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"Suspension bridge" external fixation technique for the treatment of proximal humeral fractures

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Background: The purpose of this study was to investigate the clinical efficacy of the "suspension bridge" external fixation technique for the treatment of proximal humeral fractures with or without soft tissue defects and infection, as well as postoperative revision.
Methods: From August 2013 to June 2018, 9 patients with proximal humeral fractures were selected. There were 5 males and 4 females, with an average age of 55.2 years (range: 32-74 years). Five patients were diagnosed with acute fractures (soft tissue defects in 2 patients). Of these patients, 1 patient was diagnosed with a fracture of the anatomic neck, 2 patients with 3-part fractures, and 2 patients with 4-part fractures. Internal fixation failure occurred in 4 patients, who needed revision surgery. Of these 4 patients, 1 patient was diagnosed with an anatomic neck fracture and 3 patients with 4-part fractures before surgery. Postoperative plate and screw fixation failure was the main cause of revision. One patient had an accompanying skin defect, and 1 had an infection. The "suspension bridge" external fixation technique was used to treat the fractures in the revision surgeries.
Results: The operative time was 84.1 minutes (range: 63-120 minutes), and the blood loss was 224.4 mL (range: 140-320 mL). The follow-up period was 35.1 months (range: 16-72 months). All fractures unioned, with an average unioning time of 12.7 weeks (range: 8-16 weeks). At the final follow-up, the flexion was 131.8° (range 108°-152°), extension 39.9° (range 32°-47°), abduction 128.6° (range 110°-150°), internal rotation 43.9° (range 34°-55°), and external rotation 60.7° (range 46°-72°); the mean visual analog scale score for pain was 1.3 (range 0-3), and the mean Neer score was 87.4 points (range 75-98 points). Efficacy was assessed as excellent in 4 patients, good in 3 patients, and acceptable in 2 patients; the excellent or good rate was 77.8%. No adverse events, such as postoperative infection, fixation failure, and nonunion, occurred during the follow-up.
Conclusion: The "suspension bridge" external fixation technique is an effective method for the treatment of proximal humerus fractures, and it can also be used for the treatment of skin defects and infections.
Level of evidence: Level IV; Case Series; Treatment Study

Keywords: Proximal humeral fractures; external fixation; shoulder joint; revision surgery

Our hospital's Ethical Committee classified this study as an audit and advised that no ethical approval was necessary. All clinical investigations were conducted in accordance with the guidelines of the Declaration of Helsinki. All patients were informed and signed the surgical consent form before surgery.

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Proximal humeral fractures are a common type of fracture in clinical practice, accounting for 4%-5% of all fractures.[8] With population aging, the incidence of proximal humeral fractures has gradually increased.[4] Most proximal humeral fractures can be treated conservatively,[9,12] but surgery is still the preferred treatment for unstable fractures. At present, despite the continuous development of internal fixation materials and surgical techniques, the incidence of postoperative complications is still as high as 16%-49%.[14] The complications associated with concurrent soft tissue defects and infection and with postoperative revision due to fixation loosening are highly challenging. This study aimed to investigate the safety and efficacy of the ''suspension bridge'' external fixation technique for the treatment of proximal humeral fractures with or without soft tissue defects and infection and for postoperative revision, as well as to evaluate this new treatment for clinical application.

Materials and methods

General data

This is a prospective case series of 9 patients. Among them, 5 were male and 4 were female. The average age was 55.2 years (range: 32-74 years). Five patients had left shoulder fractures and 4 had right shoulder fractures. Five patients were diagnosed with acute fractures. Of these patients, 1 patient was diagnosed with a fracture of the anatomic neck, 2 patients with a 3-part fracture, and 2 patients with a 4-part fracture. A patient with a 3-part fracture and another patient with a 4-part fracture had soft tissue defects. Revision surgery was needed in 4 patients, 1 of whom was diagnosed with an anatomic neck fracture and 3 with 4-part fractures before surgery. All fractures were fixated with a locking proximal humeral plate. After the operation, the fixation failed and the position was lost; one of these patients also had a skin defect and another had an infection. Three patients in this study were injured in traffic accidents and 6 by falling. For the patients with acute fractures, the time from fracture to surgery was 4.9 days (range: 3-7 days). The time to revision surgery was 10.6 days (range: 6-16 days) after surgery.

