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COMPARATIVE ANALYSIS OF THE RIGIDITY OF OSTEOSYNTHESIS OF THE PROPOSED WIRE-ROD APPARATUS

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ABSTRACT. A proposed wire-rod apparatus (PWRA) was offered for arthrodesis of the knee joint (AKJ). **Objective:** Conduct mechanical tests of PWRA and a combined wire-rod apparatus (CWRA) to determine rigidity of osteosynthesis (RO) provided by the devices and make a comparative analysis. To evaluate RO of PWRA and CWRA comparative mechanical tests were carried out for the devices that are used for AKJ. PWRA was tested in two different assemblies. The tests were performed according to medical technological guidelines as outlined in "Technique for testing rigidity of transosseous osteosynthesis during preoperative planning". Rigidity of the frames were tested longitudinally (distraction and compression) twice, total, 12 times; in frontal, sagittal and transverse planes twice for each of 3 constructs, total 18 times. Statistical analysis was produced with MedCalc software for Windows (version 12.7.8.0) using Mann-Whitney test (independent samples).

Keywords: stiffness coefficients, rigidity of osteosynthesis, Ilizarov apparatus, external fixation apparatus, wire-rod apparatus.

AMS Subject Classification: 05B30.

1. Introduction

In case of failure of conservative treatment in patients with septic osteoarthritis different surgical techniques can be used, including knee arthrodesis. Today various external fixators devices (EFD) for the joint arthrodesis are widely used [12, 15, 19, 25].

Successful AKJ is known to involve stable fixation that can be easily controlled and allow for early functional weight-bearing providing comfortable conditions for a patient [1 4].

With advances in trauma and orthopedics the Ilizarov method is constantly improved, new EFD being developed with new techniques devised for treatment of trauma and orthopaedic conditions [10, 13]. Improvements in EFD are strongly associated with biomechanics of transosseous osteosynthesis [7, 8, 9, 21]. Special mechanical and biomechanical tests are devised by researchers to examine RO of EFD [11, 14, 26].

RO to be provided by an EFD is one of the most important characteristics [14, 17, 21, 23]. Multiple bench and biomechanical tests of RO allow for identifying most effective constructs [1, 16, 17, 23].

We decided to improve the apparat and offered to use ¾ of Ilizarov half-rings instead of full rings (Registered rationalization proposal June 18, 2015, Certificate No. 4). This design was not found in the affordable literature when applied for AKJ and mechanical testing was needed to examine RO of the construct. Objective conduct mechanical tests of to determine RO and make a comparative analysis.

2. Material and Methods

Mechanical testing on request of Azerbaijan Research Institute of Traumatology and Orthopedics was conducted at Mechanical Experimental Laboratory, Ministry of the Defence Industry, Republic of Azerbaijan, Sharg Manufacturing Group and IGLIM Research, Development and Production.

Rigidity tests of EFD were performed according to medical technological guidelines as described in “Technique for testing rigidity of transosseous osteosynthesis during preoperative planning” [14].

RO was determined in accordance with medical technology of examining rigidity with transosseous osteosynthesis [7, 22-24, 27]. The technology is performed with algorithm of standard actions and calculations of determining major characteristics of rigidity with EFD (Fig. 1).

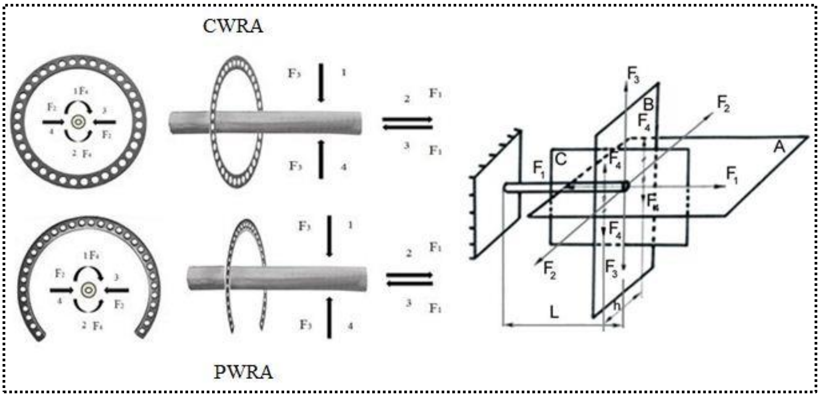

***Fig. 1** Diagram of experiment: Direction of resulting loading vector (side view of module): 1 – «flexion» (F 3), 2 – «distraction» (F 1), 3 – «compression» (F 1), 4 – «extension» (F 3) (a). Direction of resulting loading vector (inferior view of module): 1 – internal rotation (F 4), 2 – external rotation (F 4), 3 – «abduction» (F 2), 4 – «adduction» (F2) (b). General diagram of standard shifting loads: A – coronal plane, B – transversal (horizontal) plane, C – sagittal plane. F 1 – longitudinal load to simulate distraction and compression, F 2 – transverse load to simulate abduction and adduction, F 3 – transverse load to simulate flexion and extension, F 4 – rotational load to simulate internal and external torsion (c)*

