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Review article

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Current approaches to treatment of patients with closed fractures of the patella

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Abstract

Introduction Treatment of patients with acute fractures of the patella is the task of the trauma and orthopedic service and should provide restoration of the integrity of the bone tissue and the extensor apparatus of the knee joint for its early mobilization. There is an opinion that conservative treatment cannot meet requirements of patients' quality of life, and therefore, most traumatologists are inclined to surgically treat patellar fractures. **Purpose** Based on the available literature data, to determine the most rational way to treat patients with patellar fractures **Materials and methods** Available studies published in the last 10 years were analyzed. The databases NCBI Pubmed, Healio Orthopedics, Medline were searched. **Results** Such osteosynthesis methods as patella suture, osteosynthesis with plates, special internal devices, external fixation devices, Kirschner wires and wire cerclage, various screws were covered. The question of clinical application of patellectomy was touched upon; the contribution of the Department of Traumatology, Orthopedics and Urgent Surgery of the Krasnov Samara State Medical University to the development of operative techniques of osteosynthesis of the patella, the basic concepts of scientific research, and also the most optimal ways of treating patients with patellar fractures were described. **Conclusion** The conservative method of treating patients with patellar fractures is most relevant if there are contraindications to surgery. It inevitably leads to persistent arthrogenic contracture. The best functional results of treatment have been achieved with surgical treatment due to the possibility of early mobilization of the knee joint. According to the data of available studies, plates and screws as well as osteosynthesis with Kirschner wires and wiring cerclage show maximum stability. There is evidence of a direct correlation between the risk of developing infectious complications and pain in the postoperative period and the number of elements of subcutaneous metal implants. Thus, the most optimal way to treat closed fractures of the patella is osteosynthesis with the use of wires and wire cerclage according to the tension band principle.

Keywords: patella, osteosynthesis, patella fracture, tension band wire, outcomes

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INTRODUCTION

Treatment of patients with acute patellar fractures is the sole task of the trauma and orthopedic service. It should provide restoration of the integrity of the patella bone tissue and of the extensor apparatus of the knee joint. A prerequisite for treatment is the restoration of the congruence of the articular surface of the patella, as well as the creation of conditions for early mobilization of the knee joint by achieving absolute stability of bone fragments [1–4]. The current science of traumatology and orthopedics should solve the listed tasks as fully as possible.

Purpose Based on the available literature data, to determine the most rational way to treat patients with patellar fracture.

MATERIAL AND METHODS

We analyzed the data of scientific studies on various approaches to the treatment of patients with patellar fractures with an emphasis on the analysis of various methods of osteosynthesis. Scientific articles and guidelines were searched for in the scientific databases NCBI Pubmed, Healio Orthopedics, Medline, published in the period from 2010 to 2019. The search was carried out using the keywords "fracture of patella", "patellar fracture", "patella", "treatment of fractures of patella", "osteosynthesis of the fracture of patella", "suture of patella". The criteria for including the studies into the review were the presence of a description of specific methods and methods of treating patients with patellar fractures, the experimental or clinical relevance of the described techniques or methods, and the publication time. Thus, 55 publications were selected for analysis.

RESULTS AND DISCUSSION

According to the analyzed literature, the treatment of patients with patellar fractures distinguishes two fundamentally different approaches, conservative and surgical [5]. There is an opinion that conservative treatment is applicable in the absence of displacement of patella fragments or if the diastasis between fragments is no more than 3-4 mm [1, 2, 3, 6, 7]. In addition, for deciding on the possibility of conservative treatment of a patient with a patellar fracture, it is recommended to perform a knee flexion test up to 60º. If there are no signs of displacement of fragments in flexion to the specified angle under the control of an image intensifier, then a conservative approach with the possibility of gradual early mobilization of the injured knee joint in a dynamic functional brace is acceptable [5]. However, this approach condemns the patient to lower limb

immobilization in a high plaster cast for up to 4–6 weeks, followed by a long period of rehabilitation. Under such conditions, the development of contracture of the knee joint, arthrofibrosis, atrophy of the quadriceps femoris muscle is inevitable thus creating the conditions for rapid progression of post-traumatic osteoarthritis of the knee joint [1]. Obviously, the effect of conservative treatment cannot meet the patients' quality of life requirements. Considering the facts described, the overwhelming majority of orthopedic traumatologists are inclined towards surgical treatment of patellar fractures in the absence of contraindications to it.

A summary of the advantages and disadvantages of conservative treatment of patients with closed patellar fractures is shown in Table 1.

At present, all methods of osteosynthesis may be conditionally divided into three groups:

1) Osteosynthesis with plates and screws, as well as with special implants;

2) Extra-focal osteosynthesis with AEF;

3) Intraosseous osteosynthesis with wires, screws, wire cerclage [1, 5, 8].

Osteosynthesis of the patella with various types of plates has become widely used relatively recently. The most detailed description of osteosynthesis with plates and screws was done by Florian Gebhard, Phil Kregor, Chris Oliver [9]. After open reduction of the fragments and their fixation with a bone holder or Kirschner wires, the plates are modeled so that there are at least two fixation points on each fragment. The clinical experience of Taylor et al. shows satisfactory results in the treatment of patients with patellar fractures using a combination of plates and interfragmental screw fixation [8, 10, 11]. With proper preoperative planning and manual skills of the surgeon, plating is a fairly good way of osteosynthesis of multi-fragmented patellar fractures and achieves absolute stability of the fragments.

Osteosynthesis of the patella with plates provides stable fixation of bone fragments, and allows active movements in the knee joint in the early postoperative period. There are experimental and clinical data demonstrating that the osteosynthesis of the patella using a locked plate has greater load resistance by 33 % and provides 5 times less displacement of fragments than intraosseous osteosynthesis with a tension band technique [12–15].

However, plating in patellar fractures is quite a complicated type of osteosynthesis and requires a sufficient level of manual skills from the operator. In addition, osteosynthesis with special plates is an expensive method of treatment and restricts its wide application in clinical practice. There are also other disadvantages, such as a high risk of purulent and septic complications due to the subcutaneous location of the implant, significant trauma to the peripatellar soft tissues [16].

