HISTORICAL ASPECTS OF TRANSPEDICULAR FIXATION OF THE SPINE: LITERATURE REVIEW

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The main historical aspects of the evolution of transpedicular fixation of the spine were analyzed according to the literature. The main historical stages in the development of transpedicular fixation of the spine were identified: vertebral screw fixation (King, 1944), pedicle screw plate system (Roy-Camille, 1970), external transpedicular fixation — Fixateur Externe (Magerl, 1977), internal transpedicular fixation — Fixateur Interne (Dick, 1982), transpedicular titanium implants (1987). They played a significant role in the formation of modern surgical technologies for posterior metallic osteosynthesis and the creation of multifunctional transpedicular fixation devices, which are now considered to be the gold standard of posterior fixation for various pathologies of the thoracic, lumbar and lumbosacral spine.

Key Words: transpedicular fixation of the spine, stages of development.

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Towards the end of the XX century, transpedicular fixation (TPF) as a method of posterior spinal fusion has become not only the most common, but also the most reliable method of metallic osteosynthesis in unstable and complicated injuries, as well as in various pathologies of the thoracic and lumbar spine.

The name of the method for fixation of the spine «transpedicular fixation» (from latin *fixus trans pediculus*, fixation through a pedicle of vertebral arch) has first appeared in foreign literature in the late 1970s in a paper by Hermann [1]. It should be noted that there are other names as well: interpeduncular fixation, intrapeduncular screw fixacion, pedicle screw fixacion, pedicular fixacion, intra-body spinal fixation, transpedicular osteosynthesis, pediculocorporal spinal fusion, etc. [2–6]. However, the term "TPF" has the highest citation index.

TPF of the spine has over half a century of history. During this entire period, the main task of scientists has been to look for various techniques of posterior spinal fusion to strengthen the spine and improve the results of surgical treatment.

Historically, there are several stages which defined the development of TPF of the spine, modern surgical techniques of dorsal metallic osteosynthesis and the use of multifunctional transpedicular devices:

1) vertebral screw fixation [7];
2) pedicle screw-plate system [8];
3) external fixation [9];
4) internal fixation [10];
5) implants made from titanium alloy.

The history of TPF originates from the vertebral screw transarticular fixation of the spine. In 1944, Donald King (USA; Fig. 1) published his own results [7] of internal osteosynthesis of the lumbosacral spine for spondyloarthrosis (Fig. 2).

King proposed using short metal screws with a length of 3/4 to 1 inch, which were passed through the articular processes parallel to the lower edge of the vertebral arch (Fig. 3). Patients were prescribed bed rest for three weeks after the surgery.

Later, Canadian orthopedist Harold Boucher (Fig. 4) attempted to improve the fixation of the lumbosacral spine and thereby provide for faster activation of patients after the surgery.

In 1959, he described an improved technique for posterior spinal fusion of the lumbosacral spine [11], where he used longer (up to two inches long) steel screws that were passed through zygapophysial joints but now through the roots of the arches into the vertebral bodies (Fig. 5).

Although these methods of screw fixation had rather narrow spectrum of indication and did not achieve widespread use in spine surgery, they are the ones that provided the first significant impetus to further development of TPF of the spine.

The internal pedicle screw fixation, developed by the French orthopedist Raymond Roy-Camille in the early 1960s, has been recognized as the crucial stage in the development of one of the modern areas of TPF using plates (Fig. 6).

Roy-Camille proposed special modeled plates with holes spaced 1.3 cm from each other, which allowed installation of screws with a diameter of 4.5 mm into the pedicles (Fig. 7); in 1963 he used this technique for the first surgery for severe fracture-dislocation of the spine. In 1970 he published the results and description of the plate implants together with Demeulenaere [8].

Later, on the basis of studies [12], he not only described the anatomical landmarks for insertion of screws in the thoracic and lumbar spine, developed the indications and the main stages of TFP surgical technique for spinal injuries and diseases, but also improved his own plates by using collar reinforced holes (so-called Pedicle Screw Plates (PSP); Fig. 8).

