DOI 10.18019/1028-4427-2016-4-36-41

Comparative analysis of rigidity provided by wire and half-pin devices used for arthrodesis of the knee joint

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A wire-and-half-pin device (WHPD) was offered for arthrodesis of the knee joint (AKJ). **Objective** Conduct mechanical tests of WHPD and a combined wire-and-half-pin device (CWHPD) to determine rigidity of osteosynthesis (RO) provided by the devices and make a comparative analysis. **Material and methods** To evaluate RO of WHPD and CWHPD comparative mechanical tests were carried out for the devices that are used for AKJ. WHPD 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" (Kornilov N.V. et al., 2005). 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). **Results** Comparative analysis of the findings showed inconsiderable differences in RO between CWHPD and WHPD-II that we improved. **Conclusion** The findings allow for safe application of the device we improved for AKJ with no risk of losing RO.

Keywords Knee joint, arthrodesis, external fixation, Ilizarov apparatus, wire-and-half-pin device, rigidity of osteosynthesis

Extrenal fixation devices (EFD) are widely used in current trauma and orthopaedic practice. They are employed for both bone reduction and fixation in trauma and deformity correction, and for arthrodesis of joints [9, 25, 27, 28, 31].

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 [2, 3].

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 [22, 23]. Special mechanical and biomechanical tests are devised by researchers to examine RO of EFD [8, 14].

RO to be provided by an EFD is one of the most important characteristics [8, 11, 15, 17]. Multiple bench and biomechanical tests of RO of original Ilizarov assemblies and half-pins, combined wire-and-half-pin constructs allow for identifying most effective frames [1, 10, 11, 15].

Improvements in EFD are strongly associated with biomechanics of transosseous osteosynthesis. One of the trends in optimization of fracture healing includes techniques of staged destabilization of transosseous frame to transfer some of the weight from the fixation components to the regenerate bone. Dynamization technique with transosseous frame is well established and is used in clinical practice with wires gradually removed from reposition-fixation rings by the end of fixation phase [6, 17, 20, 21].

L.N. Solomin et al. (2005) offered the so called Module Transformation (MT) that was supposed to include the following steps throughout the fixation period [17]:

• Gradual decrease in the number of connecting rods and transosseous components;

• Reduce the number of rings with no need for additional transosseous elements;

• Change geometry of external supports by dismantling a part of a ring.

The purpose of MT is to improve the quality of patient's life, decrease transfixational contracture and infection rate. Application of MT allows for early rehabilitation treatment creating optimal conditions for bone healing [17].

Various modifications of EFD is currently used for AKJ [9, 24, 25, 26, 27, 30, 31].

It is known that stable bone fixation provided with a wire and half-pin module with a single ring can be greater than that provided by a two-ring construct and wires [10]. We suggest that CWHPD used for AKJ is most effective although no publication in the affordable literature report the tests examining rigidity of osteosynthesis used for AKJ.

In our experience patients have some discomfort and even pain with CWHPD due to the limb's weight that is transferred to the bone via the wires and rods of the frame when staying in bed.

We decided to improve the frame to prevent the limb's weight affecting the transfer to the frame components with the patient's horizontal position. So we offered to use ¾ of Ilizarov half-rings instead of full rings. 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 WHPD and CWHPD to determine rigidity of osteosynthesis (RO) provided by the devices and make a comparative analysis.

Aliev G.A., Ali-Zadeh Ch.A. Comparative analysis of rigidity provided by wire and half-pin devices used for arthrodesis of the knee joint. *Genij Ortopedii*, 2016, No 4, pp. 36-41 (In Russ). DOI 10.18019/1028-4427-2016-4-36-41

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" [8].

RO was determined in accordance with medical technology of examining rigidity with transosseous osteosynthesis [13, 15, 16, 18, 20]. The technology is performed with algorithm of standard actions and calculations of determining major characteristics of rigidity with EFD (**Fig. 1**).

