## HISTORY OF MEDICINE AND ANNIVERSARIES

# HISTORY OF BIOMECHANICAL RESEARCH AT THE ILIZAROV CENTER (TO THE 100TH ANNIVERSARY OF ACADEMICIAN G.A. ILIZAROV)

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## ABSTRACT

***Background.*** *Biomechanical studies of both the Ilizarov apparatus itself and the physiological system "apparatus – limb" occupy a significant place in the history of the formation and elaboration of the Ilizarov method, developed in the middle of the last century at the Kurgan Research Institute of Experimental Traumatology and Orthopaedics (nowadays – the world-famous center named after its creator). The analysis of the history of biomechanical research in the formation of Ilizarov method is not without interest.*

***The aim.*** *To analyse the history and stages of development of biomechanical research in order to substantiate the effectiveness of the Ilizarov method of transosseous osteosynthesis.*

***Results.*** *The national medical industry did not produce the appropriate equipment for biomechanical research in the early 1970s. That is why a group of engineers was included into the Laboratory of Clinical Physiology and Biomechanics (established in 1971) of the Ilizarov Center, which created equipment for studying the processes in the tissues of the limbs and in the structure of the Ilizarov apparatus itself during its traction and compression impact on biological structures. The community of physicians, scientists and engineers made it possible to overcome a number of difficulties and problems. In their scientific publications and dissertations, the laboratory staff paid great attention to biomechanical research during transosseous osteosynthesis with the Ilizarov apparatus. At present, the staff of the Ilizarov Center continues the traditions established by G.A. Ilizarov. For the first time in our country, a computer 3D video analysis of the kinematics and kinetics of orthopedic patients gait was introduced; it was supplemented with embedded software for the preparation of a clinical report of human gait biomechanics.*

***Conclusion.*** *The initial stage of the biomechanical research at the Ilizarov Center included the creation of the research equipment. Subsequently, the biomechanical studies carried out by the staff of the Center for almost half a century have shown an applied and functional result of the realization of general biological regularities of the Ilizarov's discovery. At present, the biomechanical research continues at a higher level with the use of modern high-tech equipment.*

***Key words:*** *Ilizarov method, transosseous osteosynthesis, tension stress, Ilizarov effect, biomechanics*

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# ИСТОРИЯ РАЗВИТИЯ БИОМЕХАНИЧЕСКИХ ИССЛЕДОВАНИЙ В ЦЕНТРЕ ИЛИЗАРОВА (К 100-ЛЕТИЮ АКАДЕМИКА Г.А. ИЛИЗАРОВА)

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## РЕЗЮМЕ

***Обоснование.*** *В истории становления и развития метода Илизарова, разработанного в середине прошлого века в Курганском НИИ экспериментальной травматологии и ортопедии, ныне – всемирно известном Центре, носящем имя своего создателя, значительное место занимают биомеханические исследования как самого аппарата, так и физиологической системы «аппарат – конечность». Интерес представляет анализ истории развития биомеханических исследований при становлении метода Илизарова.*

***Цель.*** *Анализ истории развития биомеханических исследований для обоснования эффективности метода чрескостного остеосинтеза по Илизарову.*

***Результаты.*** *Ввиду того, что в начале 1970-х годов соответствующего оборудования для проведения биомеханических исследований отечественная медицинская промышленность не выпускала, в состав лаборатории клинической физиологии и биомеханики Центра Илизарова (создана в 1971 г.) была введена группа инженеров, которая создавала аппаратуру для исследования процессов, происходящих в тканях конечностей и самой конструкции аппарата Илизарова при его тракционном и компрессионном воздействии на биологические структуры. Содружество врачей, научных сотрудников и инженеров позволило успешно преодолеть ряд трудностей и проблем. В научных публикациях и диссертациях сотрудники лаборатории уделяли большое внимание биомеханическим исследованиям в процессе выполнения чрескостного остеосинтеза аппаратом Илизарова. В настоящее время сотрудники Центра продолжают традиции, заложенные Г.А. Илизаровым. Впервые в нашей стране внедрён компьютерный 3D-видеоанализ кинематики и кинетики ходьбы у пациентов ортопедического профиля, который дополнен встроенным программным обеспечением для формирования клинического отчёта биомеханики ходьбы человека.*