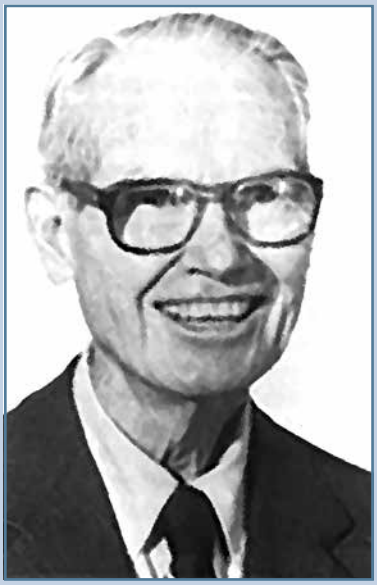


Fig. 1
Donald King

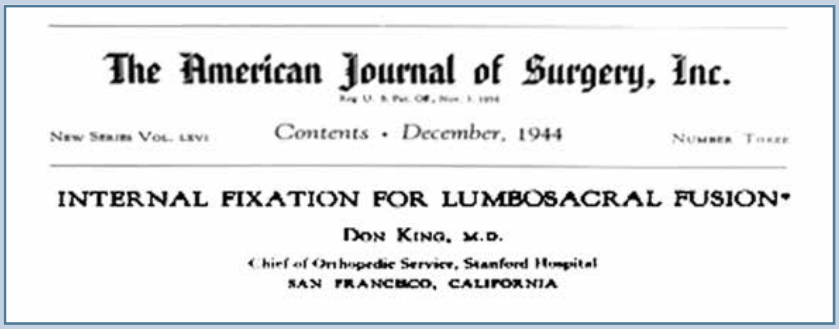
The initial period also includes the first descriptions of the use of pedicle screws for orthopedic spinal pathology. For example, in 1967 american surgeons Harrington and Tullos [13] used pedicle screws in vertebral reduction (Fig. 9).

In 1969, they published the results of surgical treatment of two children with severe progressive lumbosacral spondylolisthesis with a description of the technique of the displaced vertebra reduction using pedicle screws wired to the Harrington distraction rods mounted in a special A-frame (Fig. 10).

Starting from 1970, while developing the biomechanical concept of the external TPF, Schlapfer and Magerl (Fig. 11) from Switzerland created a system for the lower thoracic and lumbar spine [9]. The device, called "fixatuer externe", uses at least two pairs of long (5 mm) Schanz screws, which are inserted percutaneously or openly through the pedicles into the vertebral bodies above and below the level of the lesion. The screws are then fixed in an external adjustable device of Hofmann type, which consists of a pair of plates and three threaded rods with attachment points. The system provides for a dosed multiplane correction with sufficiently strong stabilization of the affected segment (Fig. 12).

Even though the external TPF technique has certain advantages, it did not achieve widespread use in vertebral surgery due to relatively narrow spectrum of indications and significant additional problems associated with potential risk of specific complications and patient curation (Fig. 13).

In early 1980s, Walter Dick successfully implemented (Fig. 14) Magerl's idea and the biomechanical principles of the external TPF as his group developed an implanted rod transpedicular device, called fixatuer interne (Fig. 15, 16). The fixator, made of medical steel, had long Schanz screws with a diameter of 5 mm, which were fixed to 7-mm threaded rods with the help of special mobile clamps. After installation, the protruding dorsal parts of the Schantz screws were removed by biting. The device provided for intraoperative multiplanar repositioning and correction of the deformity, followed by fixation of the affected spine department.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INTERNAL FIXATION FOR LUMBOSACRAL FUSION*

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Fig. 2
Frontpage of American Journal Surgery magazine, which published the first paper by King [7] on screw fixation of the spine

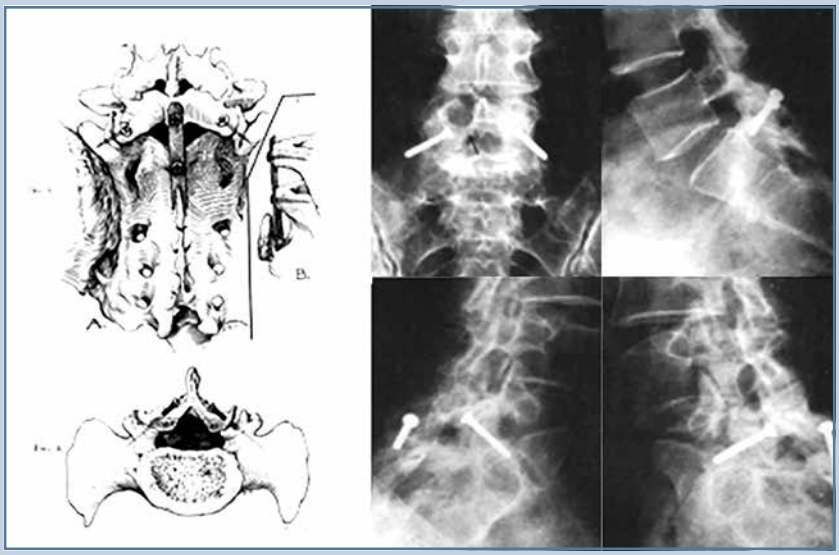

Fig. 3
A sketch of screw transarticular fixation according to King and radiographs of the lumbosacral spine after the surgery [7]