- Axial loading (F_1) defined longitudinal stability of osteosynthesis in distraction and compression. Loads $F_{1distr.}$ and $F_{1compr.}$ are exerted at the longitudinal axis of a simulated bone
- Transverse loads in frontal (F_2) and sagittal (F_3) planes defined transverse rigidity of osteosynthesis: in coronal plane simulating abduction and adduction (loads $F_{2abduction.}$ and $F_{2adduction.}$), in sagittal plane simulating flexion and extension of the limb (loads $F_{3flex.}$ and $F_{3exten.}$)
- Rotational load (F4) defined rotational rigidity of osteosynthesis simulating internal and external rotation of the limb ($F_{4exterl.}$ and $F_{4intern.}$)

The experiment conducted under Guidelines of Technique for Unified Specification of Transosseous Osteosynthesis [20] examined both types of the frames assembled according the diagrams as shown below:

$$\textbf{(CWRA)} \quad \frac{\text{VI,9,90; VII,2-8, VII,4-10}}{\text{¾ 180}} - \frac{\text{I,2-8; I,10-4; II,2,90}}{\text{¾ 180}}$$

$$\textbf{(PWRA)} \quad \frac{\text{VI,2,120; VII,4-10, VIII,8,90}}{\text{180}} - \frac{\text{I,2-8; I,10-4; II,12,120}}{\text{180}}$$

Three different assemblies were mounted including one CWRA and two PWRA. The difference in the last two constructs included a different distance between connecting rod and ¾ of a ring (Fig. 2).

Our experiment involved the technology used to explore rigidity of osteosynthesis with EFD offered by other authors [5, 6]. A wooden cylinder of 400 ± 5 mm with a diameter of 30 ± 5 mm was used as a substitute of a bone.

Fig. 2 *CWRA (left). PWRA-II (right) (photo: superior – AP view, inferior – lateral view)*
Note: According to the scheme the rods placed perpendicularly to the bone were attached to ¾ of the ring using a one-hole post of PWRA-I and three-hole post of PWRA-II

Distraction and compression were performed twice longitudinally with each of the 3 frames, total 12 times. Then the loads were applied for each of the three frames in coronal plane twice, sagittal plane twice, and transverse planes twice, total 18 times. There were total 30 (12+18) series of experiments conducted at stands R-20 («ZIP», № 2357, GOST 7855-74), MIP-100-2 («ZIP», № 171) and TIP RV 12 (№ 2046).

Loading was increased to get displacement of 1 mm at the docking site or a deformity of 1^{o} and then stopped. There was a notion of “rigidity coefficient” (K) used in the experiment and defined as a ratio between external loads and linear and angulation displacement. The more the rigidity coefficient the greater was rigidity of bone fixation [26, 28]. For instance, the rigidity coefficient of distraction and compression was calculated as follows:

$$K_{\text{distr.}} = F_{\text{distr.}}/U_{\text{distr.}}$$

$$K_{\text{compr.}} = F_{1\text{compr.}}/U_{\text{compr.}}$$

where $U_{\text{distr.}}$ and $U_{\text{compr.}}$ are displacement of fragments in axial direction during distraction and compression, correspondingly.

When conducting mechanical tests there was no need to determine a displacement value that resulted in a deformity or breakage of EFD because this information is not practically important in practice of EFD application and osteosynthesis [23].

Statistical analysis of mechanical tests were made using MedCalc software for Windows (version 12.7.8.0) and Mann-Whitney test (independent samples). A common medical criterion $P<0,05$ was used to provide statistical significance [18].

3. Results

The results of studies with RO of PWRA-I, PWRA-II and CWRA are summarized in Figures 3 and 4 and Table 1.

The results showed that the best longitudinal rigidity of osteosynthesis could be provided by CWRA during distraction, and the worst by PWRA-I. The difference between the values measured 38,1 N/mm (Fig. 3, Table 1).

Similar findings were observed in longitudinal compression with the difference of 29 N/mm (Fig. 3, Table 1).

