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IDEA DIAGRAMS IN THE FIELD OF ILIZAROV FIXATORS

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Abstract. The paper refers to presenting the current state of scientific research in the field of Ilizarov fixators used in orthopedic surgeries. The approach is not exhaustive, as the aim of the paper is to outline the general coordinates that can form the basis for structuring the information in the specialized literature in this field. To provide a scientific presentation of the current state of research, a logical-combinatorial technical creation method was used, the idea diagram method. In this way, the variety of technical solutions developed to date can be visualized in a single view. The method also presents the advantage that information is classified by fields and subfields, which allows the systematization and coding of information. The paper presents two concept diagrams, in which technical solutions are classified according to mechanical functionality and the anatomical area in which they are located on the patient's limbs. Given the open and critical nature of the method, the paper concludes by defining future avenues for development in the field.

Keywords: Ilizarov fixators, fractures, osteosynthesis, bones lengthening, external fixation reconstruction.

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1. Introduction

Ilizarov fixators, invented by G. A. Ilizarov in 1960 (Gubin *et al*., 2013) are orthopedic devices used to fixate (or lengthen) bones in the lower and upper limbs, during the osteosynthesis process in regeneration of bone tissue after fractures. These fixators consist of metal rings placed around the affected limb, rigid spacer rods that connect the metal rings, metal wires for fixing the rings to the bone structure, and fasteners such as screws, washers, and nuts (Fig. 1).

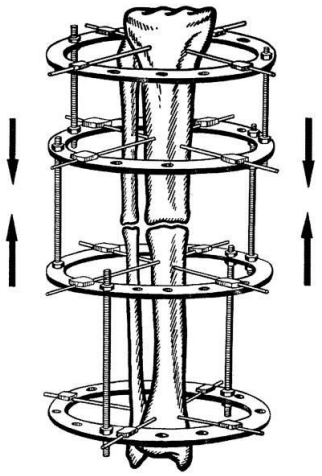


Fig. 1 – Example of Ilizarov Fixator (Spiegelberg *et al*., 2010).

The paper aims to present the current state of research in the field. The documentary information was based on patents, scientific papers, university courses and achievements of companies in the field of Ilizarov fixators. It also presents the operating principles of the Ilizarov fixator and develops idea diagrams in the field of Ilizarov fixators, with the main aim of proposing and orienting towards new methods of developing these orthopedic devices.

One of the most effective methods for analyzing the state of knowledge in a field is the idea diagram method, which belongs to the category of logical-combinatorial creation techniques and methods (Belous, 1986; Belous, 1991; Belous, 1992). In accordance with the principles, terminology, and general theory of technical creation, *an idea diagram is an open, tree-like, graphic representation containing structured information about the current state of science and technology in a field* (Seghedin, 2008). This open character (given by question marks) of idea diagrams is the main reason why this method was chosen for this paper, as it allows the weak points of the analyzed field to be identified, leading to the scientific establishment of the next directions of

research. Idea diagrams are true intellectual work techniques, characterized by a great visual advantage, allowing the concentration of a multitude of technical solutions classified according to certain criteria into a single picture. Thus, this structuring of information can form the basis for structuring databases in the analyzed field (Belous, 1986; Belous, 1991; Belous, 1992; Seghedin, 2008; Fodor and Seghedin, 2022).

2. History of the Appearance and Development of Ilizarov Prosthetic Systems

The Ilizarov fixator, as it is known worldwide, has the name of its inventor, Gavriil Abramovich Ilizarov (1921–1992). In 1950, wanting to treat patients with different bone fractures in the most effective and least invasive way, and after extrapolating a horse's yoke usage in orthopedics field, Professor Ilizarov built an orthopedic device out of a bunch of metal parts (rings, rods, wires), which he used for the first time to fix a fractured tibia. This first use of the device resulted in the healing of the bone, and over time, Professor Ilizarov discovered that the device he had originally invented for fixing fractured bones could also have the opposite effect of bone lengthening. After this discovery, Ilizarov concentrated on studying this property of the fixator and, in 1960, he developed a definition of *distraction osteogenesis*, the process by which bone tissue regenerates when subjected to continuous and controlled axial tension (Spiegelberg *et al*., 2010).