Volgas et al. described their clinical experience of using titanium mesh interlocking plates for osteosynthesis of patellar fractures. There were good clinical and functional results in the long term and one case of complications, a breakage of lockable screws with a fracture of the distal pole of the patella, which required repeated surgery [17]. Similar clinical data were provided by Moore TB, Sampathi BR et al. in a retrospective analysis of the results of surgical treatment of patients with patellar fractures using locking plates [18].

Table 1

Conservative treatment of closed fracture of the patella

Authors, year, reference list number	Description of patient's fracture	Method of conservative treatment of patients with patellar fracture	Merits	Shortcomings
Schuett D. J. et al., 2015 [1]	There is no displacement of the patella, diastasis between fragments is not more than 3-4 mm	Immobilizing splint	Simple method, patient's ability to move independently and undergo outpatient treatment	Development of KJ contracture, arthrofibrosis, atrophy of the quadriceps femoris muscle and conditions for rapid progression of post-traumatic KJ osteoarthritis
Kakazu R., Archdeacon M.T., 2016 [2]	Diastasis between fragments is not more than 2-4 mm	Immobilizing brace	Simple method, patient's ability to move independently and undergo outpatient treatment	Development of KJ contracture, arthrofibrosis, atrophy of the quadriceps femoris muscle and conditions for rapid progression of post-traumatic KJ osteoarthritis, possible nonunion, pseudarthrosis
Scolaro J., Bernstein J., Ahn J., 2010 [3]	Diastasis between fragments is not more than 2-4 mm, preserved integrity of the KJ extension apparatus	Immobilizing brace	Simple method, patient's ability to move independently and undergo outpatient treatment	Development of KJ contracture, arthrofibrosis, atrophy of the quadriceps femoris muscle and conditions for rapid progression of post-traumatic KJ osteoarthritis, possible nonunion, pseudarthrosis
Crist B.D., Borrelli J., Harvey E.J., 2020 [4]	Diastasis between fragments is not more than 2-4 mm	Immobilizing brace	Simple method, patient's ability to move independently and undergo outpatient treatment	Inevitable development of KJ contracture, arthrofibrosis, atrophy of the quadriceps femoris muscle and conditions for rapid progression of post-traumatic KJ osteoarthritis, possible nonunion, pseudarthrosis
Clemens Gwinner et al., 2016. [5]	Fragment stability after flexion test	Functional dynamic brace	Early mobilization of the knee joint, simple method, none of surgical invasiveness	The method is only suitable for fractures that do not involve articular cartilage. The risk of developing KJ contracture, arthrofibrosis remains
Gould, Fraser, 2017 [6]	Transverse fracture of the patella, diastasis between bone fragments up to 2 mm	Plaster cast	Easy patient's care, no risk of septic complications due to the absence of surgical invasion	Displacement of fragments of more than 2-4 mm is exluded, prolonged immobilization of the knee joint and the risk of contractures, an increase in the patient's disability period
Tiscareño-Lozano F.J. et al., 2018 [27]	Patellar fracture	Knee cast	The safest method in terms of septic complications	There are risks of developing arthrofibrosis, infectious complications, displacement of fragments in the postoperative period

The advantage of this osteosynthesis method is the ability to simulate the plate curvature to match the profile of the anterior surface of patient's patella and adjust the dimensions of the plate. It provides a customized approach in each case. However, the disadvantages of the described method do not differ from the disadvantages described for other methods of plating.

Quan-Ming Zhao et al. present clinical data on the use of a nickel titanium fixator for patellar osteosynthesis in comparison with titanium wire cerclage applied O- and 8-shaped, taking into account the principle of tension band. The fixator consists of two-base parts with claw-like clamps of fragments of the patella and an element connecting the bases, made of a material with shape memory that reacts to heating [19].

Fucun Liu et al. proposed an implant for osteosynthesis in the form of a ring with hook-shaped fixators located radially around the circumference, and presented the clinical results of its application. The authors achieved mostly good and satisfactory treatment results, noting that less than 20 % of patients in the long-term postoperative period were dissatisfied with the functional results of treatment [20].

The use of the implants described above has such advantages as surgical intervention time reduction and, thereby, decreased risks of purulent septic complications, sufficient stability of the fragments in each specific clinical case. However, this method is characterized by the risk of complications typical for all described methods of plate osteosynthesis. The use of this design complicates the surgical intervention from a technical point of view, from the selection of the size of the implant to the intraoperative thermal effect on it.

In general, due to the described disadvantages of plates and their high cost, these techniques have been not widely used both in Russia and abroad.

The extra-focal methods of osteosynthesis of patellar fractures include osteosynthesis using various external fixation devices. Elzhan M. Monarbekov et al. described a method of osteosynthesis of transverse fractures of the patella using an external fixation apparatus of the Ilizarov type. Its fixing elements were wires with stoppers, inserted parallel to each other, with the opposite location of the stoppers in the fragments of the patella. The wires were inserted perpendicular to the axis of the patella so that the tendon of the quadriceps femoris muscle and the proper ligament of the patella were not affected. The transosseous wires were connected to each other using half-rings and connecting elements of the Ilizarov apparatus. This design enabled to perform both intraoperative and postoperative compression between fragments, and also provided early activation of the patient with the possibility of certain amplitude of active movements in the knee joint. In addition, the method allows a dosed physical activity on the affected lower limb [21].

In 2012, Mohammed Ismail Wardak et al. concluded that the technique of external compression fixation is a fairly effective method of treatment in cases where the state of soft tissues does not provide an opportunity for open reduction and internal fixation of the fracture, in extreme conditions, in the situation with limited resources [22].

In 2016 M.M. Bari et al. described the treatment results of 25 patients with transverse fractures of the patella using the technique of external compression fixation. The essence of the method is that an external fixation apparatus is applied based on the principles of the Ilizarov apparatus with tensioned wires. Direct fracture union was achieved with restoration of the congruence of the articular surface in all patients, and the range of active and passive movements in the knee joint. However, 20 % of patients developed inflammation of soft tissues in the course of treatment that was stopped by the local use of antibacterial preparations and antiseptics [23].

The shortcoming of closed external osteosynthesis is the impossibility of visual and palpation control of matching the articular surface of the patella. Moreover, the very presence of an external fixation device on the limb and the need for daily skin care at the entrance of the transosseous elements create certain inconveniences for the patient in aesthetic and household terms [24].

