only a force of 56.9 N acts, which is located in the sagittal plane and a moment arises that bends the fragment, then at the point of its

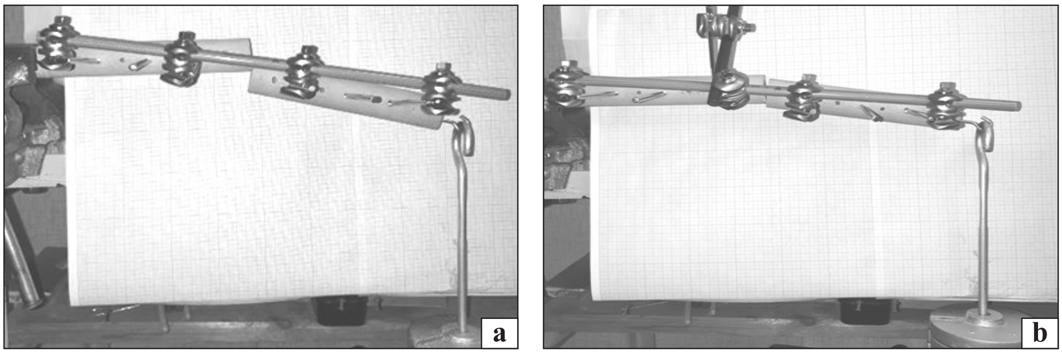

Fig. 8. The magnitude of the distal "fragment" displacement at maximum load of the model with the use of the "Orthofix" device, provided that all rods are located in the frontal plane (a) and during the insertion of one rod, which is in the proximal fragment in a plane that is at 45º to the frontal plane (b) (structure parameters 9, 14 in Table 1)

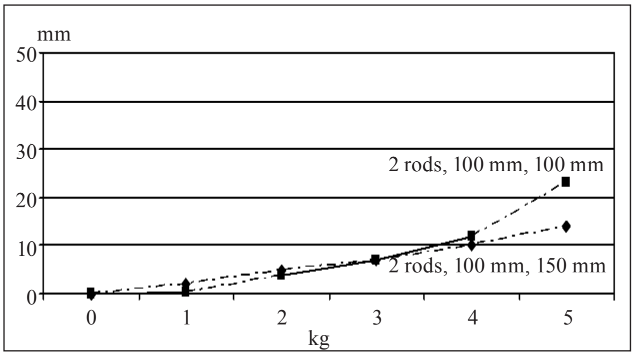

Fig. 9. Distal "fragment" displacement graphs during stepwise loading of the model using the "Orthofix" device under conditions of distance between the extreme rods of 150 and 100 mm with the same other parameters (items 5 and 9 of Table 1)

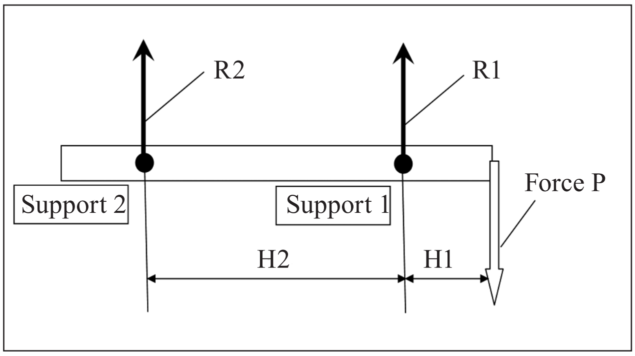

Fig. 10. Scheme for calculating the reactions of supports for the distal fragment, where P is the force with which the structure is loaded, R1 and R2 are the reactions of the supports, H1 is the distance from the point of application of the load to 1 support (1 rod), H2 is the distance between the supports (rods)

connection with the external support a torque of 5.7 N*m is added to these forces;

2) the load on the external support is not distributed evenly (consider example No. 11 of Table 1):

– the greatest in the sagittal plane is at the point of contact of rod 3 with the external support (122.6 N), and the least is in the area of location of rod 2 (7.8 N). Other zones have an intermediate load (rod 1 — 56.9 N, rod 4 — 73.5 N);