"Suspension bridge"–like external fixation device

The ''suspension bridge''–like external fixation device (Fig. 1) mainly includes an external fixation ring, olive wires, an intramedullary wire, ordinary screws, needlepoint screws, a vertical connection module, intramedullary wire washers, and a horizontal connection module. Kirschner wire and compression clamps were included as well. A Kirschner wire was used to fix the external fixation ring to the middle of the humerus, and then the vertical connection module and intramedullary wire washers were used to secure the intramedullary wire and the external fixation ring to form the 3-dimensional structure. Finally, olive wires were inserted through the reduced bone fragments, and the ends of the olive wires were compressed and fixed to the ring's main structure using a compression clamp to achieve an overall 3-dimensional structure of a ''suspension bridge''–like fixation.

Operative technique

''Suspension bridge'' external fixation surgery was performed under general anesthesia. The patient was placed in the supine position with 8-10 cm of elevation of the affected shoulder. Via a standardized deltopectoral approach, the fracture end was exposed. Excessive separation was avoided during the operation. After the fracture was reduced, a Kirschner wire was used for temporary fixation, and an appropriate external fixation ring was selected according to the size of the patient's upper arm. The external fixation ring was usually located in the middle of the humerus and fixed by a Kirschner wire. Then, a vertical connection module was used to bridge the external fixation ring and the intramedullary wire to complete the ''pedestal'' of the suspension bridge.

According to the type of fracture and the distribution of the bone mass, the upper arm was drilled from different directions, and the olive wire tips were pierced from the outside, anterior, and posterior sides, avoiding the inside. This facilitated the postoperative movement of the patient's shoulder. When drilling the olive wires in, vascular and nerve damage was avoided according to the anatomic relationship of the operation area. At the same time, attention was also paid to the tension of the patient's skin.

According to the position relationship between the olive wires and the outer fixing ring, the appropriate connection module was selected to properly pressurize the olive wires and fix them to the main structure of the ring, thus forming a complete ''suspension bridge'' 3-dimensional structure fixation. The tail of the olive wires were left outside and bent for easy removal after fracture unioning. Moving the shoulder joint showed that the fracture was stable and that the shoulder joint was moving satisfactorily. Finally, the wound was washed, hemostatized, and layered sutured.

For revision surgery, the patient was placed in the supine position with elevation of the affected shoulder. An incision was made along the original incision site to separate the soft tissue and expose the internal fixation plate for removal. The fractured fragment was managed, and autogenous bone or allogeneic bone grafting was performed according to the situation. ''Suspension bridge''–like external fixation surgery was performed as above.

Postoperative management and follow-up

Soft cotton pads were packed under the patient's axilla, and the neck-wrist strap was used to suspend the front arm for 2-4 weeks. After surgery, sterile gauze was usually used. When the pin tract was dry, no special treatment was required. If superficial pin tract infection occurred, a normal saline (nonalcoholic) wet compress, 3 times a day, was used to keep the pin tract clean, along with concurrent oral antibiotic treatment. On the first postoperative day, patients were encouraged to actively move their wrist and elbow joints. Three days after surgery, abduction and motion (front to back) of the shoulder joint was initiated. After 2 weeks, the patients began to move their shoulder joint passively and increase active movement. After 8-10 weeks, exercise with weight-bearing was started.