The most popular group of patellar osteosynthesis techniques is intraosseous osteosynthesis. This group combines various methods of osteosynthesis with wires, screws and cerclage elements.

Various methods of osteosynthesis of the patella using a circular suture with a free wire cerclage and suture materials have been described [25, 26].

The essence of the methods consists in stitching the lateral extensor apparatus and the parapatellar aponeurosis with suture material, followed by a circular parapatellar suture with soft material. Yangyang Sun et al. described the method of osteosynthesis of the patella using a steel wire cerclage according to the following system: in the peripatellar soft tissues around the fragments of the patella from the proximal and distal poles, two segments of the cerclage were drawn, the two loops of which were extended to the anterior surface of the patella, and the ends of the cerclage were twisted together; the third piece of wire cerclage was passed in a circular fashion through the extended loops, the ends of which were twisted on the lateral side of the patella.

Tiscareño-Lozano F.J. et al. described a simplified technique for fixing fragments of a comminuted fracture of the patella using two wire cerclages that passed circularly and in an 8-shaped way through the tendon of the quadriceps femoris muscle and the proper patellar ligament, tensioning the ends on the lateral surface of the patella [8].

The authors report good results of clinical application of this method in patients. Complications were detected in 11 % of patients and included infection, breakage of implants, discomfort and pain in the area of surgery in the postoperative period. The method is good and convenient as it does not require insertion of fixation elements through the fragments and does not imply additional trauma to the bone tissue, does not require a long time for performance, is simple to perform in the

operating room, and is minimally expensive. However, during wiring cerclage, the tendon of the quadriceps femoris muscle and the patellar ligament are damaged. By tensioning the wiring nodes and performing active movements in the postoperative period, soft tissues are subjected to pressure from the side of the cerclage which causes pain. In addition, septic complications and pain are possible due to the subcutaneous location of the wire cerclage and twist nodes and irritation of the peripatellar soft tissues. Also, there is a high risk of nodes to untie, weakening of the tension band and secondary displacement of fragments with migration of metal fixators.

Xiaozheng Tang et al. described a method of osteosynthesis of the patella using a five-pointed star-shaped lattice suture and the results of its application in clinical practice. After open reduction of the fragments, a 5-pointed star construct made of polydioxanone 0-0 suture material was modeled intraoperatively, and the construct was located on the anterior surface of the patella and was fixed with two semicircular sutures made of polydioxanone 2–0 at the apex of the star. The knots of the semicircular sutures were tightened on the lateral surfaces of the patella. According to the authors, the structure formed corresponded to the principle of tension band (the principle according to which the tensile forces acting on the patella tangentially are compensated by the fixator on one side and contribute to the compression of fragments on the opposite side). The authors present satisfactory clinical and functional treatment results of 25 patients with a transverse patellar fracture and note the absence of delayed fracture consolidation and non-union, displacement of fragments, and purulent inflammatory wound complications [28].

Various techniques of patella suture are most often used for avulsion fractures of the poles, including the popular anchoring of fragments and the technique of patella suture combined with wire fixation of fragments [8, 29–31]. These methods have proven themselves in clinical practice, providing the restoration of the integrity of the knee joint extensor apparatus.

Today, orthopedic traumatologists widely use the Weber method in clinical practice for patellar osteosynthesis based on the tension band principle, and the literature compares various methods of osteosynthesis with it [1, 32–34]. Prior to osteosynthesis, open reduction of the fragments is performed followed by internal fixation. This is a principle that must be observed during the osteosynthesis of all intra-articular fractures to enable visual, palpation and instrumental control of the articular surfaces of the fragments to be reduced [35]. In addition, intraoperative interfragmental compression and additional compression of fragments under axial and eccentric loading ensures absolute stability of bone fragments, which is also important in osteosynthesis of intraarticular fractures [36]. So, in the postoperative period, early activation of the patient, early initiation of exercise therapy, a dosed load on the lower limb is possible, that reduce the risk of developing arthrofibrosis and knee joint contractures.

Another advantage of the osteosynthesis with Kirschner wires and wire loops is its applicability for vertical (longitudinal) fractures of the patella by a modified method using the tension band principle described by Joao Alberto Larangeira et al. [37]. Jae-Woo Cho et al. described a modified, but a more complex method of osteosynthesis of the patella with wires and wire cerclage using the tension band principle but the principle of the method remains the same [38].

All osteosynthesis methods for patellar fractures that use Kirschner wires and wire cerclage are characterized by the same disadvantages. One of them is irritation of the tendon of the quadriceps femoris muscle and peripatellar soft tissues with the ends of the bent wires and wire cerclage, and, as a consequence, persistent pain in the postoperative period, restricting active movements in the knee joint, which, together with insufficient rehabilitation measures, leads to unsatisfactory functional results of treatment [39]. There is a high risk of developing purulent inflammatory complications and suppuration of sutures in the area of surgical intervention, the formation of fistulas in the sites of wire cerclage knots, and wire migration.

Bong-Ju Lee et al. described a modified method of osteosynthesis of the patella with Kirschner wires and Arthrex FiberWire braided suture, which consists in conducting the wires parallel relative to each other and the patella axis and applying FiberWire 8-shaped material with extra rounds around the wires, observing the principle of the tension band.

The authors report satisfactory clinical results of treatment of patients with transverse patellar fractures with the technique described and only one patient with complications in the postoperative period, and namely, displacement of fragments and nonunion. Among the advantages of choosing FiberWire material, the authors attribute the tensile strength of the material, which is not inferior to wire cerclage, as well as the convenience of manipulating the knot when tensioning the band [40].

It would seem that the mechanical essence of the tension band principle of the Weber method is clear and well studied [41]. However, Mohammed Ali, Jan Kuiper and Joby John demonstrated the effect of the location of the wire cerclage nodes relative to the exit points of the wires from the patellar cortical plate and the orientation of the 8-shaped wire cerclage relative to the patellar axis on interfragmental compression and general stability of osteosynthesis in an experiment on wooden models of the knee patella, [42, 43]. The obtained data are applicable in clinical practice and can improve the clinical and functional results of treatment when using the classical Weber method.