***Заключение.*** *Начальный этап развития биомеханических исследований в Центре Илизарова включал создание исследовательской аппаратуры. В последующем проводимые сотрудниками Центра в течение почти полувека биомеханические исследования показали прикладной, функциональный результат реализации общебиологических закономерностей открытия Г.А. Илизарова. В настоящее время биомеханические исследования осуществляются на более высоком уровне с использованием современного высокотехнологичного оборудования.*

***Ключевые слова:*** *метод Илизарова, чрескостный остеосинтез, напряжение растяжения, эффект Илизарова, биомеханика*

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June 15, 2021 marked the 100th anniversary of the birth of Gavriil Abramovich Ilizarov, an outstanding scientist, academician of the Russian Academy of Sciences.

G.A. Ilizarov was an excellent organizer and inspirer of ideas, who gather around him a team of like-minded people and created a new method of treating injuries and diseases of the musculoskeletal system – the method of transosseous osteosynthesis.

Biomechanical studies of both the Ilizarov apparatus itself and the physiological system "apparatus – limb" occupy a significant place in the history of the formation, elaboration and justification of the Ilizarov method, developed in the middle of the last century at the Kurgan Research Institute of Experimental Traumatology and Orthopaedics (nowadays – the world-famous center named after its creator). In this work, we will focus on the analysis of the main stages of the development of biomechanical studies conducted and currently being conducted to physiologically determine the effect of the prolonged compression-distraction impact of the Ilizarov apparatus on the limb segment.

## THE AIM OF THE WORK

To analyze the history and stages of development of biomechanical research in order to substantiate the effectiveness of the Ilizarov method of transosseous osteosynthesis.

After a historical insight and assessment of biomechanical approaches to the formation of the philosophy of the Ilizarov method from a biological standpoint the authors suggest that the reader evaluate the role of clinical biomechanics for improving diagnostic procedures and surgical interventions in orthopedics and traumatology.

In 1951 G.A. Ilizarov developed an apparatus which is an external fixation device consisting of a series of ring supports connected by threaded rods for fixing thin wires crosswise through the bone in a tensioned state [1]. This development reflected the concept of induction of local bone formation in a minimally invasive way, which provides for accurate reposition and stable fixation of bone fragments, exclusion of micro-mobility at their junction, sparing treatment of the soft tissues surrounding the bone, preservation of sources of osteogenesis. The theoretical basis of the distraction osteosynthesis method is the general biological regularity of stimulation of tissue regeneration and growth under the influence of tension stress, established on the basis of clinical experience and fundamental research and registered as a discovery [2]. After receiving good results of treatment of traumatological and orthopedic patients [3, 4] using the apparatus developed by G.A. Ilizarov [1], there were many uncertainties regarding the features of blood circulation and innervation of the operated limb segment, the condition of bones, surrounding soft tissues, muscle and joint function at various stages of treatment and rehabilitation.

To fill this gap, the Laboratory of Clinical Physiology and Biomechanics was established in 1971, headed by O.V. Tarushkin, Doctor of Biological Sciences (Fig. 1a). The national medical industry did not produce the appropriate equipment for biomechanical research in the early 1970s. That is why a group of engineers was included into the Laboratory, which created equipment for studying the processes in the tissues of the limbs and in the structure of the Ilizarov apparatus itself during its traction and compression impact on biological structures. The community of physicians, scientists and engineers made it possible to achieve a number of objectives.

***a***

***b***

***FIG. 1.***

*Heads of the Laboratory of Clinical Physiology and Biomechanics:* ***a*** *– Oleg V. Tarushkin, Dr. Sc. (Biol.) (1971–1977);* ***b*** *– Vladimir A. Shchurov, Dr. Sc. (Med.), Professor, High Level Certificate Physician (1977–2008)*

The photo (Fig. 2) shows the meeting of the Ilizarov Center staff with Wolf Messing in December, 1971. Among those present we can see Oleg V. Tarushkin and Vladimir A. Shchurov (indicated by white arrows), who at different times headed the Laboratory of Clinical Physiology and Biomechanics.

