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Progress on Kirschner wire insertion techniques for patellar fractures

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Highlights

- Distance and position of Kirschner wires influence the stability of tension band wiring.
- Kirschner wire guiding device can improve the accuracy of Kirschner wire placement.
- Designing an optimal guide device is the primary development direction to improve the accuracy of Kirschner wire placement.

Abstract

Tension band wiring has been widely used in patellar fracture internal fixation. However, Kirschner wires (K-wires) insertion is time-consuming, because it requires multiple intraoperative fluoroscopies to adjust the insertion angle, and the accuracy of insertion is not ideal. In this review, we summarize the measurement of patellar anatomical parameters, K-wires placement level, and application of guiding devices, with the focus on improving the accuracy of K-wire insertion from perspectives of K-wire placement and guiding devices. This review hope to provide some inspiration for new guiding devices with auxiliary K-wire placement.

Keywords: Internal fixation, guiding device, patellar fracture, Kirschner wires

Introduction

Patellar fracture is a common knee trauma, accounting for about 1% of all fractures occurring in the body [1, 2]. The treatment methods may be conservative or surgical, among which the most common surgical treatment is tension band wiring fixation [3]. Tension band wiring has been employed for the internal fixation of patellar fractures for over 60 years. In 1954, Pauwels applied the standard tension band wiring to patellar fracture surgery [4]. The quadricipital tendon and patellar ligament were connected with metal wire, and the fracture sites were bound to convert the tensile forces into the compression forces of the articular surface to promote fracture healing. However, the wire was easy to slip with unstable fixation and had poor mechanical properties. Arbeitsgemeinschaft für Osteosynthesefragen (AO) modified the standard tension band wiring by adding two Kirschner wires (K-wires) to improve the mechanical properties of the tension band wire [5]. At present, modified tension band wiring is the most common surgical method for the treatment of patellar fractures, exhibiting good biomechanical properties and clinical treatment effects [6]. However, the challenges of K-wire placement in clinical K-wire tension band surgery have not been overcome. The challenges include difficulty in determining the optimal level of K-wire placement, and the inaccuracy of intraoperative free-hand K-wire placement.

The operating points of modified tension band internal fixation for patella are as follows: reduction of the fracture segments, insertion of two K-wires with a distance of 20-25 mm in a

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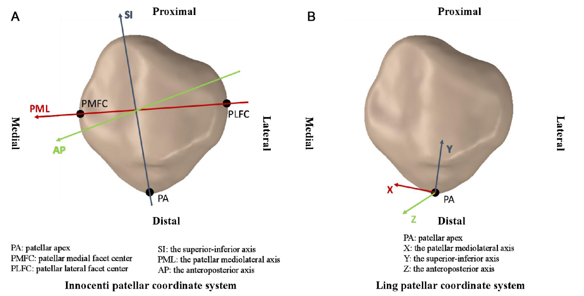

Figure 1. The type of patellar coordinate system. (A) Iccocenti petella coordinate system; (B) Ling patella coordinate system.

longitudinal parallel position about 5 mm from patellar anterior surface, cutting the K-wires, bending the ends, wrapping the “0” or “8” shaped wire and tightening it to be as close to the surface of patella as possible [5].

During knee flexion, the patella is pulled at an angle by the quadriceps muscle and the patellar ligament. The simultaneous action of wire, K-wires, and femoral condyle on the patella can convert the tension between the fracture fragments into the pressure between the fracture sites. This conversion helps prevent separation of fracture sites and safeguards the integrity of the articular surface [7-9]. The role of K-wires is paramount in tension band wiring, but K-wire placement has not been fully discussed. Patellar morphology is irregular, so it is difficult to determine the point of entry according to the bone marker. In clinical practice, the accuracy of freehand placement is low, and the K-wire tends to be upward, downword, or not parallel.