Osteosynthesis of the patella with screws has been also known. Two screws with a diameter of 3.5 mm are used, which are inserted parallel to each other perpendicular to the fracture line after preliminary open reduction. In this case, the screws are installed as tightening screws. Also known is the combination of osteosynthesis with partially threaded cannulated screws and wire cerclage.

This construct, according to Carpenter et al., Chih-Hsien Chen et al. is more stable than osteosynthesis with screws [44, 45]. The advantages of the described methods include reducing trauma to the peripatellar soft tissues by metal fixators. The risk of metal fixators migration is reduced, as they are securely fixed to each other. In addition, the design ensures absolute stability of the fragments. These advantages are confirmed by a retrospective analysis of the clinical data of surgical treatment of patients with a transverse patellar fracture by Wang Chengxue, Tan Lei et al. According to the data provided, the method of osteosynthesis with cannulated screws is characterized by a lower incidence of purulent septic complications and complications associated with the breakage and migration of metal fixators in comparison with the tension band method [46].

Along with the advantages, there is a big drawback of this method of osteosynthesis. It is the way for osteosynthesis of fractures with two large fragments (transverse fractures) since the insertion of screws through small fragments in multiple or marginal fractures may lead to their intraoperative fragmentation. In an experiment on a model of the patella with a simulated transverse fracture and fixation with cannulated screws and wire cerclage, Chih-Wei Chang et al. showed that from a biomechanical point of view, for a more even distribution of the load on the metal implant, it is necessary to correctly position the screws (5 mm below the patella pole). This arrangement of screws will reduce the risk of metal fixator migration and breakage [47]. Taking this aspect into account, there is a possibility of technical difficulties in osteosynthesis of the patella with cannulated screws and wire cerclage due to the peculiarities of the morphology of the fracture and the anatomical features of the patient.

Alayan A et al. used compression plunge screws in combination with a FiberWire N 5 cerclage suture and tension band with Arthrex FiberWire N 2 material in an experimental study on cadavers. Experimental data were obtained indicating that diastasis between fragments does not differ by either using the technique described by the authors or Weber osteosynthesis; however, the Weber osteosynthesis strength at maximum tensile load is higher. The advantages of the method of osteosynthesis with plunging screws and cerclage made of FiberWire material are the presumptive reduction of pain in the postoperative period, caused by trauma to the soft tissues by the subcutaneously protruding parts of the metal implants in the case of classical methods of osteosynthesis, and easy of manipulation of the cerclage node and the tension band by tightening [48].

Some authors (E.A. Litvina, 1995; JFS Sutton et al., 1976) described partial or complete patelllectomy for multi-fragmented fractures of the patella. Brooke (1937) expressed the opinion that the patella does not play a significant function in the human body. However, most authors opine that, it is better to preserve the patella to restore the function of the full-fledged extensor apparatus of the knee joint [49]. At the moment, partial or complete patelllectomy is recommended as a method of treating patients with patellar multi-fragmented injuries when it is impossible to perform osteosynthesis with restoration of the articular surface [1]. However Khidzhazin V Kh and Solod I.E. et al. express the opposite opinion that in clinical practice it is quite possible to avoid partial or total patelllectomy in multi-fragmented fractures in accordance with the principles of preserving all fragments and applying a sufficient number of wire bands to the patellar fragments [49].

In 2015, at the Department of Traumatology, Orthopedics and Emergency Surgery of the Krasnov Samara State Medical University developed a new method of osteosynthesis of the patella with wires and wire cerclage. It implies that two wires are inserted in a direction parallel to each other perpendicular to the longitudinal axis of the patella, the wire cerclage was applied 8-shaped at the ends of the wires and was tensioned [50]. The most obvious advantage of the method is the orientation of the wires in the fragments of the patella, which does not affect the tendon of the quadriceps femoris muscle and the patellar ligament itself, thus causing significantly less pain in the postoperative period due to the minimization of the number of irritating metal fixators located near the surrounding peripatellar soft tissues. Also in the postoperative period there was a significant increase in the range of active movements in the knee joint. However, by tensioning the cerclage wire intraoperatively, as well as when performing active movements in the knee joint, tangential displacement of the fragments (to a fracture) was observed. Hence, it can be concluded that this method does not provide the necessary interfragmental compression but also violates the principle of the tension band. Thus, we can talk about the macromobility of fragments of an intra-articular fracture, which may lead to pseudarthrosis and pathological fracture consolidation [35]. The identified shortcomings of the proposed method of patella fixation resulted in further study of this topic and the creation of another method of fixation.

In 2019, the staff of the department developed a new method of osteosynthesis of the patella using Kirschner wires and wire cerclage. The essence of the method consists in holding two wires parallel to the patellar axis on both sides of the patella's own ligament from the distal fragment to the proximal one without letting the ends of the wire exit from the cortical plate of the proximal fragment. The third wire is passed perpendicularly to the previous two through the proximal fragment. Further, the wire cerclage is 8-shaped with the ends of the wires and wires cross along the front surface of the patella and are twisted with pliers, thus performing interfragmental compression. This method differs from the previous one, proposed by the staff of the department, in that it considers the tension band principle, which ensures the absolute stability of bone fragments when tightening the wire cerclage due to the implementation of interfragmental compression. In addition, it is applicable not only for transverse fractures of the patella (which is typical for the Weber method of osteosynthesis), but also in multi-gragmented fractures when the proposed design is supplemented with wire cerclage. The method

allows performing active movements in the knee joint in the early postoperative period, a dosed axial load on the lower limb, which reduces the risk of developing contractures of the knee joint and atrophic processes in the extensor muscles of the femur. A patent of the Russian Federation was obtained for the described method [51]. The method has proven itself well in experiment and clinical practice. Active work is underway to monitor the long-term clinical results of treating patients with this pathology.