Fig. 4
Harold Boucher

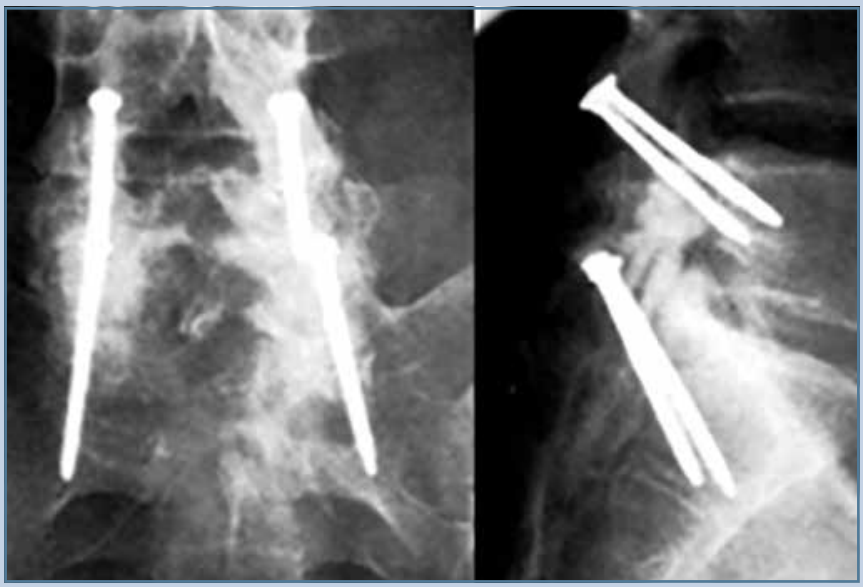

Fig. 5
The Boucher technique of transpedicular screw fixation [11]

Fig. 6
Raymond Roy-Camille

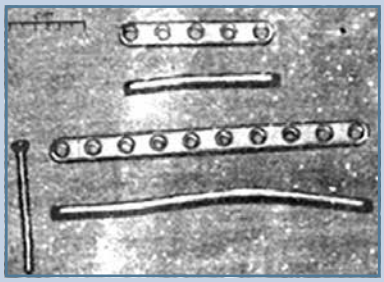

Fig. 7
First generation Roy-Camille plates [8]

In 1982, Dick (Fig. 17) became the first to use the internal rod TPF in clinical practice at the university orthopedic clinic in Basel (Switzerland). He published the results of testing this technology not only for injuries, but also for various orthopedic pathologies of the spine in 1985 [10, 14]. It is this historical stage that became fundamental in the further development of modern internal structures. Mathys Medical (Switzerland) has mastered the industrial production of this type of fixator under the name "AO" (Synthes).

In 1982, independently of the Swiss AO-group, Paul Kluger (Germany) created and patented its own internal transpedicular system made of medical steel (Fig. 18). Even though this fixator was distinct not only in using telescopic rods,

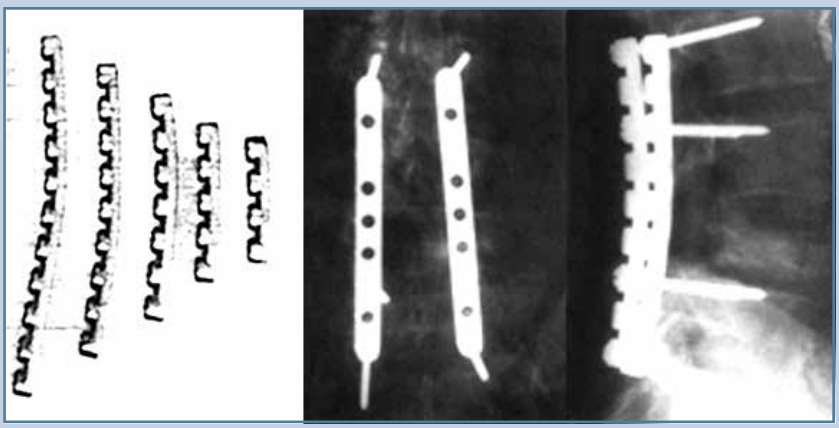

Fig. 8
Modified Roy-Camille plates with collar reinforced holes [12]