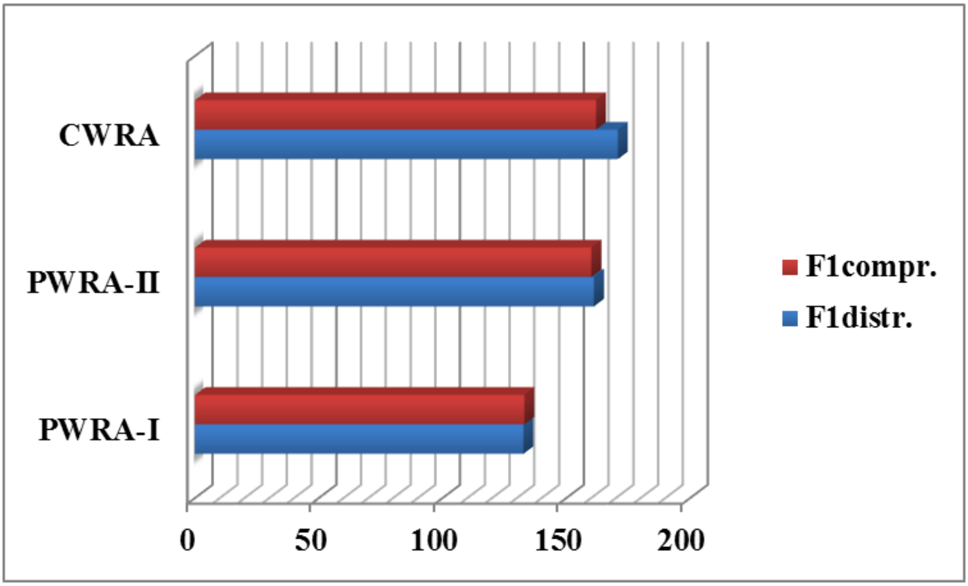

Fig. 3 *RO with loads (F_1) applied longitudinally (simulated distraction and fixation)*

Maximum values in coronal plane were shown with CWRA and minimum values with PWRA-I, with the difference of 0.8 N×mm/degr (Fig. 4, Table 1).

Similar findings were observed with loads applied in sagittal plane with the difference of 1 N×mm/degr (Fig. 4, Table 1).

Similar findings were observed with loads applied in transverse plane with the difference of 1.1 N×mm/degr (Fig. 4, Table 1).

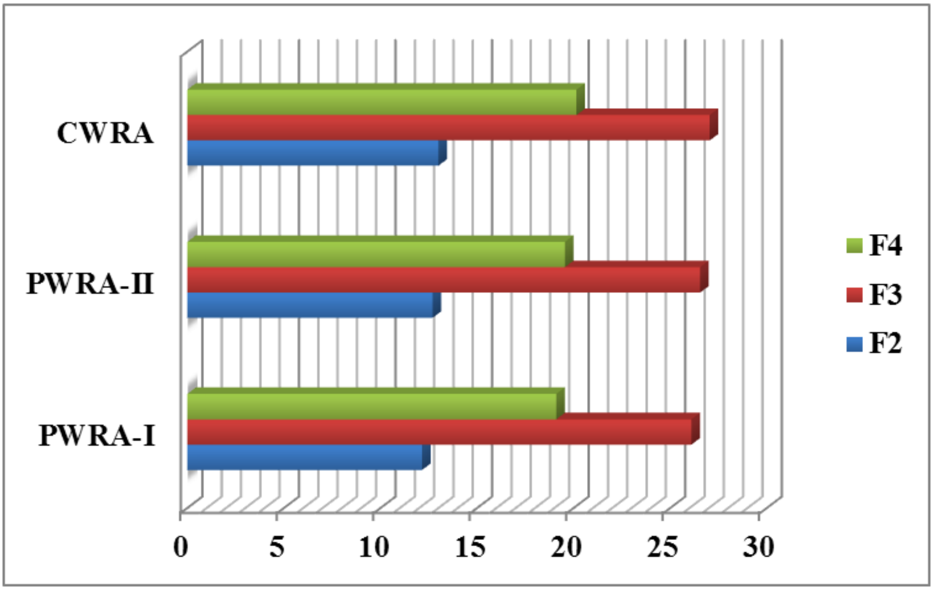

Fig. 4 *RO values with loads applied in different planes (simulated loads in coronal (F_2), sagittal (F_3) and transverse (horizontal) (torsion) (F_4)) planes*

	PWRA-I	**PWRA-II**	**CWRA**
Longitudinal rigidity of osteosynthesis, distraction, N/mm	132,7±3,55	161,2±1,25	170,8±0,4
Longitudinal rigidity of osteosynthesis, compression, N/mm	133,0±4,30	160,1±0,2	162,0±0,3
Coronal plane, N×mm/degr	12,2±0,25	12,7±0,1	13,0±0,2
Sagittal plane, N×mm/degr	26,1±0,2	26,6±0,25	27,1±0,15
Transversal plane (rotation), N×mm/degr	19,1±0,3	19,6±0,35	20,2±0,45

Table 1. *Comparative characteristics of RO with PWRA -I, PWRA -II and CWRA devices*

The most considerable difference between CWRA and PWRA-I was observed in longitudinal distraction, and minimal difference was shown in coronal plane (Fig. 3, 4 and Table 1).