Table 2

Surgical methods of treating patients with patellar fracture

Authors, year, reference list number	Description of patient's fracture	Method of surgical treatment of patients with patellar fracture	Merits	Shortcomings
Schuett D.J. et al., 2015 [1]	Simple and multi-fragmented fractures of the patella with damage to the articular surface	Osteosynthesis of patellar fractures with screws, Kirschner wires and wire cerclage	The number of cases of dysregeneration is minimized, the patient's rehabilitation period is short	Likelihood of purulent infectious complications, osteomyelitis, traumatic performance, damage to muscles and periosteum
Kakazu R., Archdeacon M.T., 2016 [2]	Simple and multi-fragmented fractures of the patella with damage to the articular surface	Osteosynthesis of patellar fractures with screws, Kirschner wires and wire cerclage	The best functional treatment results are achieved. The risk of non-union and the formation of a patellar pseudarthrosis is decreased	Likelihood of purulent infectious complications, osteomyelitis, traumatic performance, damage to muscles and periosteum
Scolaro J., Bernstein J., Ahn J., 2010 [3]	Comminuted fractures with damage to extensor apparatus	Osteosynthesis of patellar fractures with screws and wire cerclage	Conditions are created for anatomical reduction and sufficient fixation of bone fragments. Indications for patelllectomy are significantly decreased	The risk of non-union, migration of metal fixators in the postoperative period remains. The need for repeated surgery to remove metal fixators
Crist B. D., Borrelli J., Harvey E. J., 2020 [4]	Simple and multi-fragmented fractures of the patella with damage to the articular surface	Osteosynthesis of patellar fractures with screws, Kirschner wires and wire cerclage	The application of the tension band principle achieves sufficient interfragmental compression and absolute stability of bone fragments, which allows early active mobilization of the knee joint to begin in the postoperative period.	The risk of developing septic complications, osteomyelitis, pain in the postoperative period
Giannoudis P.V., 2020 [7]	Simple and multi-fragmented fractures of the patella with damage to the articular surface	Osteosynthesis of patellar fractures with screws, Kirschner wires and wire cerclage	The principles and conditions for making a decision on the tactics of managing patients with patellar fractures, conservative or surgical treatment, are described.	Likelihood of purulent infectious complications, osteomyelitis, traumatic performance, damage to muscles and periosteum
Gwinner C. et al., 2016 [5]	Transverse fractures of the patella	Osteosynthesis with wires and wire cerclage applying tension band	More stable and rigid fixation, early KJ mobilization in the postoperative period, opportunity not to immobilize the limb	Risk of purulent infectious complications, osteomyelitis, pain in the postoperative period
	Complex fractures	Osteosynthesis with scres and special plates with angular stability and additional fixation of small fragments with suture material	Sufficient interfragmentary compression and absolute stability of bone fragments. Early active KJ mobilization	High risk of purulent infectious complications, osteomyelitis, pain in the postoperative period
	Complex multifragmented fractures	Total or partial patellectomy	Sufficient interfragmentary compression and absolute stability of bone fragments. Early active KJ mobilization	Risk of purulent infectious complications, osteomyelitis, pain in the postoperative period. There is a risk of developing an overload of the extensor apparatus of the knee joint, pain, and limitation of the function of the knee joint
Florian Gebhard et al., 2016 [9]	Transverse and complex fractures of the tibia	Weber osteosynthesis; methods to reduce and fixate the fracture	Sufficient interfragmentary compression and absolute stability of bone fragments. Early active KJ mobilization. Specific surgeons' manual skills and instruments are not required.	Risks of purulent septic complications, osteomyelitis in the postoperative period. Irritation of periarticular soft tissues with metal implants may provoke pain by the start of active KJ exercises
Henrichsen J.L. et al., 2018 [8]	Complex comminuted and multifragmented fractures	Osteosynthesis of patellar fractures with low-profile plates and screws	More stable and stronger fixation, early mobilization of the knee joint in the postoperative period, possibility not to immobilize the limb	High risk of purulent septic complications, and pain in the postoperative period
Taylor B.C. et al., 2014 [10]	Complex comminuted fractures	Techniques of osteosynthesis of the patella with various plates	Good and satisfactory treatment results. Minimization of the limb immobilization time due to high stability of bone fragments	There were cases of inflammation in the periarticular soft tissues in the postoperative period. Risk of purulent septic complications and osteomyelitis
Matthews B. et al., 2013 [11]	Elderly patients with poor condition of bone tissue	Osteosynthesis with special implants and plates	Stronger and more stable fixation of bone fragments with minimal stress on the bone tissue during active movements. Reduced likelihood of accelerating post-traumatic osteoarthritis	High risk of purulent septic and inflammatory complications in periarticular soft tissues due to the subcutaneous location of metal fixators