Fig. 9
Paul Harrington

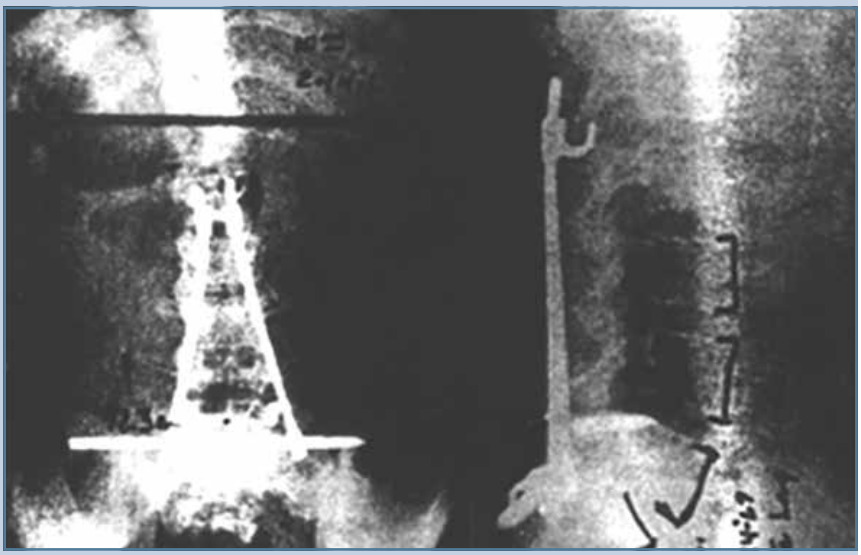

Fig. 10
Radiography of the spine, demonstrating Harrington and Tullos technique [13]

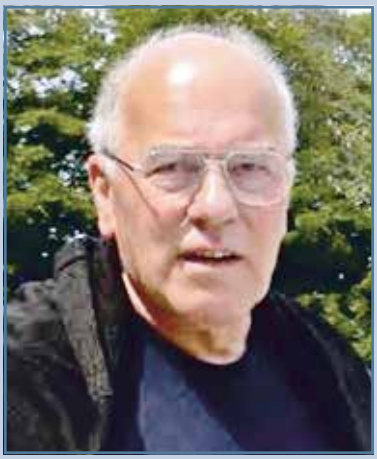

Fig. 11
Friedrich Magerl

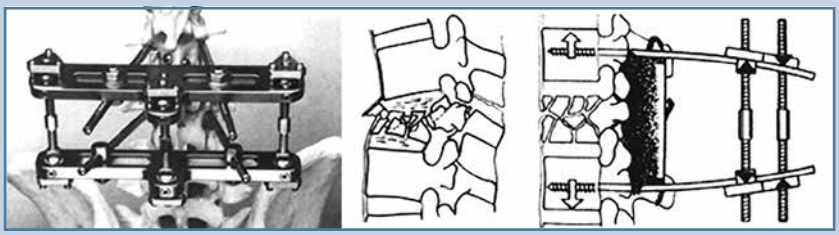

Fig. 12
Magerl external transpedicular fixator [9] and a sketch of its application for comminuted fracture [37]

but also in a significant number of additional installation tools, the results of its use were encouraging, especially in case of severe spinal injuries [15]. Endotec (Germany) and Tornier (France) have launched industrial production of this fixator.

Almost simultaneously, in Switzerland, Jacob and Waldis [16] developed a device with a threaded rod, which was called "The Balgrist Fixator". This system was introduced in the Department of Orthopedic Surgery at the University of Balgrist (Zurich) in 1983 in the form of the so-called Mark-I modification. However, the results of its clinical use showed the need to improve its design, and, despite the creation of a new modification, the Mark-II, it has not been developed further (Fig. 19).

Simultaneously, US specialists have been developing TPF system with screws and plates. In 1982, Artur Steffee (Fig. 20) was one of the first to develop and in 1984 to introduce the Variable Screw Placement (VSP) plate-based spinal fixation system [4].

This improved implant differed from the Roy-Camille plates by tighter fastening of screws with special nuts, as well as easier installation due to the possibility of a screw displacement along the plate in the semi-oval slots (Fig. 21).

Sometime later, Edward Luque from Mexico has first tried to re-implement the earlier Harrington idea of connecting rods and pedicle screws. However, the wire fixation of screws to Luque rods did not produce the expected results due to insufficient connection strength.

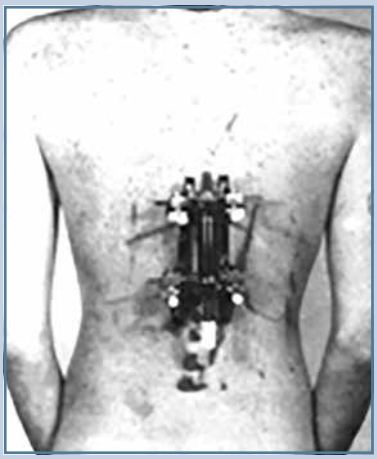

Fig. 13
Exterior view of the patient with external transpedicular fixator of the spine [38]

Fig. 14
Walter T. Dick

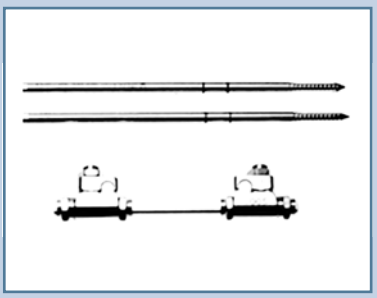

Fig. 15
General view of fixateur interne [10]

However, starting from 1985, Luque [2] began to use plate fixators, called the "Danek Plate Screw System", with innovative cannulated transpedicular screws (Fig. 22). It should be noted that in terms of its strength and resistance to dynamic loads this modification has been significantly inferior to Steffee's device due to the re-use of the weakest structural link of the Roy-Camille's plate.