The most considerable difference between CWRA and PWRA-II was observed in longitudinal distraction, and measured 9.6 N/mm minimal difference was shown in coronal plane (Fig. 3 and Table. 1) and minimum in coronal plane with the difference of 0.3 N×mm/degr (Fig. 4, Table 1).

4. Discussion Of Results

The results showed that CWRA provided less RO, by 17.8 % as compared with PWRA-I sand by 3.3 % as compared with PWRA-II. The greatest difference in the findings if RO tests were observed in longitudinal distraction and compression (Fig. 3, Table 1). If these values with PWRA-II were close to those of CWRA (161.2 ± 1.25 versus 170.8 ± 0.4) during distraction, PWRA-I showed more difference (132.7 ± 3.55 versus 170.8 ± 0.4) (Table 1). Testing RO in longitudinal compression showed inconsiderable difference between PWRA-II and CWRA (160.1 ± 0.2 versus 162.0 ± 0.3), whereas it appeared to increase between PWRA-I and CWRA (133.0 ± 4.30 versus 162.0 ± 0.3) (Table 1).

No considerable difference was found in RO tests in coronal plane (12.2 ± 0.25 versus 12.7 ± 0.1 and CWRA 13.0 ± 0.2) (Table 1), and equally, RO tests in sagittal (26.1 ± 0.2 versus 26.6 ± 0.25 and CWRA 27.1 ± 0.15) (Table 1) and transverse planes (19.1±0.3 versus 19.6 ± 0.35 and CWRA 20.2 ± 0.45) (Table 1).

Therefore, the findings allowed us to conclude that RO in longitudinal compression and distraction was higher with CWRA, slightly less with PWRA-II (by 3.3 %) (statistical difference of the values was significantly less, $P < 0,05$).
Our findings are similar to those obtained by

L.N.Solomin et al. (2005), who observed decrease in RO by 5 % on average at the final stage of MT after removal of posterior half-rings with all types of simulated loading [21] despite of some difference in the constructs.

We are in line with L.N.Solomin et al. (2005) that decrease in a construct's weight, making it less bulky and more comfortable for a patient is a priority in improving EFD [21]. The improvement in CWRA offered for AKJ meet the above requirements without a considerable decrease in RO. This assembly is especially comfortable for a patient when he stays in bed with the limb's weight being transferred not to the frame, i.e. wires and half-pins, but to the limb itself.

5. Conclusions

- Based on the findings we can conclude that the difference in RO values between the PWRA-II device offered and CWRA is not considerable (by 3.3 %). The results of experiments allow for application of PWRA in arthrodesis of the knee joint without any risk of losing RO.
- The findings showed that the increase in the distance between fixation of the rod and rings of PWRA-II resulted in increase in RO.

References

1. Andrianov M.V., Combined transosseous osteosynthesis for femoral fractures and their consequences, Avtoref. dis. kand. med. nauk.SPb., (2007), 25 p.
2. Aliev F.A., Larin V.B., Velieva N.I., Algorithms of the Synthesis of Optimal Regulators/ Outskirts Press, (2022), 412 p.
3. Beidik O.V., Butovskii K.G, Ostrovskii N.V., Liasnikov V.N., Modeling external transosseous osteosynthesis, Saratov, (2002),191 p.