From a medical point of view, bone lengthening takes place in a series of clinical phases, with the possibility of adapting each phase according to the patient's health condition. Phase 1 involves the placement and fixation of metal rings around the extremities of the affected limb, followed by osteotomy surgery, in which the bone is completely severed halfway along its length to facilitate the transition to phase 2, bone lengthening. At this stage, the patient extends the spacer rods by 1 mm/day (0.25 mm/6 hours), during which time they undergo physical therapy to stimulate the muscles. In general, the lengthening stage lasts around 2-3 months, depending on the distance by which the bone is lengthened (max. 4-5 cm) and the treatment adapted to each patient. The third phase of the medical process of bone lengthening using the Ilizarov method involves strengthening the newly formed bone, during which the patient keeps the fixator on the affected limb for a period twice as long as the lengthening period (Spiegelberg *et al*., 2010). Most medical cases involve congenital malformations, where patients are born with one of their upper or lower limbs shorter than the other, or cosmetic cases, where patients choose to undergo such a procedure to increase their height.

From a technical point of view, the distraction osteogenesis method can be applied using versatile technical solutions, adapted to the patient's needs and

the case to be treated. Specialized clinics currently use fixators ranging from classic or axial-external fixators to fixators with multiple properties, such as Taylor Spatial Frame fixators, which correct the bone in three dimensions (Keshet and Eidelman, 2017). This current technical solution restores joint mobility (elbow, knee, wrist) and guides the bone in the correct direction of development, through a complex structure with six telescopic rods and the use of specialized software that generates a daily rod adjustment program.

With a view to developing a family of current technical solutions, the following sections of the paper refer to methodology used in idea diagrams and to a classification of Ilizarov fixators, used both for bone fixation and for bone lengthening.

3. Methodology Used to Obtain the Idea Diagrams of Ilizarov Fixators

The development of an idea diagram is achieved by following certain steps. Essentially, the effectiveness of an idea diagram depends on the extent of the bibliographic research, on the one hand, and, on the other hand, it is influenced by the extent to which those technical solutions, representative of each field and subfield of classification of the solutions, found in the specialized literature are selected.

When developing the idea diagrams in the field of Ilizarov fixators, the following steps were considered (Seghedin, 2008):

a. Defining the field of science and technology in which the concept map will be developed. At this stage, the title of the concept map is established. In this case, two idea diagrams were chosen, one for fixators classified according to their biomechanical functionality and one according to the anatomical area in which they are located;

b. Documentary information on technical solutions in the field, criteria and subcriteria for classifying these solutions. This stage, like any information stage, is particularly important because the richness of the information in the idea diagram depends on the depth of the documentary information. Thus, invention patents, scientific papers, doctoral theses, achievements of companies in the field, etc. were analyzed;

c. Establishing the criteria and subcriteria for classifying solutions in the field. Various classification options for fasteners were analyzed, and certain criteria and subcriteria for their classification were established. This method of classification provides the general structure of the idea diagram;

d. Establishing representative Ilizarov fixation solutions for each classification level or sublevel. The aim was for these solutions to be representative in terms of level of detail, quality of graphic representation etc.;

e. Drawing up idea diagrams;

f. Making any necessary corrections;

g. Establishing paths and directions for development in the field. The paths of development in the field were formulated as clearly and concisely as possible for each level of classification of solutions;

h. Formulating new creative themes. Creative themes were formulated with a view to obtaining new technical solutions to fill in the "gaps" and answer the questions raised in the idea diagram.