• Axial loading (F1) defined longitudinal stability of osteosynthesis in distraction and compression. Loads F1distr. and F1compr are exerted at the longitudinal axis of a simulated bone.

• Transverse loads in frontal (F2) and sagittal (F3) 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 $F_{3flex.}$ и $F_{3exten.}$).

• Rotational load (F4) defined rotational rigidity of osteosynthesis simulating internal and external rotation of the limb ($F_{4exterl.}$ и $F_{4intern.}$).

The experiment conducted under Guidelines of Technique for Unified Specification of Transosseous Osteosynthesis [19] examined both types of the frames assembled according the diagrams as shown below,

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

$$(\text{WHPD}) \rightarrow \frac{\text{VI}, 9{,}90;\ \text{VII}, 2-8, \text{VII}, 4-10}{¾\ 180} - \frac{\text{I}, 2-8;\ \text{I}, 10-4;\ \text{II}, 12{,}90}{¾\ 180}.$$

The diameter of rings measured 180 mm, distance between the rings was 155±5 mm, diameter of wires was 2 mm, diameter of threaded rods was 6 mm.

Three different assemblies were mounted including one CWHPD and two WHPD. The difference in the last two constructs included a different distance between connecting rod and ¾ of a ring.

Our experiment involved the technology used to explore rigidity of osteosynthesis with EFD offered by other authors [4, 5]. A wooden cylinder of 400 ± 5 mm with a diameter of 30 ± 5 mm was used as a substitute of a bone.

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).

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 "WHPD-I"and three-hole post of "WHPD-II".

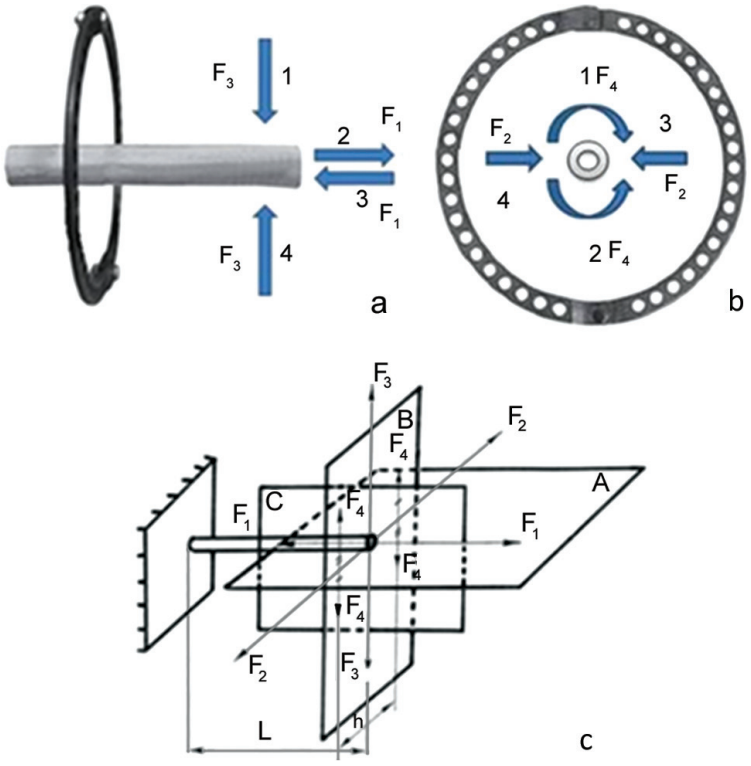

Fig. 1 Diagram of experiment: Direction of resulting loading vector (side view of module): 1 – «flexion» (F_3), 2 – «distraction» (F_1), 3 – «compression» (F_1), 4 – «extension» (F_3) (**a**). Direction of resulting loading vector (inferior view of module): 1 – internal rotation (F_4), 2 – external rotation (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**)

Loading was increased to get displacement of 1 mm at the docking site or a deformity of 1º 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 [14, 29]. For instance, the rigidity coefficient of distraction and compression was calculated as follows,

$$K_{distr.} = F_{distr.}/U_{distr.}$$
$$K_{compr.} = F_{1compr.}/U_{compr.},$$

where $U_{distr.}$ and $U_{compr.}$ 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 [15].