– the load in the sagittal plane creates stress in the external support, which leads to its bending. The stress that bends the external support is distributed as follows: from rod 1 it increases to 7.35 N*m (in rod zone 2), from rod 2 it continues to increase, but less actively and reaches 12.24 N*m in rod zone 3, and then decreases to 0;

– there is also a torque, which between 1 and 2 rods reaches 3.7 N*m, then between 2 and 3 rods decreases to 2.5 N*m, after 3 rod is equal to 0 (provided that 3 rod can completely absorb all the torque). It should be noted that in the sections between 1–2 and 3–4 rods the torque is absorbed by the "fragment – ERD" structures, which are connected by rods, and in the section between 2–3 rods this load is perceived only by the central section of the external support. Therefore, the most loaded is the support zone with clamps between 2 and 3 rods, which explains the appearance of deformations on the model of 3 rod in the form of plastic deflection and scrolling of the clamp on the support;

3) there is a direct relationship between the rod length (L) and the acting torque. Halving the rod's length (from 100 to 50 mm) reduces the torque on it by half (from 5.7 to 2.85 N*m).

Conclusions

In the case of connecting the "fragments" with external rod devices, a structure is formed, which, under the action of a transverse load of 1–5 kg on

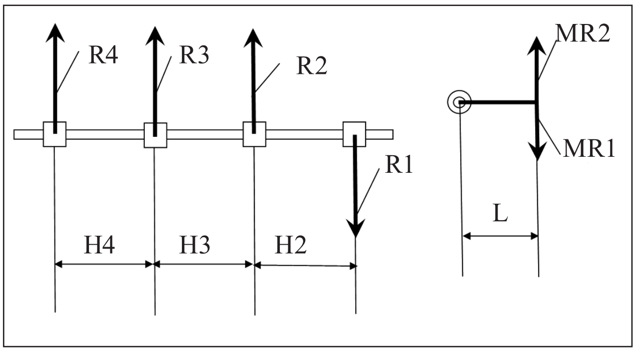

Fig. 11. Scheme for calculating the forces acting in the external support at the points of its connection with the rods, where R1 and R2 are the forces acting on the rod; R3, R4 are the reactions in the supports transmitted to the proximal fragment, MR1 and MR2 are the torques; H2 is the distance between the rods on the distal "fragment", H3 is the distance between the second and third rods close to the "fracture", H4 is the distance between the rods on the proximal "fragment"

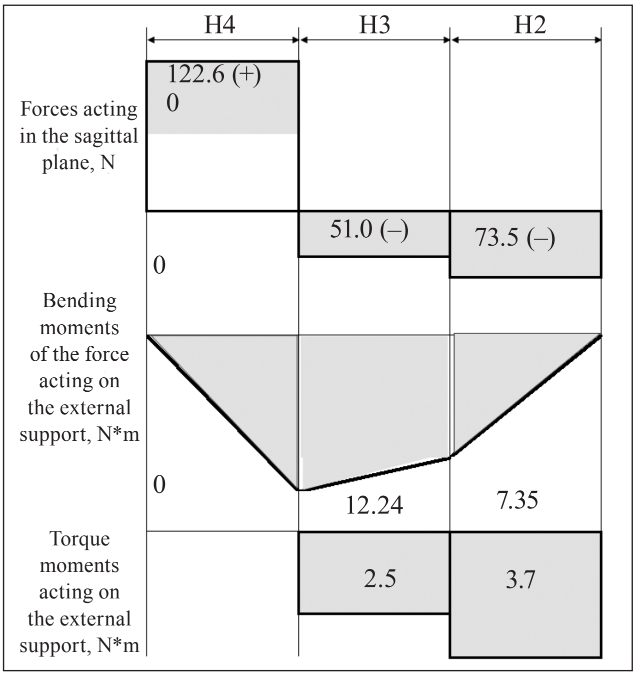

Fig. 12. External support load diagrams

Table 2

Calculation of all forces and torques acting on the external support at the rod attachment points for structures with two rods in debris