4. A General Clasification of Ilizarov Fixators

Following an analysis of specialist literature, it was found that Ilizarov fixators can be classified into two main categories:

a. Ilizarov fixators used for bone fixation:
   1. By number of rings:
      a) Monocircular;
      b) Bicircular;
      c) Multicircular.
   2. By type of fixation on the bone:
      a) With tension wires – Kirschner wires;
      b) With threaded metal rods;
      c) With rods and wires.
   3. According to the spatial position of the rings:
      a) Positioning in a single plane;
      b) Multiplanar positioning.
   4. By degree of rigidity:
      a) Semi-rigid fasteners;
      b) Rigid fasteners.
   5. By anatomical localization:
      a) Fixators for the lower limb;
      b) Fixators for the upper limb.

b. Ilizarov fixators used for limb lengthening:
   1. By type of elongation mechanism:
      a) Manual (mechanical);
      b) Automatic (digitally controlled electromechanical motors) Ortho-SUV, SmartFIX robotized;
      c) Hybrid – with force reducer or ratchet.
   2. According to the construction of structural elements:
      a) Simple axial – linear;
      b) Multiaxial – three-dimensional;
      c) Multiple segmentation – double osteotomy.
   3. After positioning the fasteners:
      a) Bicircular;
      b) Multicircular;
      c) Semicircular.

4. According to the anatomical location of the fitting:
   a) Fixators for the lower limb;
   b) Fixators for the upper limb.
5. By component material:
   a) Classic – stainless steel;
   b) Titanium or light alloys;
   c) Modern composites – carbon, reinforced polymers.

5. Drawing Idea Diagrams of Ilizarov System

Idea diagrams are part of the category of logical creation techniques and contain extensive information about the target field.

In accordance with the principles, terminology, and general theory of technical creation, an idea diagram is an open, tree-like, graphic representation containing structured information about the current state of science and technology in a field (Seghedin, 2008).

Mind maps can be approached both as intellectual work techniques and as creative techniques. As intellectual work techniques, mind maps are often used, not necessarily under this name, due to their ability to concentrate representative solutions from a given field into a single picture or chart. This allows for various ways of structuring information, various classifications, orderings, hierarchies, etc., which are necessary steps in carrying out intellectual work in a systematic manner. As creative techniques, idea diagrams are a way of stimulating creativity, due to their open nature, which allows new ways of developing the field of study to be identified (Seghedin, 2008).

Considering the steps achieved initially, two idea diagrams were defined:

1. Idea diagram according to fixators biomechanical functionality (Fig. 2);
2. Idea diagram according to anatomical area in which fixators are located (Fig. 3).

Based on the classification criteria identified in the specialized literature, other ways of classifying Ilizarov fixators were summarized, allowing for a general, comprehensive, and concise overview of the solutions currently available. The open and critical nature of the two diagrams can be seen here through the free question marks, which allow the weak points of the Ilizarov fixators field to be identified, leading to the scientific establishment of the next directions of research.

6. Conclusions and Establishment of the Main Directions for Future Development in the Field

By drawing the two idea diagrams, their effectiveness was confirmed in terms of how they can be used to visualize, in a concentrated manner, the current state of knowledge in a field. This visualization allowed for a critical, comparative analysis of all the solutions found in the specialized literature.

Furthermore, the open nature of the idea diagrams made it possible to identify those areas not covered by technical solutions, those areas corresponding to the question marks specific to idea diagrams.

Following a general analysis of the current state of the art in the field of Ilizarov fixators, as well as an analysis of the drawn idea diagrams and considering the knowledge fields not yet covered, in accordance with the question marks in the diagrams obtained, the following further directions for development emerged:

1. Generating solutions for fixators in which the ring displacement rods are actuated simultaneously;
2. Generating solutions in which the rods are actuated mechanically, using electric motors;
3. Generating fastener solutions in which the rings are moved automatically in correlation with the level of osteosynthesis.