The most urgent tasks that the Center's staff faced in the early 1970s were the development of a safe method of drilling bone tissue with a wire and the evaluation of the mechanism of fixation of the wires when they pass through the cortical plate of the bone. On the instructions of G.A. Ilizarov, the Laboratory of Clinical Physiology and Biomechanics developed a method for measuring the temperature during bone drilling with a wire at any depth during its insertion [5] (Fig. 3).

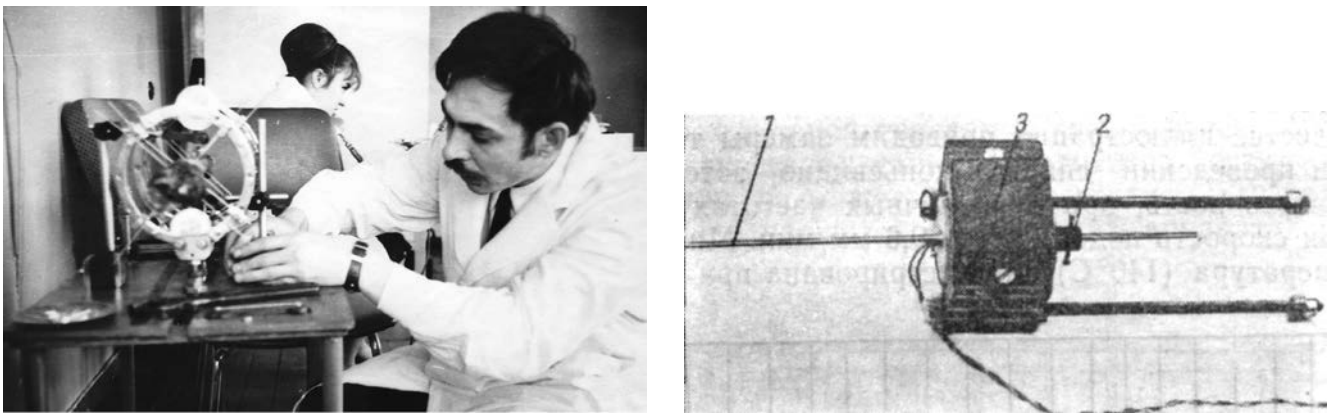
The effect of the tension forces of the wires on the rigidity of the bone fragments fixation in the apparatus was thoroughly studied. The rigidity of Kirschner wires in various configurations of the Ilizarov apparatus was analyzed (Fig. 4, 5) [6].

G.A. Ilizarov also set the task for the laboratory staff to evaluate the dynamics of deformation properties of a regenerated bone during the treatment.

The laboratory has developed an *in vivo* method for measuring the axial motion of bone fragments under conditions of compression osteosynthesis by the Ilizarov apparatus. Tensometric sensors were used to analyze changes in the distance between the wires coming out of the bone proximally and distally from the fracture site under conditions of axial functional load with different forces. This method allowed to evaluate the rigidity of the "apparatus – limb" system and the rheological properties of distraction regenerated bone [7, 8] (Fig. 6).

An original biomechanical track "Podographometer" was constructed in order to study the functions of the musculoskeletal system. This device allowed to automatically register and process the temporal indicators of gait [9, 10]. A quantitative assessment of gait was made. The obtained data were subjected to statistical development on the computer "NAIRI-2" according to the program developed by E.B. Smirnov –

***FIG. 2.***
*Meeting of the staff of the Ilizarov Center with Wolf Messing (December 20, 1971)*




***a*** ***b***

***FIG. 3.***
***a*** *– engineer V.A. Nemkov at work,* ***b*** *– thermocouple wire for measuring the temperature during bone drilling (1 – wire; 2 – collector; 3 – case) [5]*

one of the employees of the Center [11]. The functional results of treatment and the effectiveness of rehabilitation measures were evaluated in orthopedic and trauma patients treated by the Ilizarov method, using Podographometer.