In 1984 Leon Wiltse from the USA developed a fundamentally new implant for the lumbar spine based on modeled corrugated rods [5]. The original design consists of one or two rods with a diameter of 4.4 mm and blocking clamps for pedicle screws with a diameter of 5–7.5 mm (Fig. 23). The results of surgeries performed in May 1985 demonstrated the functional advantages of the created pedicle fixator, thanks to possibility to perform intraoperative modeling of the rods and achieve multisegmental multilevel stabilization of the lumbar and lumbosacral spine. It should be noted that the idea of combining corrugated modeled rods and clamp-type connections of pedicle screws not only significantly expanded the capabilities of TPF but also was successfully used in the development of multifunctional rod structures by other implant manufacturers.

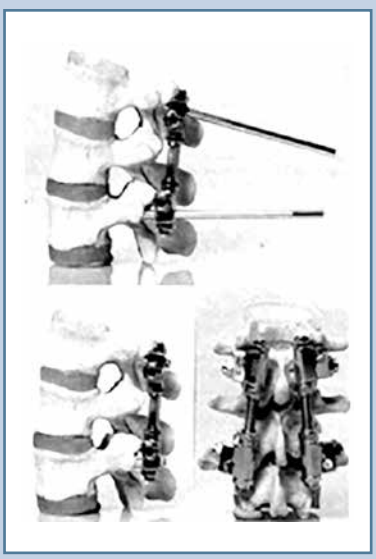

Fig. 16
Fixatuer interne installed on a vertebral block [10]

Based on the analysis of Roy-Camille and Magerl concept, as well as on his own morphometric and biomechanical research [17, 18] Martin H. Krag from Vermont Medical University not only proposed new approaches to TPF surgical technique, but also developed a clamp transpedicular fixator on rigid smooth rods, which was called «Vermont Spinal Fixator» and used in the clinic since 1986 (Fig. 24).

At the same time, in 1986, Jurgen Harms (Germany) developed [19] the dorsal segmental modular spinal system on threaded rods - MOSS System (Fig. 25) based on the biomechanical concept of polysegmental ventral fixation of the vertebral bodies with USIS (Universal Segmental Spinal Instrumentacion, Zielke, 1974).

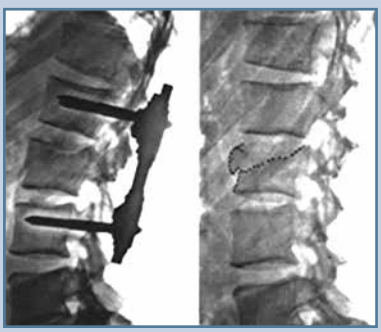

Fig. 17
Spine radiographs with fixatuer interne [14]

Fig. 18
General view of the Kluger telescopic rod fixator [15]

Fig. 19
Radiographs of the lumbar spine with an installed Balgrist "Mark-I" rod transpedicular fixator and general view of the Mark-II modification [16]

Fig. 20
Artur Steffee

The first generations of implants for TPF, called Puno-Winter-Byrd (PWB) System, had been created under the leadership of Puno from the University of Louisville (Kentucky, USA) and have been used since March 1988 [20]. Modernization of these devices led to the creation of an original unit for fixing transpedicular screws, which became the prototype of modern polyaxial screw systems (Fig. 26).

A new stage in the development of TPF from titanium alloys began in the late 1980s. "Stryker" (USA) created Diapason rod system made of titanium alloy in 1987 and introduced it into clinical practice in October 1988. The features of the implant are in the original technical solution for connecting the tapered shank screw with a smooth modeled rod by means of a special stopcock (Fig. 27). In 1990 the implant was supplemented with a washer to prevent excessive stress in the structure and to increase the degree of freedom at the screw-rod junction. It is this technical solution of screw and rod connection that has become the most promising in the development of modern modifications of TPF.

Along with the development and improvement of TPF, the researchers continued to develop combined dorsal systems with elements of intraossal (screw) and paraossal fixation using different hooks attached to arches and pedicles, transverse and spinous processes and taking into account the anatomical and morphological features of the upper and mid-thoracic spine in combination with non-standard biomechanical situations.

In early 1980s Charles Edwards (USA) developed a modular spinal system «The Edwards Modular System» with various variants of screws and hooks [21]. The proposed features of the implant included the use of universal rods bearing the main load, and new technical solutions for fastening both the hooks themselves and the hooks with pedicle screws (Fig. 28).