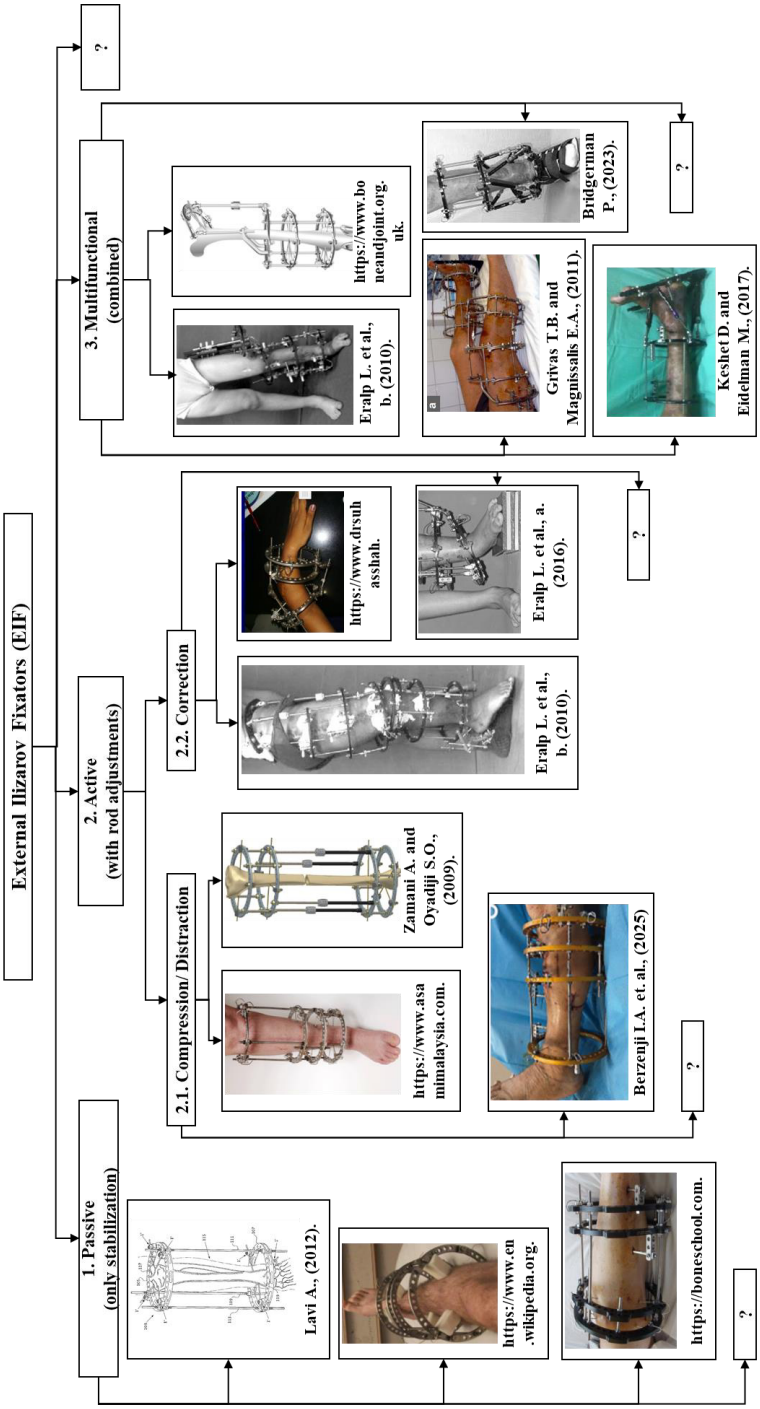


Fig. 2 – Idea diagram according to fixators biomechanical functionality.