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 [12].

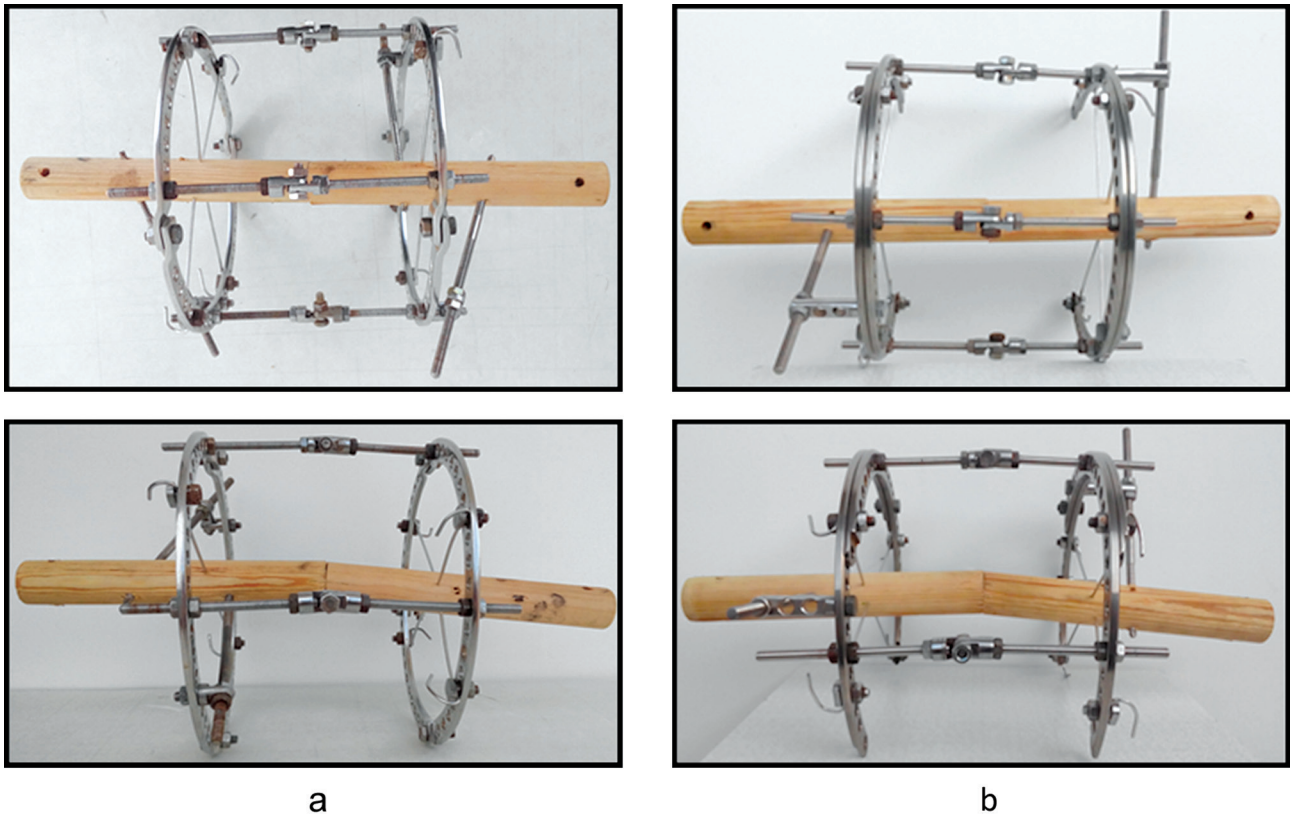

Fig. 2 CWHPD (**a**). WHPD-II (**b**) (photo: superior – AP view, inferior – lateral view)

RESULTS

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

The results showed that the best longitudinal rigidity of osteosynthesis could be provided by CWHPD during distraction, and the worst by WHPD-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**).