To ensure the accuracy of the position of the K-wires, multiple fluoroscopy and adjustment of the insertion point of the K-wires are required during operations [10]. High-dose radiation exposure can cause damage to patients and doctors, and insertion of multiple K-wires can further damage the structure of patella. Therefore, the problem of patellar K-wire placement needs to be addressed urgently. In this paper, the measurement of patellar anatomical parameters, the level of K-wire placement, and the K-wire guiding devices are reviewed to provide a basis for future research on K-wire placement techniques.

Review progress

Patellar anatomical morphometry

The patellar tension band technique has undergone continuous development and refinement. Most of the existing studies are conducted from the perspective of fixation methods and implant types, using clinical experiments, biomechanical experiments, and finite element analysis methods, rarely considering the influence of K-wire placement on the mechanical properties of tension band [11, 12]. The possible reasons are the irregular shape of the patella and the error in the morphological measurement method of patellar anatomy, which make it difficult to accurately classify the placement level of K-wires.

The patella is the largest sesamoid bone in the body, with irregular structure. Although patellar vary in shape, the typical anatomical structure includes the base, patellar apex (PA), patellar anterior surface, the articular surface, and patellar ridge. In patellar fracture surgery and total knee arthroplasty, accurate patellar anatomical parameters serve as a foundation for precise surgical procedures. Scholars have explored a variety of methods to measure the patella, including methods based on image, patellar specimens, and image algorithm [13-16]. However, due to the inconsistency of projection angle, measurement index, and measurement benchmark, the measured parameters are difficult to be unified, and there are numerical errors, which cannot accurately describe the actual morphology of the patellar. Regarding the above challenges, scholars created the patellar coordinate system to measure and describe the patellar morphology. Innocenti et al. performed a 3D reconstruction of 33 healthy patellar specimens. A total of 7 anatomical landmarks were marked, including PA, patellar ridge top, patellar ridge bottom, patellar lateral facet center, patellar medial facet center, patellar medial facet bottom, and patellar medial facet top [17]. The patella mediolateral axis - superior-inferior axis - anteroposterior axis orthogonal coordinate system was established according to the three relatively stable points (patellar medial facet center, patellar lateral facet center, and PA), and the patella was measured to verify the feasibility of the coordinate, as shown in **Figure 1A**. Based on the 3D reconstruction model of the patella, Ling et al. established a spatial coordinate system with the PA as the origin **Figure 1B** [18]. The X-axis is parallel to the maximum lateral connection line of the medial and lateral contour of the patella, the Y-axis is parallel to the patellar ridge, and the Z-axis is perpendicular to the XY plane. Based on the established patellar coordinate system, the position of the K-wires was meticulously categorized. Wang et al. pointed out that the existing measurement methods of patellar anatomical parameters are

Table 1. K-wire placement

Researchers	Method	K-wires Depth	K-wires Distance	K-wires Position
AO principle	Clinical surgery	5 mm from patellar anterior surface	A distance of 20-25 mm	Parallel
Hsu et al.	Clinical surgery	Avoid proximity to the anterior surface	None	None
Wang et al.	Finite element method	None	None	Parallel
Ling et al.	Finite element method	Level 3 and below	The medial and lateral 1/4	Parallel
Kim et al.	Finite element method	5 mm from the middle layer	None	Parallel

Note: K-wires, Kirschner wires; AO, Arbeitsgemeinschaft für Osteosynthesefragen.

mostly used for total knee arthroplasty, showing poor guiding significance for patellar fracture surgery, and there is a lack of appropriate K-wire guiding instruments in clinical practice [19]. Therefore, based on the 3D reconstruction of 94 healthy patellar, they measured the height of the PA, the height of the patella, the width of the patella, the thickness of the patellar ridge, the inner 1/3 thickness and the outer 1/3 thickness in MIMICS software, and designed a guiding device to assist the insertion of K-wires. Based on the clinical effects, the lateral 1/3 thickness is shown to have important clinical significance for patellar tension band wiring and can be used as a reference for K-wire insertion depth, which is 15.38±1.89) mm in males and 14.01±1.72 mm in females. This guiding device aims to assist doctors to improve the accuracy of K-wire placement, but the categorization of the optimal K-wire placement levels is only based on clinical experience and clinical effects. The categorization basis of the K-wire placement levels and the selection of the optimal K-wire placement level need to be further verified.