No. in Table 1	Geometrical parameter of the structure, mm					Magnitude of all forces and torques at maximum load (5 kg)						
	Distance from the loading point to the first rod, H1	Distance between the first and second rods H2, H4	Distance between the second and third rods (zone of "fracture"), H3	Distance between the third and fourth rods, H4	Rod length (distance between the fragments and the external support) L	R1, (H)	MR1, (H*м)	R2, (H)	MR2, (H*м)	R3, (H)	MR3, (H*м)	R4, (H)
5	25	150	50	150	100	56.9	5.70	7.8	0.8	122.6	5.0	73.5
7	25	150	50	150	50	56.9	2.85	7.8	0.4	122.6	2.5	73.5
9	50	100	100	100	100	73.5	7.30	24.5	2.5	171.6	5.0	122.6
11	50	100	100	100	50	73.5	3.65	24.5	1.2	171.6	2.5	122.6

the distal “fragment”, moves in width and at an angle. At the same time, the linear displacement of the end of the distal “fragment” near the fracture occurs within 1–41.7 mm, depending on the geometry of the formed “fragment - device” structure.

The first parameter in terms of significance that affects the displacement of the distal “fragment” is the distance from the bone to the support. At a distance of 50 mm, the displacement of the fragment is 2–4 times smaller than at 100 mm.

The second is the length of the bone section between the extreme rods screwed into the fragment. With a decrease of 30 %, the displacement increases by 64 % and almost does not depend on whether 2 or 3 rods were inserted.

Under stepwise transverse loading, the deformation of the structure at the initial stages (1, 2, 3 kg) is elastic in nature and with an increase (up to 4–5 kg) a residual deformation occurs, which is associated with the movement of the clamp on the cylindrical support or plastic deformation of the rods, which was inherent in the devices “HB ORTHO” (Ukraine).

Recommendations

The regularities that we discovered experimentally and through mathematical calculations can be used to improve external fixation devices and methods for connecting fragments with them.

1. When connecting fragments with external rod devices “HB ORTHO” and “Orthofix”, in cases where the external support is located at a distance of 100 mm from the bone or more, there is a risk of their repeated displacement, and in order to reduce it, it is necessary to have the information provided and learn to anticipate dangerous situations when the patients perform movements. The treatment method should include teaching the patient the procedure for transitioning from a horizontal position to a vertical one and vice versa and the “correct” way of walking with crutches.

2. When performing the operation of connecting fragments with an external rod apparatus for a diaphyseal fracture, the following principles should be observed:

– screw rods into each of the fragments at the maximum permissible distance from each other (within the diaphysis);

– place the external support as close as possible to the surface of the segment. A distance of 1–3 cm is rational;

– in the case of a bone fracture in the middle part of the diaphysis, it is advisable to use two rods in each of the fragments;

– use two-plane insertion of rods in the presence of a short fragment and a significant layer of soft tissues.

The manufacturer of the HB ORTHO device should pay attention to the design shortcomings identified as a result of the study and improve the device and its equipment.

Conflict of interest. The authors declare that there is no conflict of interest.

Prospects for further research. It is expected that the proposed methodology for studying the movement of fragments will be used to evaluate the properties of other fixation devices intended for the treatment of fractures.

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FEATURES OF DEFORMATION OF THE «DEBRIS – EXTERNAL CORE APPARATUS» MODEL IN THE CASE OF USING STRUCTURES WITH DIFFERENT STRUCTURAL GEOMETRY

O. K. Popsuishapka [1, 2], I. A. Subbota [1]

[1] Sytenko Institute of Spine and Joint Pathology National Academy of Medical Sciences of Ukraine, Kharkiv
[2] National Medical University, Kharkiv. Ukraine

✉ Olexii Popsuishapka, MD, Prof. in Traumatology and Orthopaedics: alexecorn@gmail.com; https://orcid.org/0000-003-1893-2511
✉ Igor Subbota: gs1971@ukr.net