However, combined Edwards systems have retained the common shortcomings of earlier designs: relatively low mobility and strength of fixation of the main load-bearing nodes. At present they

Fig. 21
Plate-based Steffee transpedicular fixator (from AcroMed (USA) leaflet)

Fig. 22
Danek Plate Screw System with cannulated transpedicular screws developed by Luque [2]

can be viewed to a greater extent only in a historical context, however similar combined systems developed by French orthopedists Yves Cotrel and Jean Dubousset (Fig. 29) in the early 1980s , and first presented in 1985 in Switzerland, became a special event in the development of dorsal metallic osteosynthesis [22].

Subsequently, a CD instrumentation has been developed, which includes transpedicular systems Compact CD Low Back, Tenor, and TSRH, previously produced by Sofamor Danec (Fig. 30), and then by Medtronic Sofamor Danec (USA).

It should be noted that along with rigid transpedicular systems that ensure the formation of a bone or osteofibrous block at the level of stabilization, a new direction has appeared in TPF in the late 1980s: dynamic systems.

Henri Graf from SaintMaurice clinic in Lyon (France) proposed an alternative concept of dynamic intervertebral stabilization (flexible intervertebral stabilisacion) and developed special transpedicular titanium screws that are connected using flexible polyester band to limit flexion loads (Fig. 31). In 1992, Graf presented encouraging results from the clinical use of the Global Stabilizacion System in patients with degenerative lumbar disc lesions [23].

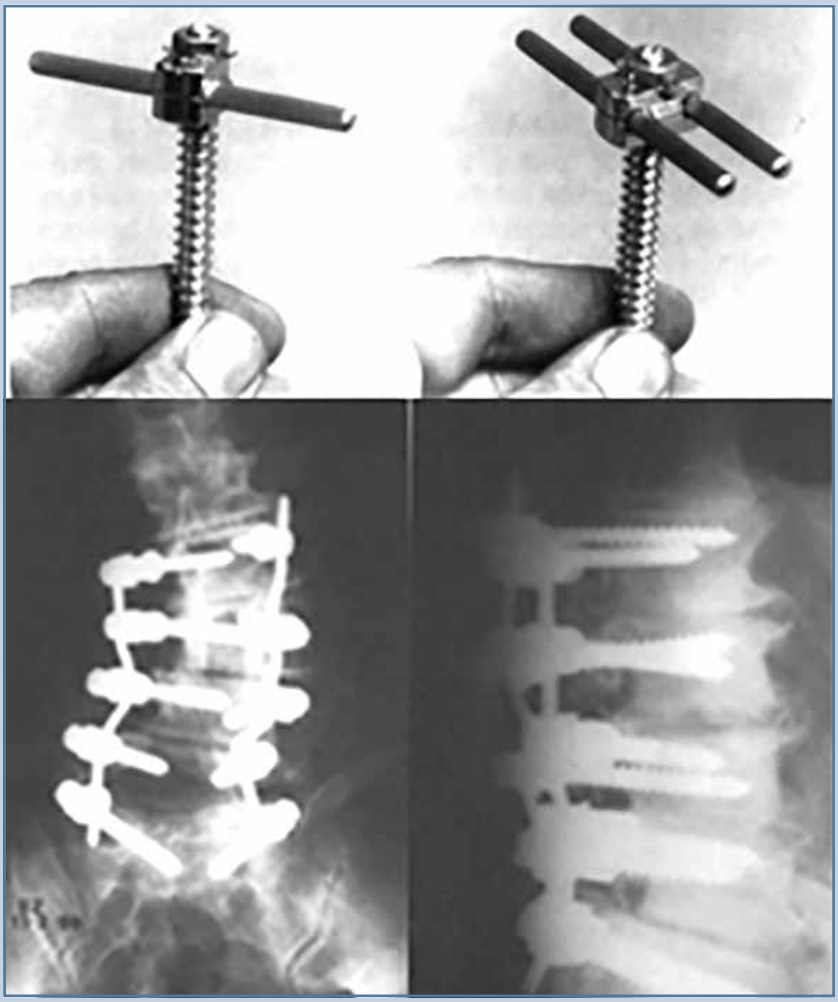

Fig. 23
Modeled single- and two-rod transpedicular fixation system developed by Wilse and spondylograms of a patient after surgery [5]

The rather rapid formation of the main areas of the TPF and their widespread introduction into clinical practice abroad served as a pretext for close attention of the leading Soviet clinics to the new technologies of posterior metallic osteosynthesis of the spine.

In the USSR and the CIS countries, internal and external TPF developed in three directions [24–27]:

1) the use of foreign analogues of Roy-Camille plates, AO metal plates;

2) the development of domestic transpendicular fixation systems and their introduction into clinical practice;

3) the use of original foreign transpedicular implants.