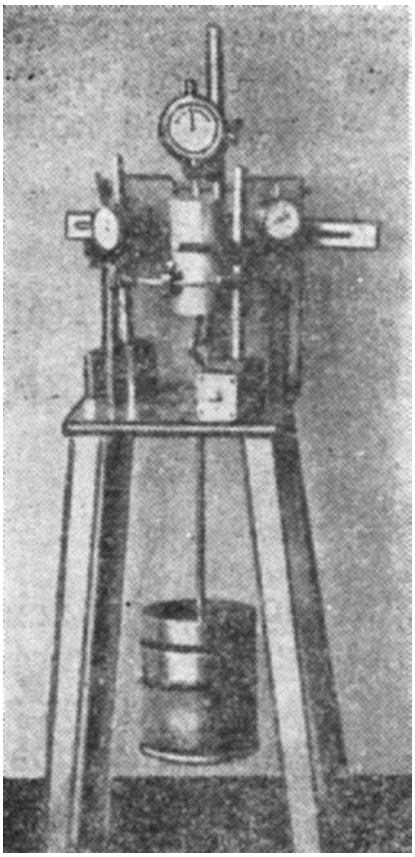


***FIG. 4.***
*Stand for measuring wire deflections [6]*

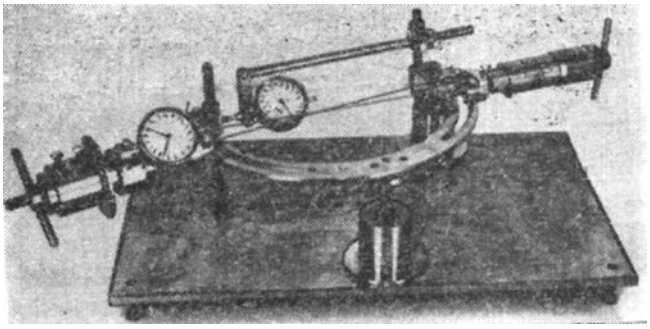
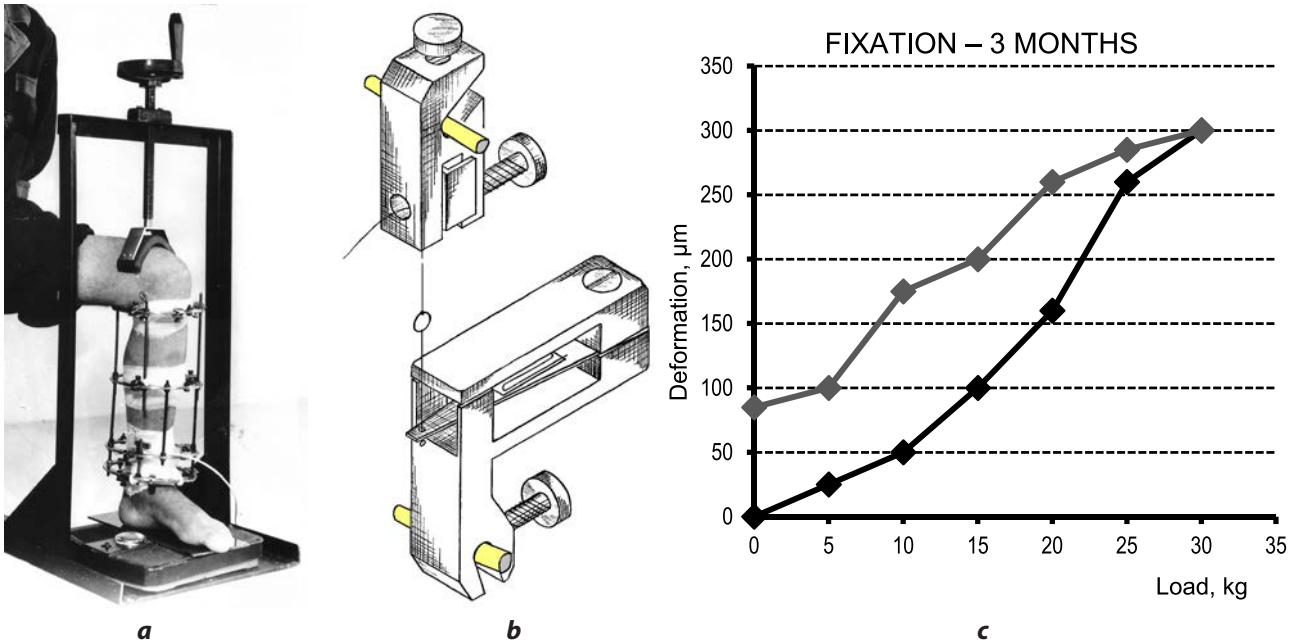