K-wire placement

The placement level of K-wires is a key factor affecting the treatment efficacy of tension band wiring. The categorization methods of placement levels are shown in **Table 1**. Wu et al. improved the internal fixation method of double-ended K-wire bending based on the clinical operation experience of the AO tension band. Through surgical verification and comparison with the efficacy of AO tension band surgery, it was found that double-ended K-wire bending reduced the incidence of complications and improved the surgical healing rate [20]. However, this study only analyzed the bending mode of the K-wires but did not study the influence of other factors of the K-wires on the surgical outcome. Based on the clinical operation results of 170 patients, Hsu et al. analyzed the influence of three factors, K-wire depth, length, and bending mode, on the efficacy of tension band fixation [21]. The results demonstrated that superficial K-wire depth could lead to unstable internal fixation, which was not conducive to maintaining the integrity of the articular surface. It was recommended to place the K-wires in the middle of the patella, while avoiding proximity to the anterior surface of the patella. The placement level of K-wires can affect the therapeutic efficacy of surgery, but it is difficult to give a theoretical explanation through clinical or biomechanical analyses. Therefore, some scholars used the finite element method to further study the effect of the placement level on the mechanical properties of tension band wiring.

Wang et al. adopted the finite element method to establish an “8” figure tension band internal fixation model of type C1 patellar fractures, simulated two internal fixation conditions of parallel and cross K-wire when the knee was bent at 90°, and studied the influence of the insertion angle on the fixation efficacy by analyzing the K-wire displacement, fracture surface displacement, tension band displacement, and K-wires stress [22]. The results showed that the fixation effect of parallel insertion was better than that of angular insertion. However, there is a lack of research on the depth and distance of the K-wires. Ling et al. placed the K-wires at the medial and lateral 1/4 of the maximum transverse diameter line of the patella and categorized 5 K-wire placement levels in the Z-axis direction [18]. Distinct finite element models for the “0” and “8” shaped tension bands were established, considering different K-wire placement levels. In addition, the separation and displacement of the fracture sites, the force of patella, and the mechanical strength of the K-wires were analyzed. The results exhibited that the level of K-wire placement could affect the biomechanical properties of patellar tension band wiring, and K-wire placement at a superficial level should be avoided. To find the optimal K-wire placement level in patellar tension band fixation, Kim et al. simplified the patella into a cuboid, took the middle K-wire

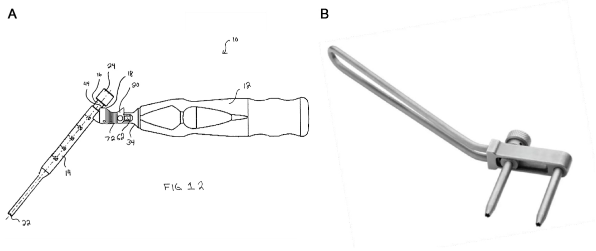

Figure 2. Types of guiding devices. (A) A guiding device for orthopedic surgery (patent No. US7131974 B2); (B) A parallel drill guide. Figure 2 is cited from [25, 26].

placement as the benchmark in the sagittal plane, and divided the superficial layer and the deep layer with an interval of 5 mm [23]. A simplified model of the "8" shaped tension band fixation system was established, and three K-wire placement conditions, shallow, medium, and deep, were set up. The effect of the depth of the K-wires on the mechanical properties of the tension band wiring was studied by the finite element method. It was found that the pressure on the articular surface was the largest, and the displacement of the fracture sites was smaller than 1 mm when the K-wires were placed in the deep layer, which was helpful for fracture healing.