Continuation of table 2

Surgical methods of treating patients with patellar fracture

Authors, year, reference list number	Description of patient's fracture	Method of surgical treatment of patients with patellar fracture	Merits	Shortcomings
Wurm S. et al., 2015 [12]	Experiment on synthetic models of the patella made of hard polyurethane foam with a simulated transverse fracture	Osteosynthesis with a plate with angular stability	Greater mechanical strength properties than osteosynthesis with wires and cerclage using the tension band principle. There was less diastasis between bone fragments in simulating physical activity	It is necessary to have specialized plates with angular stability for osteosynthesis of patellar fractures and trained surgeon
Thelen S. et al., 2013 [13]	Cadaver experiment using knee joint preparations with simulated transverse fracture	Osteosynthesis with two bilaterally located locking plates, wires and a wire cerclage using the tension band principle with cannulated screws	The use of two bilaterally located locking plates provides greater stability under physical cyclic loads	Specialized plates with angular stability for osteosynthesis of patellar fractures and trained in them surgeons are required. The technique is not applicable to all variations in patellar fracture morphology
Dickens, A. J., 2015 [14]	Experiment on synthetic models of the left patella made of hard polyurethane foam with simulated simple transverse fracture	Osteosynthesis with screws with augmentation with a low-profile plate	Augmentation with a low-profile plate and screws increases the stability of the osteosynthesis with screws in comparison with the use of a tension wire band	Increased risk of septic complications and pain during physical exertion in the postoperative period due to the subcutaneous location of the plate. It is necessary to have specialized plates and trained surgeon to work with them
Wurm S. et al., 2018 [15]	Simple and comminuted fractures of the patella with displacement of fragments	Osteosynthesis with plates with angular stability	Greater stability of bone fragments and resistance to stress	More pronounced pain and discomfort in the area of surgical intervention during physical exertion is noted, the risk of purulent septic complications in the postoperative period increases
Thelen S. et al., 2012 [16]	Cadaver experiment with the use of KJ preparations and simulated transverse fracture	Osteosynthesis with a plate with angular stability, cannulated screws and wire cerclage	Osteosynthesis with a plate with angular stability has the greatest resistance to cyclic physical activity.	The risk of septic complications and pain during physical exertion in the postoperative period increases due to the subcutaneous location of the plate. It is necessary to have plates for osteosynthesis of patellar fractures and trained surgeons
Volgas D., Dreger T., 2017 [17]	Complex comminuted and multifragmented fractures of the patella	Osteosynthesis with mesh titanium plates	Sufficient stability of bone fragments. Good and satisfactory clinical results	There were cases that developed pain in the post-op period and the metal fixators had to be removed
Moore T.B. et al., 2018 [18]	Complex comminuted fractures	Osteosynthesis with locked plates	Good clinical results. Sufficient stability of bone fragments	High cost of specialized locking plates; risk of septic complications and pain in the postoperative period due to the subcutaneous location of metal fixators
Quan-Ming Zhao A. et al., 2017 [19]	Simple and comminuted fractures	Osteosynthesis with nickel-titanium concentrator	Reduction in the duration of the operation; sufficient stability and interfragmentary compression	High cost of the implant; risk of septic complications and pain in the postoperative period due to subcutaneous placement of the metal implant and irritation of periarticular soft tissues
		Osteosynthesis with wire cerclage	Sufficient stability of bone fragments; good and satisfactory clinical results	Risk of septic complications, osteomyelitis in the postoperative period; irritation of periarticular soft tissues with metal implants may cause pain by the start of active KJ movements
Liu F. et al., 2012 [20]	Complex comminuted and simple transverse fractures	Osteosynthesis with special implanted rings	Satisfactory stability and good and fair clinical results	Cost of implants. Skills in performing osteosynthesis with a specialized implant are required. Risk of septic complications and pain in the postoperative period due to the subcutaneous location of the implants
Elzhan M. et al., 2018 [21]	Transverse and transverse comminuted fractures	Osteosynthesis with a device for closed reduction and fixation of fragments	Good clinical results and fewer complications as compared with an open technique of osteosynthesis	Negative impact on quality of life in the period of consolidation due to apparatus of external fixation on the limb and patient's regular cleansing of transosseous elements entrance sites
Wardak M.I. et al., 2012 [22]	Simple, comminuted and multi-fragmented fractures, treatment in conditions of poor soft tissue condition and limited resources	Miniinvasive osteosynthesis with a special external fixator	Effectiveness of the method in the condition of compromised soft tissues, extreme situations, with limited resources. Reduced operating time for fracture osteosynthesis	External fixator on the limb and the need for pin tract care; no direct control of bone fragment and articular surface reduction

Continuation of table 2

Surgical methods of treating patients with patellar fracture

Authors, year, reference list number	Description of patient's fracture	Method of surgical treatment of patients with patellar fracture	Merits	Shortcomings
Bari M.M. et al., 2016 [23]	Transverse fractures with longitudinal displacement of more than 3 mm and more than 2 mm in the sagittal plane	Osteosynthesis of the patella with a compressive external fixator (CEF)	Good clinical outcomes; low invasive osteosynthesis	Cases of inflammation of the soft tissues in the areas of the AEF wires were noted. The need for regular care of the percutaneous elements of the metal fixator; lack of the possibility of direct control of fragments and the articular surface reduction
Henrichsen J.L., 2018 [8]	Simple transverse and comminuted fractures with fragments displacement	Osteosynthesis with wires and wire cerclage	Sufficient bone fragment stability. Good and satisfactory clinical outcomes	High risk of purulent septic complications in the postoperative period. High risk of pain due to the location of the nodes of the cerclage wire in the projection of the patella retainers. High risk of breakage and migration of cerclage wire
		Osteosynthesis with low profile plates	Plates ensure early mobilization of knee joint and better clinical results of treatment	High risk of purulent septic complications and pain in the postoperative period due to percutaneous placement of metal fixators and periarticular soft tissue irritation
Camarda L. et al., 2016 [25]	Simple transverse fractures, comminuted fractures, evulsion fractures of the lower pole	Osteosynthesis with non-metal implants, suture material	Wide possibility to use in routine practice, minimum of metal implants in the soft tissue, good and satisfactory clinical results	Insufficient stability of bone fragments, the need for immobilization of the limb in the postoperative period, high risk of arthrofibrosis and KJ contracture in the postoperative period and an increase in the period of disability. Limited possibility of early active movements in the knee joint
Sun Y. et al., 2019 [26]	Comminuted and multi-fragmented fractures with fragments displacement	Wire cerclage osteosynthesis based on principle of tension band	No need to insert Kirschner wires. The technique can be used for multi-fragmented fractures. Good clinical results	High risk of purulent septic complications in the postoperative period. High risk of pain due to the location of the knots of the cerclage wire in the projection of the patella retainers. High risk of breakage and migration of wire cerclage
Tiscareño-Lozano F.J. et al., 2018 [27]	Complex multi-fragmented fractures with fragments displacement	Osteosynthesis with double wire cerclage inserted through the quadriceps tendon insertion and proper patellar ligament into the bone	Good clinical results; possibility to start early active movements in the knee joint	Risk of inflammatory processes in soft tissues and pain in the postoperative period due to irritation of periarthricular soft tissues with metal fixators. Insufficient strength of the wire cerclage, high risk of breakage of metal fixators with early active mobilization of the limb
Tang X. et al., 2018 [28]	Transverse fractures with fragment displacement	Star figure from suture material	Lower risk of purulent septic complications in the postoperative period. Satisfactory stabilization of bone fragments, satisfactory clinical results of treatment	Risk of osteosynthesis failure of due to the low strength of the suture material relative to the wire cerclage, the need for immobilization of the limb. Irritation of the periarticular soft tissues at the points of attachment of the figure
Kadar A. et al., 2015 [29]	Fracture of the distal pole of the patella with displacement	Osteosynthesis of the patellas with anchor fixator	The effectiveness of osteosynthesis of fractures of the distal pole of the patella was clinically proven. Restoration of the flexor apparatus of the knee joint	Risk of septic complications and breakage of fixators. The need for plaster immobilization of the knee joint in the early postoperative period
		Partial patellectomy	Sufficient interfragmental compression and absolute stability of bone fragments. Early active KJ mobilization	Higher risk of an overload of the extensor apparatus of the knee joint, pain, and limitation of the function of the knee joint. Purulent septic complications, osteomyelitis, pain are possible
Swensen, S. et al., 2017 [30]	Fracture of the distal pole of the patella with displacement of fragments	Osteosynthesis with soft tissue material	Reduced risk of purulent septic complications and pain due to the absence of metal implants and thus of irritation of periarticular soft tissues	Insufficient stability of bone fragments, low strength and resistance of the system to physical stress, the need to immobilize the limb until consolidation of the fracture