***FIG. 5.***
*Stand for measuring the deformation of the Ilizarov apparatus parts under different loads [6]*

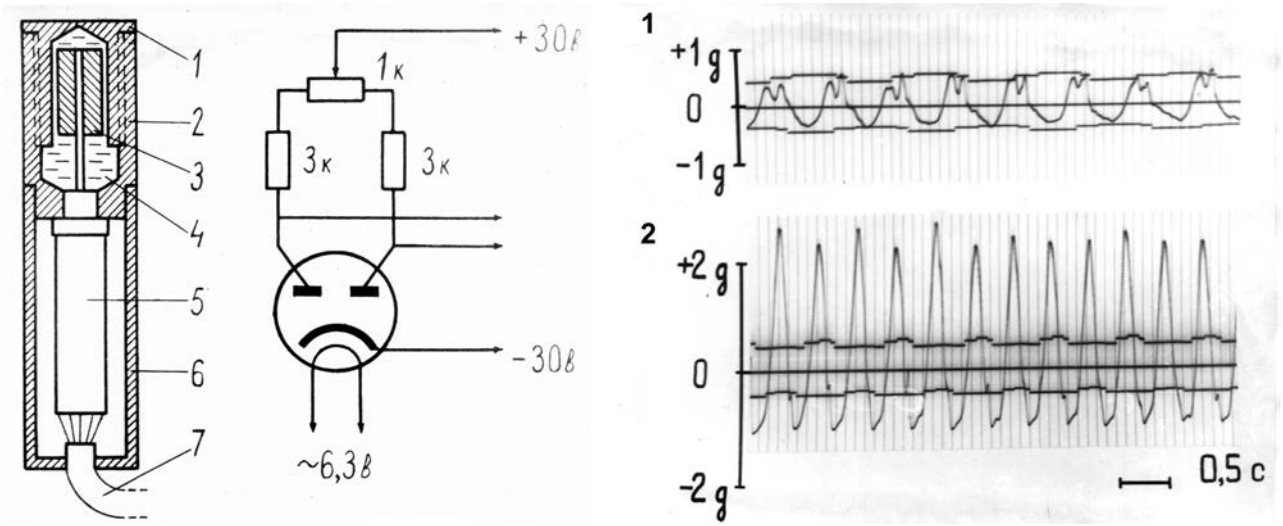
A mechatronic pedometer was developed to assess the motor activity of patients with injuries and diseases of the musculoskeletal system [12]. The design of the accelerometer sensor is proposed (Fig. 7) to determine the qualitative and quantitative characteristics of kinematics of the gait of a healthy and a diseased person, to assess the dynamics of the locomotor act under the influence of the treatment and functional rehabilitation [13]. Approaches in determining the biomechanics of movement, which are used in modern electronic gadgets, were applied in these designs.

Evaluation of the functional load on the lower limb during transosseous osteosynthesis by the Ilizarov apparatus was carried out using an original technique (cargometry) and a device developed at the Center. Clinical approbation of this technique carried out by Boris I. Kudrin, Candidate of Medical Sciences, allowed to estimate the supporting capabilities of the limb during walking in the course of treatment with the Ilizarov apparatus by the integral values of time and strength parameters of the interaction of the limbs with the biomechanical track [14–16] (Fig. 8).