Guiding devices and their clinical application

In clinical practice, most physicians perform free-hand K-wire placement based on experience. Therefore, inexperienced young physicians often need multiple intraoperative fluoroscopies to determine the optimal placement position, with low accuracy, long operation time, and large amount of intraoperative radiation.

Because of the above problems, researchers have been actively exploring and studying guiding devices for patellar K-wire placement. In 2002, Chen et al. developed a multi-functional K-wire guiding devices to meet clinical needs [24]. In 2006, Keyer et al. invented a guiding device for orthopedic surgery, as shown in **Figure 2A** (patent No. US7131974 B2) [25]. Their device has a simple structure, consisting of the first bit and the second bit that can slide relative to each other. However, even with the assistance of this device, it is difficult to conduct a good K-wire placement in patellar fracture fixation surgery, due to patellar irregularity. Arthrex disclosed a parallel drill guide, as shown in **Figure 2B**, which consists of a handle and two drill bits. In contrast to Keyer's, this device can ensure that the two K-wires are placed in parallel, but the position of the K-wires still needs to be determined based on doctors' experience [26]. In 2016, Liu et al. reported a caliper-type guiding device [27]. The research team started to develop the guiding device in 2010. They developed two generations of guiding devices successively and conducted mechanical test and clinical application research to verify its clinical value. Their guiding device significantly improved the accuracy of K-wire placement and shortened the average operation time from 76.09±10.77 minutes to 61.20±5.45 minutes. In 2017, Duan et al. designed orthopedic reduction forceps specifically for compression reduction, aiming to reduce the gap in patellar fractures and to guide K-wire placement [28]. There was a significant difference in operation time between the experimental group and the control group, in which the operation time of the experimental group was 17% less than that of the control group. The mean number of K-wire insertion was 2.05±0.28 and 2.48±0.71, respectively, and the mean number of fluoroscopies was 5.65±0.56 and 8.64±2.25, respectively. It can be seen that the forceps can reduce the number of K-wire insertion and fluoroscopies. In 2020, Wang et al. measured the anatomical parameters of normal patellar and developed a C-type guide device [19]. Using this guiding device, the appropriate depth and distance of the K-wires can be adjusted according to the individual needs, and the relative parallel of the two K-wires can be ensured. The preliminary clinical application showed that the guiding device can reduce the average fluoroscopy times by 49.4%, and the average operation time by 26.4%, as well as improve the success rate and accuracy of K-wire placement.

For internal fixation of patellar fractures, tension band wiring has been widely used, but the surgery mostly adopts the method of free-hand K-wire insertion, which requires the surgeons to have rich clinical experience and sophisticated operation skills. Because of the difficulty in the placement of K-wires, the operations usually require multiple fluoroscopies to adjust the insertion point, increasing the operation time and X-ray radiation dose.

In an attempt to improve the accuracy of K-wire placement, the following two factors should be considered: (1) The optimal K-wire placement level should be determined based on the measurement of patellar anatomical parameters. At present, there is insufficient research on patellar anatomy measurement for patellar fracture surgery, and rare studies focus on the placement level of K-wires. Based on normal patellar computed tomography (CT) image and high-reliability reference points, a 3D spatial coordinate system of patella can be established, and the depth of K-wires in the sagittal plane and the distance of K-wires in the coronal plane should be used to describe the placement level. In combination with the finite element method and clinical trials, the effects of different K-wire placement on tension band wiring can be analyzed to provide a new perspectives for K-wire placement levels of patellar tension band wiring. (2) Guiding devices with auxiliary K-wire insertion should be designed based on the K-wire placement level. At present, there are no special patellar K-wire guiding devices in clinical practice. Traditional guiding devices are mostly mechanical structures composed of members, fasteners, and scales, which have the advantages of low cost, easy manufacturing, stable performance, and high adaptability to environment. However, the majority of these devices are modifications of conventional surgical instruments in combination with surgical requirements. As a result, they are often limited to laboratory research or patent application stage and have not been widely promoted. 3D printed surgical drill guiding template is a novel way to improve the accuracy of K-wire insertion. The preparation process mainly includes the acquisition of CT image data, 3D reconstruction of the fracture model, selection of substrate, determination of K-wire entry direction, design of guiding hole, 3D printing, and post-processing. 3D printed surgical guides have been used in internal fixation surgery for fractures of the sacroiliac joint, spine, and femoral neck, but less reported in patellar fracture surgery. The reason for this is that the surgical guiding template needs to be personalized based on the patient's preoperative imaging, and the preparation process is tedious and time-consuming [29-31]. Image-guided navigation-based techniques can improve the accuracy of orthopedic surgery [32, 33]. However, the application of navigation techniques in patellar fracture surgery has not been reported in the literature. Moreover, the navigation technique uses CT scanning and 3D reconstruction, which require intraoperative image alignment and tool registration, and its radiation dose is higher than that of traditional surgery, which causes adverse effects on both patients and healthcare workers.