Continuation of table 2

Surgical methods of treating patients with patellar fracture

Authors, year, reference list number	Description of patient's fracture	Method of surgical treatment of patients with patellar fracture	Merits	Shortcomings
Massoud E.I.E., 2017 [31]	Fracture of the distal pole of the patella with displacement of fragments	Osteosynthesis with vicryl suture material and wire cerclage	Good clinical results, possibility of early KJ mobilization and weight-bearing	Clinical manifestation of degenerative phenomena in the patellofemoral joint in postmenopausal patients. Insufficient strength of implants, risk of osteosynthesis failure. Pain syndrome due to irritation of periarticular soft tissues
Yu X. et al., 2015 [32]	Transverse fractures of the patella with fragments displacement	Osteosynthesis with suture material	Simplicity of performance, not expensive materials	Insufficient strength of the material, risk of failure of the fragments reduction, the need for immobilization of the limb
		Weber osteosynthesis	Good reduction and stability of fragments, possibility of early mobilization of the limb with partial weight-bearing	Risk of breakage and migration of metal fixators, pain due to irritation of the periarticular soft tissues by protruding elements of the wires and cerclage
		Osteosynthesis with screws	Sufficient stability, possibility of early mobilization and partial weight-bearing	Relatively high trauma to soft tissues during osteosynthesis, the risk of septic complications and osteomyelitis in the postoperative period
Zhang Y. et al, 2018 [33]	Transverse fractures of the patella with fragments displacement	Osteosynthesis with cannulated screws	The proven effectiveness of alternative methods of osteosynthesis in comparison with the Weber method of osteosynthesis. Fewer episodes of reduction and fixation of the fracture failure in osteosynthesis with screws	Osteosynthesis with cannulated screws and wire cerclage contributes to the development of pain in the postoperative period due to irritation of periarticular soft tissues with protruding elements of metal fixators
		According to Weber	Good reduction and stability of fragments, possibility of early mobilization of the limb with partial weight-bearing	Risk of breakage and migration of metal fixators, pain due to irritation of the periarticular soft tissues with protruding elements of the wires and cerclage
Kidzhazin V.C. et al., 2020 [34]	Absence of contraindications to surgical intervention	Weber osteosynthesis	Best functional results in transverse patellar fractures	Risk of breakage and migration of metal fixators, pain due to irritation of the periarticular soft tissues with protruding elements of the wires and cerclage
		Crosswise osteosynthesis	Best functional and clinical results in multi-fragmented fractures of the patella	Pain syndrome due to irritation of periarticular soft tissues with protruding elements of the wires and cerclage. High risk of septic complications due to a large number of metal fixators
		Combined osteosynthesis	Satisfactory clinical results in multi-fragmented fractures	Pain due to irritation of periarticular soft tissues with protruding elements of the wires and cerclage. High risk of septic complications due to a large number of metal fixators
		Partial patelllectomy	Decreased risk of non-union and pseudarthrosis	Increased risk of KJ osteoarthritis and resuction in the strength of femur quadriceps
Rűedi T.P. et al., 2013 [35]	Intra-articular fractures	Osteosynthesis with precise anatomical reduction of bone fragments and articular surface	Minimal risks of osteoarthritis of the knee joint, overloading the extensor apparatus of the knee joint	It is more difficult to meet the principle by using closed low invasive soeosynthesis techniques
	No contraindications for surgery. Simple and multiple fractures of the patella with damage to the articular surface	The complications that develop when the principles of osteosynthesis are neglected were described.	Compliance with the basic principles of osteosynthesis of intra-articular fractures minimizes the risk of fracture non-union, pseudarthrosis and osteoarthritis	The described principles are not achieved with some methods of osteosynthesis of patellar fractures, which leads to the development of known complications