***a*** ***b*** ***c***

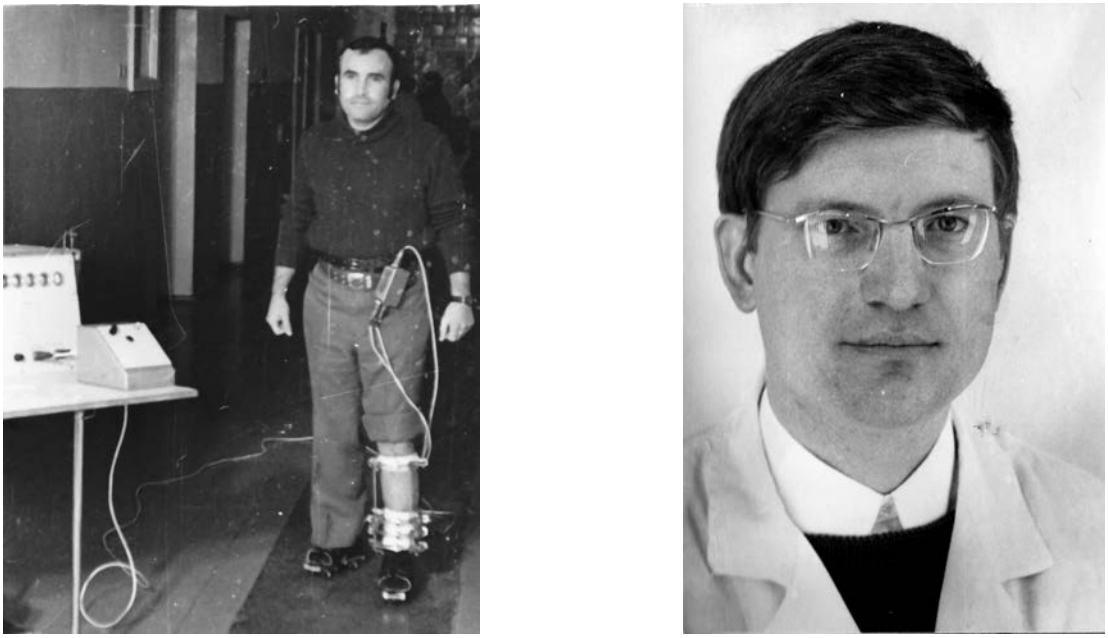
***FIG. 6.***
*Determination of the micromotion of bone fragments: **a** – the unit for determining the micromotion of bone fragments; **b** – tensometric sensor mounting; **c** – diagram for determining the rheological properties of distraction regenerated bone [7, 8]*




*a* *b* *c*

***FIG. 7***.

*Accelerometer device (**a**), the scheme of its inclusion in the measuring circuit (**b**) and the accelerogram (**c**) during walking (1) and running (2) of a healthy subject [13]*



*a* *b*

***FIG. 8.***

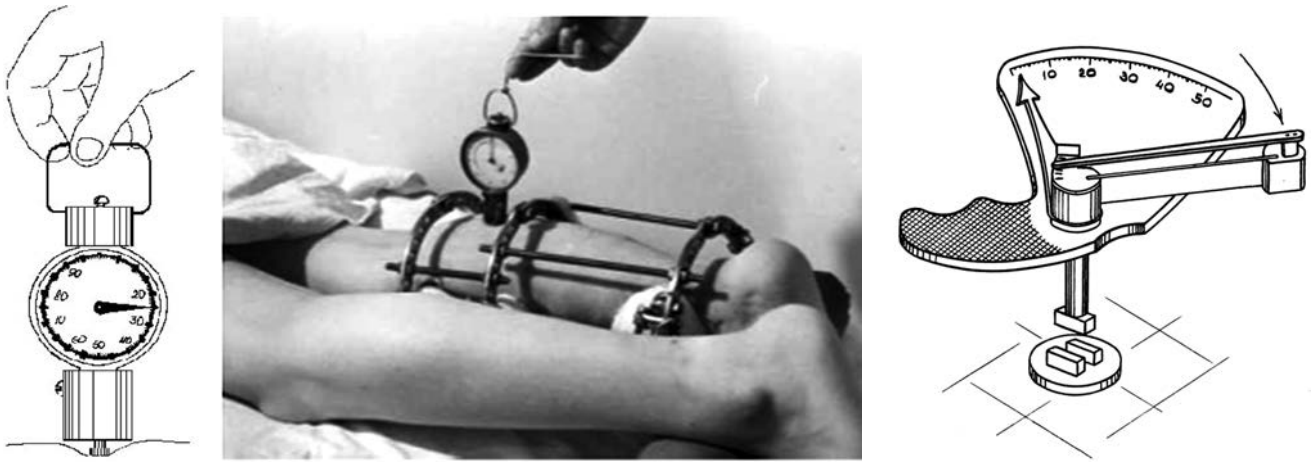
***a** – the patient during the evaluation of the lower limb functional load during transosseous osteosynthesis with the Ilizarov apparatus [16];*
***b** – Boris I. Kudrin, Cand. Sc. (Med.)*