According to the available data, the first attempts at using the simplest plate designs of Roy-Camille type in spinal injuries were conducted in 1985–1986 in clinics of traumatology and orthopedics under the guidance of A.A. Korzha and G.S. Yumashev [28, 33].

In the late 1980s, an internal transpedicular spinal fixator on the threaded rods [29] had been developed in the Republican Center for Spinal Injury of the Belarusian Institute of Traumatology and Orthopedics (NIITO) and in 1988 the first surgery was performed using a titanium implant. In the period of 1993–1997, 110 patients with spinal injuries, deformities and tumors had been operated on in BelNIITO in cooperation with the Belarusian company Medbiotech using transpedicular rod fixators made of titanium alloy [30].

Latvian NIITO has been using AO metal plates for TPF in complicated spinal fractures since 1989 and the first results of treatment of 19 patients were published in 1991. In the same year, doctors from Kharkov and Kazan presented the experience of TPF with plates of Roy-Camille type for severe spinal injuries. A.G. Aganesov (Moscow) published the results of spinal stabilization in 15 patients using Roy-Camille method after resection of the vertebral bodies to restore a spinal cord defect.

Professor S.T. Vetrile (Moscow) was one of the first to use Steffee's internal

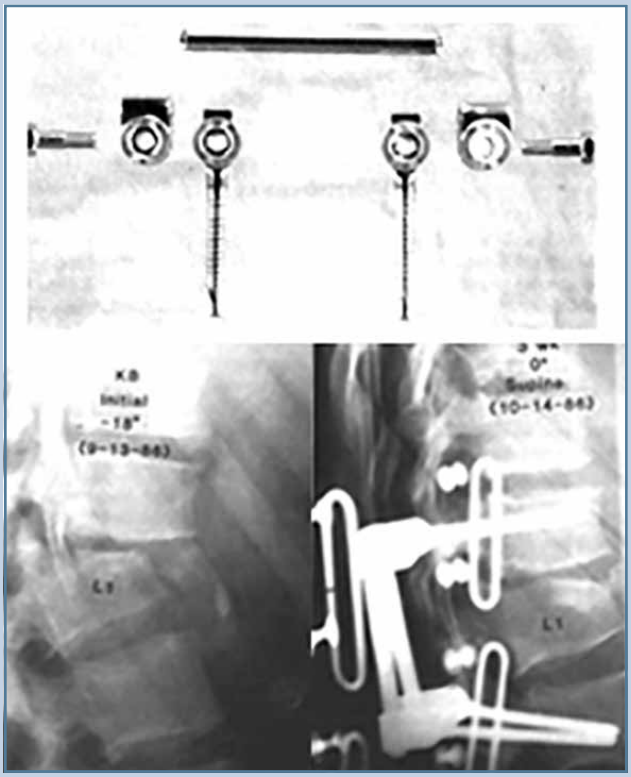

Fig. 24
Vermont Spinal Fixator, developed by Krag [18]

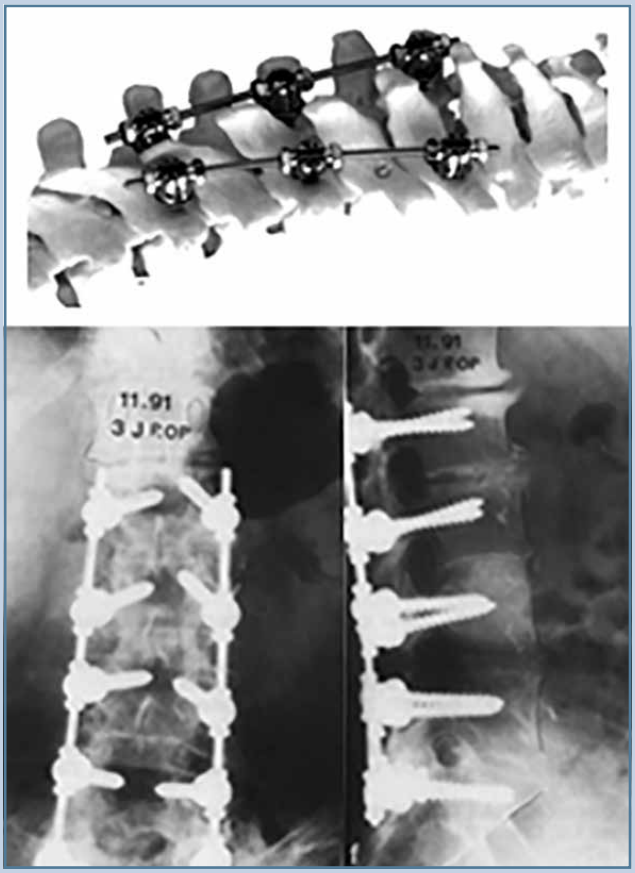

Fig. 25
Modular segmental spinal system developed by Harms [19]

transpedicular system for various types of surgical procedures on the thoracic and lumbar spine [25].