Conclusion

In summary, designing an optimal guiding device is the primary direction to improve the accuracy of K-wire placement. An optimal guiding device, which should be simple in structure and easy to operate, can assist doctors to place K-wires based on the placement levels, improve the accuracy of K-wire insertion, reduce the number of intraoperative fluoroscopies, and reduce the radiation of intraoperative X-rays to the human body. In this paper, the research progress on K-wire placement levels and guiding devices for patellar tension band wiring is reviewed to inspire the further development of guiding devices.

References

[1] Jarraya M, Diaz LE, Arndt WF, et al. Imaging of patellar fractures. Insights Imaging 2017;8(1):49-57.

[2] Hung LK, Chan KM, Chow YN, et al. Fractured patella: operative treatment using the tension band principle. Injury 1985;16(5):343-347.

[3] George DC, Georgios K, Chrysanthos DC, et al. What's new in the management of patella fractures? Injury 2022;53(6):1730-1736.

[4] Yu XL, Xu C, Li SD, et al. Progress on treatment of transverse patella fractures with tension band fixation. Zhongguo gu shang 2015;28(11):1069-1074.

[5] Lefaivre KA, O'Brien PJ, Broekhuyse HM, et al. Modified tension band technique for patella fractures. Orthop Traumatol Surg Res 2010;96(5):579-582.

[6] Sylvain S, Alexandre B, Jules C, et al. Practical guidelines for the treatment of patellar fractures in adults. Swiss Med Wkly 2020;150:w20165.

[7] Lenihan J, Ramos-Pascual S, Silvestros P, et al. Novel techniques demonstrate superior fixation of simple transverse patella fractures - A biomechanical study. Injury 2020;51(6):1288-1293.

[8] Zderic I, Stoffel K, Sommer C, et al. Biomechanical evaluation of the tension band wiring principle. A comparison between two different techniques for transverse patella fracture fixation. Injury 2017;48(8):1749-1757.

[9] Baran O, Manisali M, Cecen B. Anatomical and biomechanical evaluation of the tension band technique in patellar fractures. Int Orthop 2009;33(4):1113-1117.

[10] Wang L, Wei ZB, Yang JL, et al. Comparison of arthroscopic assisted closed reduction guider guided internal fixation and open reduction for the treatment of tibiofibular fracture. Tianjin Med J 2019;47(9):943-947.

[11] Bai ZB, Gao SC, Zhou HB, et al. Comparison of the clinical efficacy of different fixation systems for the treatment of transverse patellar fractures. Chin J Traumatol 2021;24(3):169-173.