In the late 1970s, G.A. Ilizarov formulated the concept "The stimulating effect of tension stress on tissue growth and regeneration" [2]. Obviously, there was a need for careful development of a theoretical justification and quantitative confirmation of the provisions of this concept [17]. The laboratory staff developed original designs for studying skin elasticity (elastometer) and myogenic tonus (tonometer) (Fig. 9) [18–20].

Studies of healthy children have shown that the values of skin and muscle elasticity increase with natural longitudinal growth of a limb. Patients with retardation in growth of limb segments after surgical lengthening have the same indicators of muscle and skin elasticity as healthy people with the same length of the corresponding limb [21–23].

In the process of development and continuous improvement of the Ilizarov method, there was a need for an accurate quantitative assessment of the muscle function (strength) of the operated limb. Professor V.A. Shchurov, Doctor of Medical Sciences, together with the laboratory staff, created original dynamometric stands [24, 25]. Later these methods were improved [26, 27] and published [28, 29] (Fig. 10).

At the stage of introduction of outpatient treatment of orthopedic and trauma patients into clinical practice (late



*a* *b* *c*

***FIG. 9.***

*A tonometer, an original device for studying biomechanical properties of muscles [18, 20]:* ***a*** *– external view (scheme);* ***b*** *– the process of measuring the myogenic tonus;* ***c*** *– an elastometer, the original design (scheme) for the assessment of skin elasticity [19]*

*a* *b* *c*

***FIG. 10.***

*Dynamometric stands:* ***a*** *– an external view of the dynamometric stand for studying femoral muscle strength;* ***b*** *– the process of measuring;* ***c*** *– studying the lower leg muscle strength during treatment with the Ilizarov apparatus*

1980s – early 1990s), it was necessary to develop functional criteria for transferring inpatient patients to this treatment regimen. The laboratory staff carried out comprehensive work, including the study of daily locomotor activity, linear velocity of movement, asymmetry of functional load on the limb, energy cost of locomotion.

When deciding on the advisability and timeliness of transferring inpatient patients to the outpatient treatment regimen, assessing clinical condition and analyzing their social and living conditions, it was proposed to use the following physiological criteria: value of the asymmetry of loading of the lower extremities when standing without additional support – no more than 20 %; gait velocity – at least 2 km/h; daily locomotor activity – at least 2000 m; pulse rate during walking – no more than 100–110 bpm [30].

In the 1990s–2000s, a number of PhD theses and doctoral dissertations were completed and successfully defended in the Laboratory of Clinical Physiology and Biomechanics, in which the biomechanical research was one of the leading topics.

In his doctoral dissertation (1993) V.A. Shchurov substantiated the physiological mechanism of the stimulating effect of tissue stretching that occurs during natural growth and limb lengthening according to Ilizarov [31].

In the PhD thesis of T.I. Dolganova (1993), the features of hemodynamics, biomechanical properties of tissues and the functional state of patients with leg bone defects in the treatment according to the Ilizarov method were analyzed [32]. In the work of E.N. Shchurova (1996), the role of locomotor activity in preserving the reserves of functional adaptation of blood circulation in patients with obliterating lesions of arteries of the lower extremities during treatment according to the method of G.A. Ilizarov was determined [33–35]. In the dissertation of T.I. Menshikova (1997), a physiological analysis [36–38] of the effect of lengthening of the lower extremities on the indicators of loco-