4. Beidik O.V., Kotel'nikov G.P., Ostrovskii N.V., Osteosyntesis with rod and wire-rod devices for external fixation, Samara: Perspektiva, (2002), 208 p.
5. Bushmanov A.V., Mathematical and computed modeling of fixing devices in traumatology, Blagoveshchensk: Amurskii gos. un-t., (2007).
6. Bushmanov A.V., Solovtsova L.A., Study of the Ilizarov fixator rigidity, Ros. Zhurn. Biomekhaniki, Vol.12, No.3, (2008), pp.97-102.
7. Hutchinson B.K., Binski J.C., Treatment of tibial shaft fractures with the Taylor Spatial Frame. In: Fifteenth Annual Scientific Meeting of Limb Lengthening and Reconstruction Society. North America, New York, ASAMI, (2005), p.12.
8. Ilizarov G.A., Basic principles transosseous compression and distraction osteosynthesis, Ortop. Travmatol. Protez., No.11, (1971), pp.7.
9. Ilizarov G.A., The tension-stress effect on the genesis and growth of tissues, Part I. The influence of stability of fixation and softtissue preservation, Clin. Orthop. Relat. Res., No.238, (1989), pp.249-281.
10. Ilizarov G.A., The tension-stress effect on the genesis and growth of tissues: Part II. The influence of the rate and frequency of distraction, Clin. Orthop. Relat. Res. No.239, (1989), pp.263-285.
11. Kornilov N.V., Solomin L.N., Evseeva S.A., Nazarov V.A., Begun P.I., A technique of studying transosseous osteosynthesis rigidity in planning surgeries, GU RosNIITO im. R.R. Vredena SPb., (2005), 21 p.
12. Kuchinad R., Fourman M.S., Fragomen A.T., Rozbruch S.R., Knee arthrodesis as limb salvage for complex failures of total knee arthroplasty, J. Arthroplasty, Vol.29, No.1, (2014), pp.2150-2155.
13. Lim H.C., Bae J.H., Hur C.R., Oh J.K., Han S.H., Arthrodesis of the knee using cannulated screws, J. Bone Joint Surg. Br., Vol.91, No.2, (2009), pp.180-184.
14. Mitrofanov A.I., Kaminskii A.V., Pozdniakov A.V., The knee arthrodesis potenial using computer navigation, Genij Ortop., No.4, (2013), pp.106-108.
15. Mykalo D.A., Combined transosseous osteosynthesis for leg bone fractures and their consequences. Avtoref. dis. kand. med. nauk. SPb., (2008), 22 p.
16. Nazarov V.A., Biomechanical basics of the modular arrangement of devices for transosseous osteosynthesis of long tubular bones, Avtoref. dis. kand. med. Nauk, SPb, (2006), 22 p.
17. Rebrova O.V., A statistical analysis of medical data using a package of Statistics programs, M.: Media Sfera, (2002), 380 p.
18. Sabirov F.K., Solomin L.N., Studying the modules of the first and second order arranged using extracorical fixators, Travmatol. Ortop. Rossii, N.1, (2015), pp.58-65.

19. Salem K.H., Keppler P., Kinzl L., Schmelz A., Hybrid external fixation for arthrodesis in knee sepsis, Clin. Orthop. Relat. Res., Vol.451, (2006), pp.113-120.
20. Shevtsov V.I., Shved S.I., Sysenko Iu.M., Transosseous osteosynthesis in treatment of comminuted fractures, Kurgan: ZAO: «Dammi», (2002), 326 p.
21. Solomin L.N., Fundamentals of transosseous osteosynthesis with the Ilizarov fixator: a monograph. SPb.: OOO «MORSAR AV», (2005), p.544.
22. Solomin L.N., Fundamentals of transosseous osteosynthesis: in 2 V., M.: BINOM, T.1, (2014), 328 p.
23. Solomin L.N., Kornilov N.V., Voitovich A.V., Kulik V.I., Lavrent'ev V.A., A method of standardized designation of long bone transosseous osteosynthesis: guidelines, GU RosNIITO im. R.R. Vredena, (2004), 21 p.
24. Solomin L.N., Nazarov V.A., Begun P.I., Biomechanical and constructive bases of modular transformation of devices for long bone transosseous osteosynthesis, Travmatol. Ortop. Rossii, No.4, (2005), pp.39-47.
25. Solomin L.N., Nazarov V.A., Begun P.I., Biomechanical and constructive bases of modular transformation of devices for long bone transosseous osteosynthesis, Travmatol. Ortop. Rossii, No.4, (2005), pp.39-47.
26. Solomin L.N., Vilenskii V.A., Utekhin A.I., Terrel V., A comparative analysis of osteosynthesis rigidity provided by transosseous devices based on computed navigation and by the combined wire-rod device, Travmatol. Ortop. Rossii, No.2, (2009), pp.20-25.
27. Solovtsova L.A., A technique of computer-assisted studying the rigidity of wire-rod fixing devices, Ros. Zhurn. Biomekhaniki, Vol.14, No.1, (2010), pp.17-25.
28. Soudry M., Greental A., Nierenberg G., Falah M., Rosenberg N., Periprosthetic Infection Following Total Knee Arthroplasty, Chapter 24. In: Arthroplasty – Update. Ed. P. Kinov. InTech, (2013).