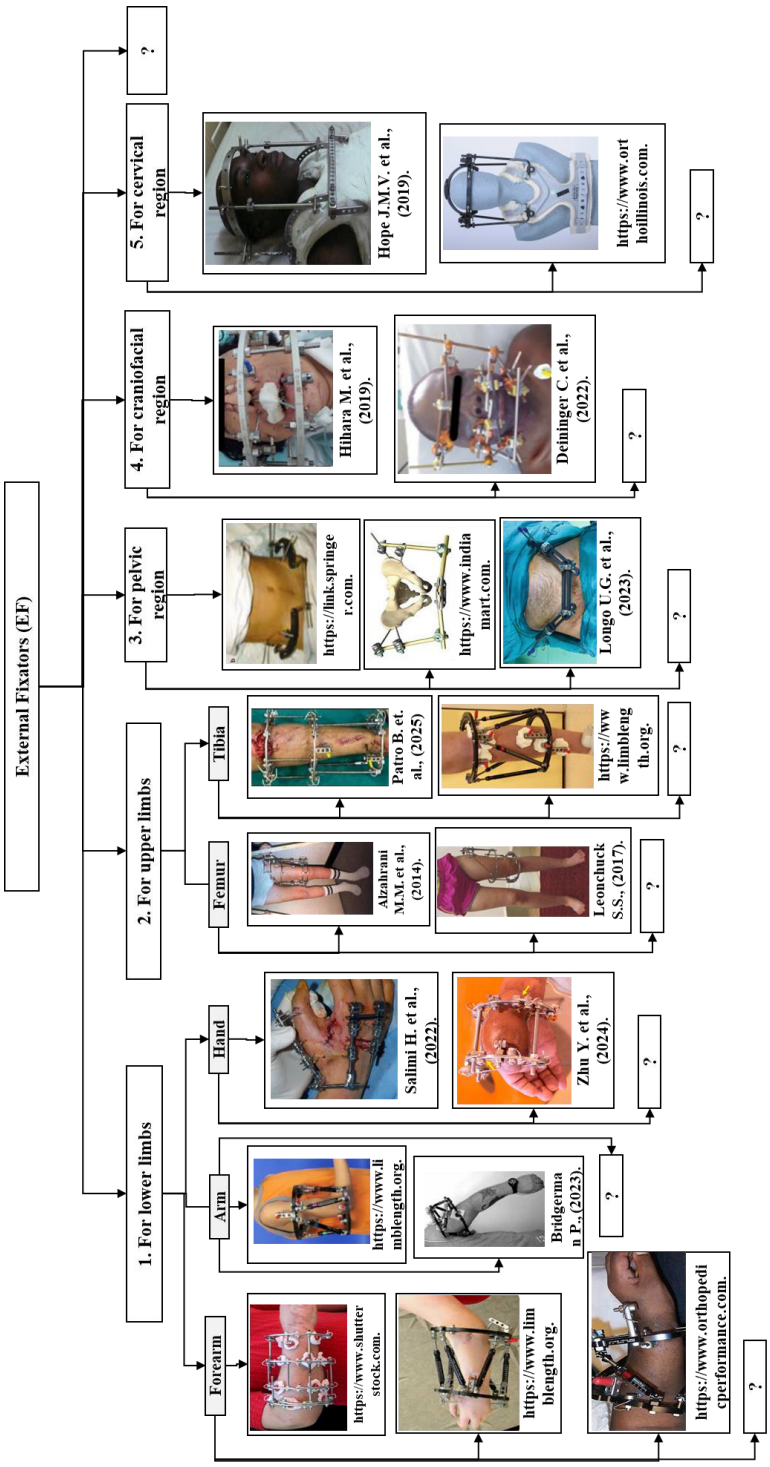


Fig. 3 – Idea diagram according to anatomical area in which fixators are located.

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DIAGRAME DE IDEI ÎN DOMENIUL FIXATOARELOR ILIZAROV

(Rezumat)

În lucrare se propune prezentarea stadiului actual al cercetărilor științifice în domeniul fixatoarelor Ilizarov. Abordarea nu are un caracter exhaustiv, miza lucrării fiind aceea de a se trasa coordonatele generale care pot sta la baza structurării informațiilor din literatura de specialitate în acest domeniu. Pentru a se realiza o prezentare științifică a stadiului actual al cercetărilor, s-a apelat la o metodă de creație tehnică de tip logico-combinatoric, metoda diagramelor de idei. În acest fel, se poate vizualiza, într-un singur tablou, care este varietatea de soluții tehnice realizate până la momentul prezent. De asemenea, metoda are avantajul că informațiile sunt clasificate pe domenii și subdomenii, ceea ce permite o sistematizare și o codificare a informațiilor. În lucrare se prezintă două diagrame de idei, în care soluțiile tehnice sunt clasificate după funcționalitatea mecanică și după zona anatomică în care sunt amplasate pe membrele pacientului. Avându-se în vedere caracterul deschis (dat de semnele de intrebare), critic al metodei, în finalul lucrării s-au putut defini viitoarele căi de dezvoltare în domeniu.