***a*** ***b*** ***c***

***FIG. 11.***

*Computer analysis of gait parameters using modern video analysis systems: **a** – general view and arrangement of the gait analysis laboratory; **b** – the process of examining the patient by the laboratory staff; **c** – external view of a patient before the examination with reflective markers and electromyographic sensors*

motor activity of patients with achondroplasia was given [39]. The work of D.V. Dolganov (1997) highlights the role of tissue hydration in the vegetative support of the limb during transosseous osteosynthesis [40, 41]. In her dissertation (2002) L.Y. Gorbacheva analyzed the influence of the functional load of the injured limb on the restoration of muscle contractility and reparative bone regeneration in the treatment of trauma patients according to the method of G.A. Ilizarov [42].

The doctoral dissertations continued the development of theoretical justification and quantitative confirmation of the general biological regularities of G.A. Ilizarov's discovery [2]. The physiological studies contributed to a deeper understanding of the mechanisms of "The Ilizarov effect", its biomechanical and structural components, illustrated the applied functional result of the implementation of the regularities of G.A. Ilizarov's discovery [43–45].

The results of many years of research and the developed designs were summarized, improved and published in the second London edition of "Biomechanics and Biomaterials in Orthopedics" in 2016 (Springer) [46].

The Ilizarov Center continues to carry out biomechanical research, the traditions of which were established more than half a century ago.

One of the areas of research is the search for diagnostic criteria for assessing disorders of the vertical orientation of the spine. The laboratory staff began to use a prolonged topographic examination to assess the stereotype of postural activity of the spine and its kinematic lability. Functional tests with correction and hypercorrection of limb shortening were introduced, which provided differentiated diagnostics of structural and functional scolioses, determination of the necessity and value of optimal correction of leg length inequality. Topographic analysis of stereotypes of postural activity and kinematic lability of the spine allowed to study pathogenetic conditions under which functional scolioses become structural ones [47–49].

In the Ilizarov Gait Analysis Laboratory of the National Ilizarov Medical Research Center for Traumatology and Orthopaedics, a computer analysis of gait parameters in orthopedic patients is performed on a 7-meter track using modern systems of video analysis of the kinetics and kinematics of human movements [50] (Fig. 11).

The data were recorded by 8 Qualisys 7+ optical cameras (Sweden) with passive marker motion capture technology, synchronized with 6 KISTLER dynamometers (Switzerland) and supplemented with 16 Noraxon wireless EMG sensors (USA). Kinematics and kinetics analysis are carried out in Qualisys and Visual 3D (C-Motion) with automated calculation of indicators. The biomechanical characteristics of the "stair movement" are determined using the "virtual platform lift" option. The research results are reflected in modern publications [51–53]. Our Center has developed embedded software for the preparation of the report on examination results in the form of digital data in tables complemented by diagrams [54].

## CONCLUSIONS

The initial stage of the development of biomechanical research at the Ilizarov Center included the creation of equipment for studying the processes in the tissues of the limbs and the Ilizarov apparatus itself during its traction and compression impact on biological structures.

The community of doctors, scientists and engineers of the Laboratory of Clinical Physiology and Biomechanics (established in 1971) made it possible to develop devices and methods for measuring the temperature during bone drilling with a wire; assessing the effect of the tension forces of the wires on the rigidity of bone fragments fixation in the apparatus; studying axial micromotion of bone fragments and rheological properties of regenerated bone; studying the functions of the musculoskeletal system (original biomechanical track, mechatronic pedometer, accelerometer); studying biomechanical properties of muscles (myotometer, dynamometric stands); analysis of skin elasticity (elastometer).

In the following years, complex biomechanical studies contributed to the theoretical justification and quantitative confirmation of the stimulating effect of tension stress on tissue growth and regeneration (the Ilizarov effect), have shown the applied, functional result of the realization of general biological regularities of the Ilizarov's discovery.

Currently, the Ilizarov Center has switched to high-tech methods of biomechanical research, developed embedded software for the preparation of a report in the form of digital data of a computer 3D video analysis of gait complemented by diagrams.

**Conflict of interest**

The authors of this article declare the absence of a conflict of interest.

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