[12] Lin T, Liu JB, Xiao BJ, et al. Comparison of the outcomes of cannulated screws vs. modified

tension band wiring fixation techniques in the management of mildly displaced patellar fractures. BMC Musculoskelet Disord 2015;16(1):282.
[13] Baldwin JL, House CK. Anatomic dimensions of the patella measured during total knee arthroplasty. J Arthroplasty 2005;20(2):250-257.
[14] Pontoh LA, Dilogo IH, Rahyussalim AJ, et al. Evaluation of patellar dimension and Bristol Index in Asian population: An MRI study. Ann Med Surg 2021;72:103072.
[15] Taj S, Raghunath G, Gurusamy K, et al. Morphometric Analysis of Dry Human Patella and Patellar Facets. Cureus 2022;14(3):22879.
[16] Yu ZG, Yao J, Wang XL, et al. Research methods and progress of patellofemoral joint kinematics: a review. J Healthc Eng 2019;9159267.
[17] Innocenti B, Bori E, Piccolo S. Development and validation of a robust patellar reference coordinate system for biomechanical and clinical studies. Knee 2020;27(1):81-88.
[18] Ling M, Zhan S, Jiang DJ, et al. Where should Kirschner wires be placed when fixing patella fracture with modified tension-band wiring? A finite element analysis. J Orthop Surg Res 2019;14(1):14.
[19] Wang FM, Xiong HL, Long XT, et al. A precise navigation device for fixation of patella fractures with modified K-wire tension band: a comparative retrospective study. J Orthop Surg Res 2021;16(1):101.
[20] Wu CC, Tai CL, Chen WJ. Patellar tension band wiring: a revised technique. Arch Orthop Trauma Surg 2001;121(1-2):12-16.
[21] Hsu KL, Chang WL, Yang CY, et al. Factors affecting the outcomes of modified tension band wiring techniques in transverse patellar fractures. Injury 2017;48(12):2800-2806.
[22] Wang MB, Lv HC, Zhang P, et al. Finite element analysis of patellar C1 fracture treated by tension band with different needle insertion angles. J Prac Orthop 2019;25(6):505-508.
[23] Kim Y, Kwon M, Ryu JY, et al. Biomechanical Analysis of the Kirschner-Wire Depth of the Modified Tension Band Wiring Technique in Transverse Patellar Fractures: An Experimental Study Using the Finite-Element Method. Clin Orthop Surg 2021;13(3):315-319.
[24] Chen LJ, Zheng W, Chen GQ. Design and application of multifunctional localizer for Kirschner wire. J Clin Orthop 2002;5(2):117-118.
[25] Keyer TR, Berger R, Kephart DS, et al. Surgical drill guide: United States, US7131974 B2. 2006;11:7.
[26] Arthrex. Parallel Drill Guide, Patella Fracture - AR-5050-11 2022. Available at: www.arthrex.com/products/AR-5050-11?referringteam=knee.
[27] Liu ZH, Zhao W, Shen QM, et al. Designing of a new drilling guide for K-wire in Tension-band wiring of patellar fractures and its experimental study. Sports Health 2016;32(13):2153-2157.
[28] Duan QM, Fang QM, Wang ZG. Development of orthopaedics-oriented reduction forcep and Initial clinical application in the patellar fracture. Chin Fore Med Trea 2017;36(6):36-39.
[29] Gauci MO. Patient-specific guides in orthopedic surgery. Orthop Traumatol Surg Res 2022;108(1):103154.
[30] Zhao YH, Luo HT, Ma YL, et al. Accuracy of S2 Alar-Iliac Screw Placement Under the Guidance of a 3D-Printed Surgical Guide Template. World Neurosurg 2021;146:e161-e167.
[31] Huang AB, Qi YS, Song CH, et al. Novel customized template designing for patellar resurfacing in total knee arthroplasty. J Orthop Res 2016;34(10):1798-1803.
[32] Zheng YS, Yang JZ, Zhang F, et al. Robot-assisted vs freehand cannulated screw placement in femoral neck fractures surgery: A systematic review and meta-analysis. Medicine 2021;100(20):e25926.
[33] Beisemann N, Gierse J, Mandelka E, et al. Comparison of three imaging and navigation systems regarding accuracy of pedicle screw placement in a sawbone model. Sci Rep 2022;12(1):12344.