We should also mention one of the few patent-protected domestic transpedicular implants developed in 1995 by V.D. Usikov [6]. The first results of using a titanium smooth-rod fixator, called a device for pediculocorporeal spinal osteosynthesis, were published in 1995.

In early 1990s a new direction of external TPF has been formed in Russia and Ukraine. In 1986, a method of external TPF with new rod systems was used in the Department of Pathology of the Spine of the Kharkov NIITO.

This approach is also being developed in the RSC «Restorative Traumatology and Orthopedics n. a. G.A. Ilizarov" (Kurgan), Kazan and Ural NIITO [31, 32]. Original devices for external TPF created in these centers provide for gradual (staged) correction of traumatic, posttraumatic and other deformities of the thoracic and lumbar spine in one- and two-stage surgical interventions.

Modern surgical technique of internal TPF of the spine in case of spinal injuries and pathologies has become available in many regions of Russia and the CIS countries since mid-1990s using both foreign and domestic transpedicular implants [33–36].

The study has no sponsorships. The authors declare no conflict of interest.

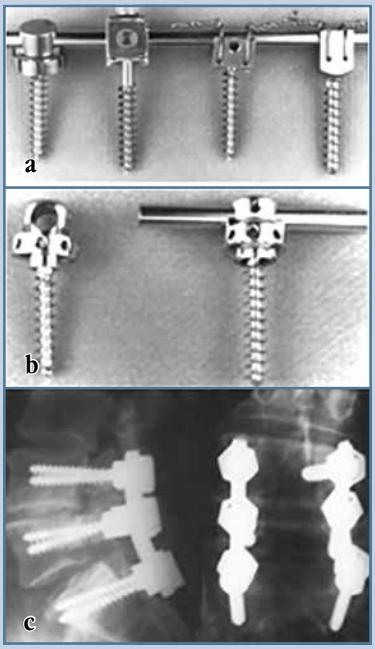

Fig. 26
General view of the first generations of the Puno-Winter-Byrd rod transpedicular systems **(a)** and the last modification with a polyaxial screw **(b, c)** [20]

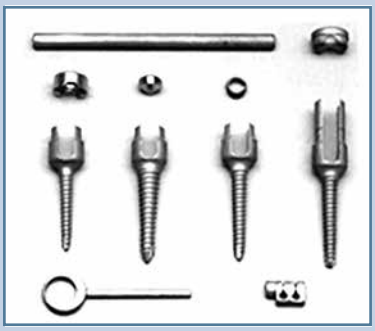

Fig. 27
Transpedicular implants Diapason (from Stryker (USA) leaflets)

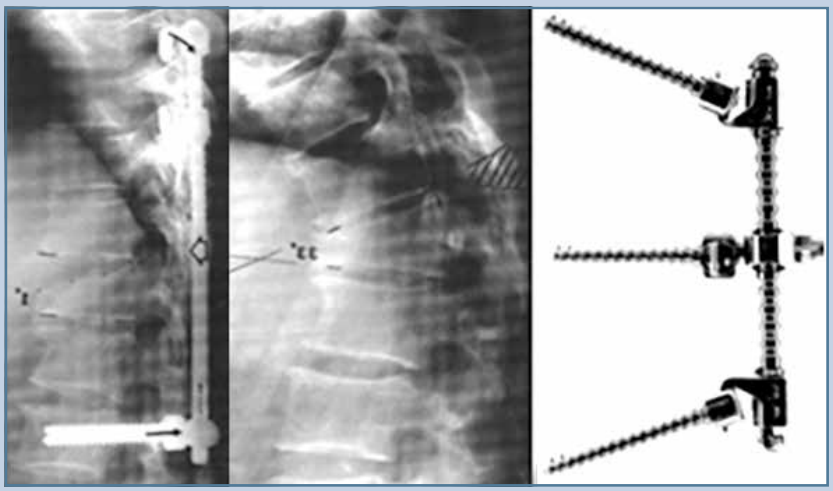

Fig. 28
The Edwards rod fixator [21]

Fig. 29
French orthopedists Yves Cotrel and Jean Dubousset, creators of CD instrumentation and technique for correcting scoliotic spinal deformities

Fig. 30
The Tenor transpedicular fixation system (from Sofamor Danek (USA) leaflets)

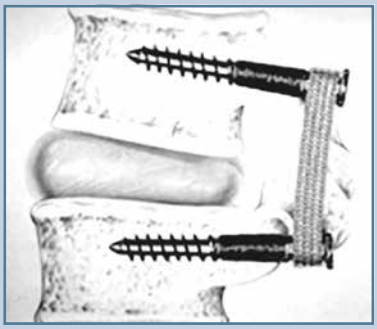

Fig. 31
The Graf dynamic stabilization system [23]

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