Continuation of table 2

Surgical methods of treating patients with patellar fracture

Authors, year, reference list number	Description of patient's fracture	Method of surgical treatment of patients with patellar fracture	Merits	Shortcomings
Larangeira J.A. et al., 2015 [37]	Open vertical fracture of the patella	Osteosynthesis with vertically positioned Kirschner wires and wire cerclage	Good clinical results of treatment. Sufficient stability of bone fragments. Minimal number of metal implants. Absolute stability of bone fragments, early activation of the patient, mobilization of the lower limb	High risk of purulent septic complications due to the open nature of the fracture and the initial installation of internal metal fixators
Cho J.W. et al., 2019 [38]	Complex multi-fragmented fractures	Osteosynthesis with miniplates augmented with tension band	Sufficient stability of bone fragments, possibility of early mobilization of the knee joint. Good and satisfactory clinical treatment results	More pronounced pain in the postoperative period due to the subcutaneous location of metal fixators, high risk of purulent septic complications, availability of implants and trained surgeons to work with them
Greenberg A. et al., 2017 [39]	Patients operated on for a patellar fracture with radiographic signs of consolidation	Operations to remove metal fixators	After removal of metal fixators, pain reduces considerably and the quality of life improves	The greatest number of patients with pain in the postoperative period was observed in the groups of Weber osteosynthesis and cannulated screws. Patients with diabetes mellitus need special preparation for surgery to remove metal fixators
Lee B.J. et al., 2019 [40]	Simple transverse and comminuted fractures with displacement of fragments	Osteosynthesis with Kirschner wires and FiberWire suture material using the tension band principle	Various clinical results. Minimal use of metal implants, minimization of septic complications. Satisfactory stabilization of bone fragments	High cost of FiberWire material in clinical practice. A clinical observation of the loss of fixation and reduction of bone fragments in the postoperative period was described
Zderic I. et al., 2017 [41]	Cadaver experiment using knee joint preparations with simulated transverse patellar fracture	Weber type osteosynthesis with screws and wire cerclage	Achieves the required stability of bone fragments of osteosynthesis	Less strength of the metal fixators system during physical exertion
		Osteosynthesis with screws and wire cerclage	Achieves the required stability of bone fragments of osteosynthesis. Ensures more strength of the system	Higher risk of developing pain and septic complications due to a large number of metal fixators
Ali M. et al., 2016 [42]	Experiment on wooden models with simulation of knee joint transverse fracture	Weber type osteosynthesis with various location of wire entrance in the frontal plane	Horizontal orientation of the 8-shaped wire cerclage ensures more stability to physical loads	
Ling M. et al., 2019 [43]	Experiment with simulation of knee joint transverse fracture	Weber type osteosynthesis with various location of wire entrance in the saggittal plane	Location of Kirschner wires closer to articular surface ensures more angular stability of bone fragments	
N,V. Zagorodniy et al., 2017 [44]	In case there are no contraindications to surgical intervention	Osteosynthesis of patellar fractures with lag screws	Decreased soft tissue trauma, less risk of fixator migration, sufficient stabilization of bone fragments	The method is applicable to fractures with two large fragments of satisfactory bone quality. The risk of breakage and migration of metal fixators remains
		Osteosynthesis with Kirschner wires and wire cerclage according to the principles of tension band	Achievement of absolute stability of bone fragments with the possibility of early mobilization of the knee joint and partial weight bearing	The risk of developing pain syndrome in the postoperative period due to irritation of periarticular soft tissues with metal fixators
		Partial and complete patellectomy	Option of choice for complex multi-fragmented fractures in the absence of the possibility of preserving fragments	Increase in the load on the patellar ligament, change in the biomechanics of the knee joint. Restricted KJ mobility, pain, KJ instability, edema
Chen Ch.H. et al., 2019 [45]	Experiment with simulation of knee joint transverse fracture	Osteosynthesis with full thread, prtial thread and headless screws	Full thread screws enhance bone fragment stability	Due to the different state of the bone tissue, it is not always possible to perform sufficient interfragmental compression at the stage of fracture reduction followed by fixation with full-threaded screws.

Continuation of table 2

Surgical methods of treating patients with patellar fracture

Authors, year, reference list number	Description of patient's fracture	Method of surgical treatment of patients with patellar fracture	Merits	Shortcomings
Wang C.X. et al., 2014 [46]	Transverse fractures with displacement	Osteosynthesis with titanium cannulated tension screws	Very good clinical results. The techniques may be considered as an alternative treatment in transverse fractures of the patella	The technique is applied in fractures with two large bone fragments
Chang C.W. et al., 2018 [47]	Experiment with simulation of knee joint transverse fracture	Insertion of cannulated screws at different level n the sagittal plane	Location of metal fixators in the bone thickness has an impact on metal construct load distribution	Significant complexity of surgical techniques due to anatomical features of the patella, variability of fracture morphology
Alayan A. et al., 2018 [48]	Experiment on cadavers with simulation of knee joint transverse fracture	Osteosynthesis with cannulated screws and wire cerclage	Both methods ensure sufficient fragments stability for early mobilization	Pain in the postoperative period due to soft tissue irritation with protruding elements of metal fixators
		Use of internal screws in combination with tension band using FiberWire material		Lower strength characteristics compared with osteosynthesis with cannulated screws and wire cerclage
Hijazin V. et al., 2018 [49]	Multi-fragmented fractures	Osteosynthesis with 3 or 4 wires and several tension bands	Sufficient interfragmentary compression, sufficient stability of bone fragments that allow avoiding partial patellectomy	Increased number of metal implants that are located percutaneously enhances the risk of purulent and septic complications and pain
RF patent for invention № 2612100, 11.03.2017, 2017 [50]	No contraindications for surgery. Transverse fracture of the patella	Osteosynthesis with two wires and wire cerclage	Traumatization of the patella's own ligament and tendon of the quadriceps femoris muscle is minimized, pain is reduced in the postoperative period. Sufficient stability of bone fragments is achieved	Due to the peculiarities of the location of wires the principle of tension band is violated what leads to angular deformation of the patella. There increases the risk of migration of metal fixators
RF patent for invention № 2724822, 25.06.2020, 2020 [51]	No contraindications for surgery. Comminuted patellar fractures	Osteosynthesis of patellar fractures with three wires and wire cerclage	Compliance with the tension band principle, sufficient compression and absolute stability of bone fragments. Trauma of peri-atricular soft tissues is minimal due to the peculiarities of Kirschner wires insertion and wire cerclage	

CONCLUSION

Based on the data from the analyzed publications, it can be concluded that the conservative method of treating patients with a patellar fracture is most relevant if there are contraindications to surgery. It should be understood that the patient may develop a persistent arthrogenic contracture. Fracture of the patella is an intra-articular injury, and the obligatory restoration of the articular surface of the patella by surgical treatment allows avoiding further complications such as arthrogenic contracture of the joint, patellofemoral arthrosis of the knee joint. It is an undoubted advantage of the surgical method. Early mobilization of the knee joint produces loading on the elements of the metal implant and the patella bone structure. Therefore, the surgeon who chooses the method of osteosynthesis has to take into account not only the load on the metal fixator but also the cyclic load in the postoperative period. According to investigations, maximum stability is achieved using plates and screws, osteosynthesis with Kirschner wires and wire cerclage. According to the analysis of publications, in early knee joint movements, the risk of infectious, inflammatory complications and pain in the postoperative period increases with an increase in the number of metal implant elements. In addition, the condition of the soft tissues also affects the likelihood of septic complications. From this point of view, the most optimal are the methods of osteosynthesis with the use of wires and wire cerclage and AEF. Since the generally accepted indication for the osteosynthesis of a patellar fracture with the AEF is an open nature of the fracture, it can be concluded that the most optimal way to treat closed fractures of the patella is osteosynthesis with the use of wires and wire cerclage according to the tension band principle.

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