Maximum values in coronal plane were shown with CWHPD and minimum values with WHPD-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**).

The most considerable difference between CWHPD and WHPD-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 CWHPD and WHPD-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**).

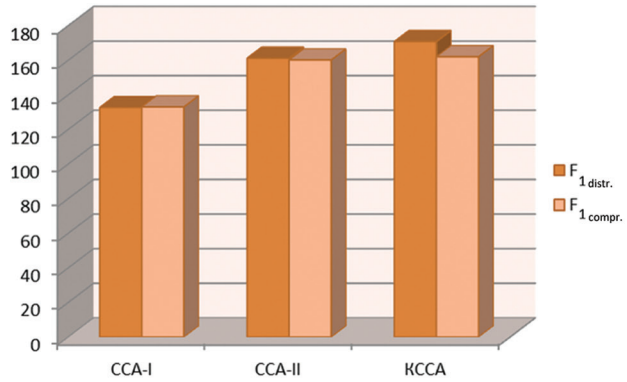

Fig. 3 RO with loads (F_1) applied longitudinally (simulated distraction and fixation)

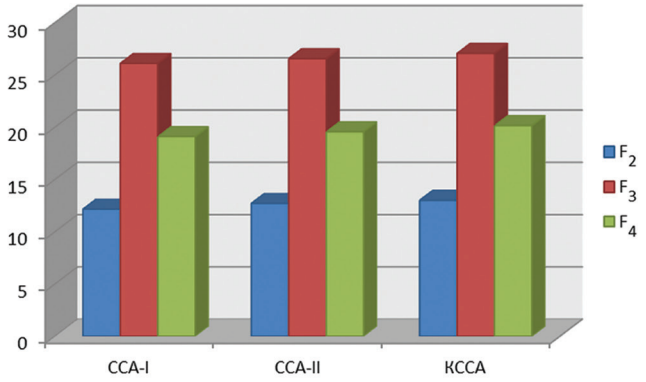

Fig. 4 RO values with loads applied in different planes (simulated loads in coronal (F_2), sagittal (F_3) and transverse (horizontal) (torsion) (F_4)) planes

Table 1

Comparative characteristics of RO with WHPD-I, WHPD-II and CWHPD devices

	WHPD-I	WHPD-II	CWHPD
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

DISCUSSION OF RESULTS

The results showed that CWHPD provided less RO, by 17.8 % as compared with WHPD-I sand by 3.3 % as compared with WHPD-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 WHPD-II were close to those of CWHPD (161.2 ± 1.25 versus 170.8 ± 0.4) during distraction, WHPD-I showed more difference (132.7 ± 3.55 versus 170.8 ± 0.4) (**Table 1**). Testing RO in longitudinal compression showed inconsiderable difference between WHPD-II and CWHPD (160.1 ± 0.2 versus 162.0 ± 0.3), whereas it appeared to increase between WHPD-I and CWHPD (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 CWHPD 13.0 ± 0.2) (**Table 1**), and equally, RO tests in sagittal (26.1 ± 0.2 versus 26.6 ± 0.25 and CWHPD 27.1 ± 0.15) (**Table 1**) and transverse planes (19.1±0.3 versus 19.6 ± 0.35 and CWHPD 20.2 ± 0.45) (**Table 1**).

Therefore, the findings allowed us to conclude that RO in longitudinal compression and distraction was higher with CWHPD, slightly less with WHPD-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 [17] 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 [17]. The improvement in CWHPD 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.

CONCLUSIONS

• Based on the findings we can conclude that the difference in RO values between the WHPD-II device offered and CWHPD is not considerable (by 3.3 %). The results of experiments allow for application of WHPD 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 WHPD-II resulted in increase in RO.

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Received: 14.06.2016

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