On the third day, 1 month, and 3 months after surgery, radiography with anteroposterior views was repeated on the affected shoulder joint. After 3 months, follow-up was performed monthly until the fracture unioned. After fracture union, the external

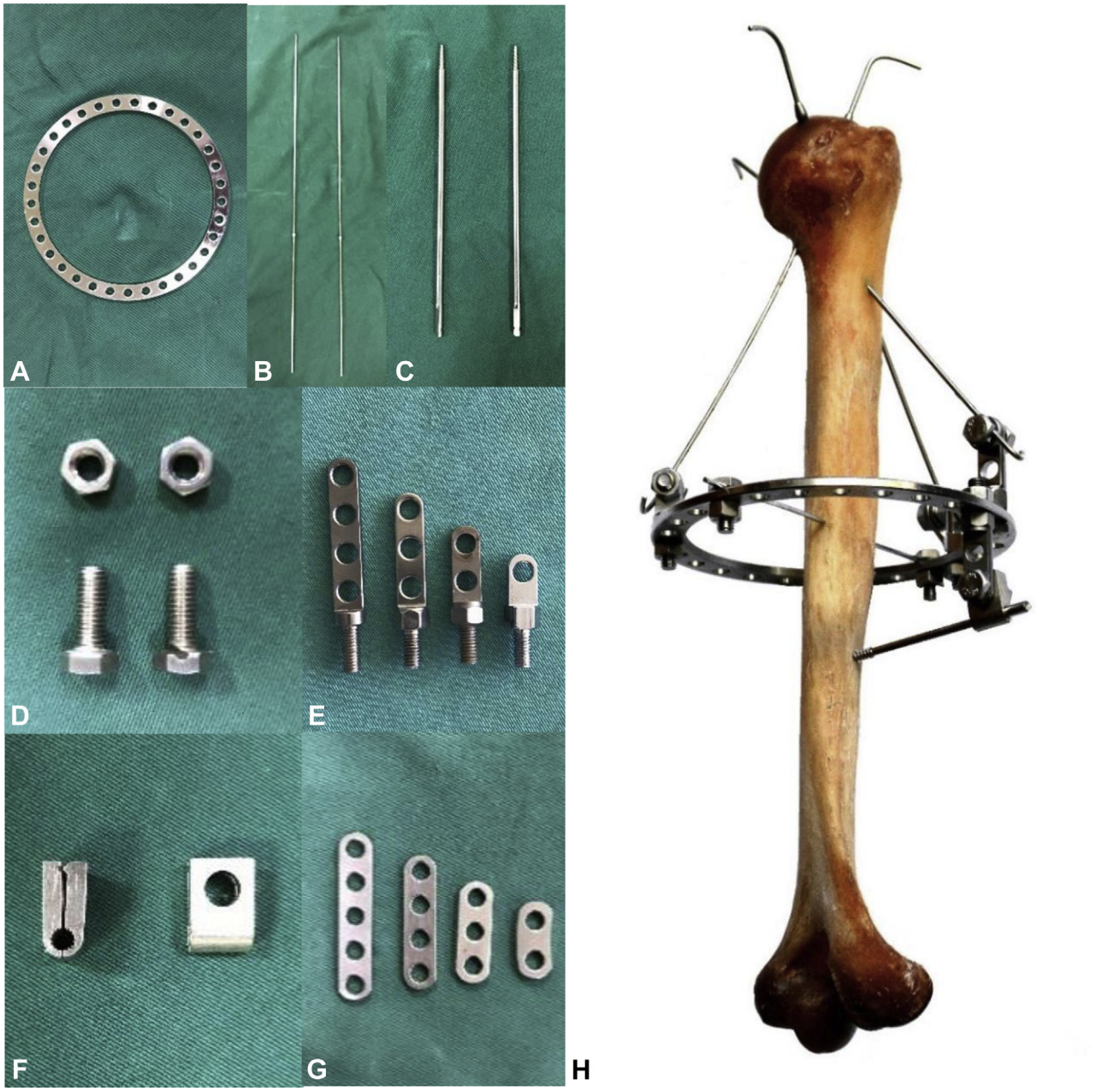

Figure 1 (**A**) External fixation ring, (**B**) olive wires, (**C**) intramedullary wires, (**D**) ordinary screws and needlepoint screws, (**E**) vertical connection module, (**F**) intramedullary wire washer, (**G**) horizontal connection modules, and (**H**) schematic diagram of a ''suspension bridge''–like external fixation device.

fixation device was removed. The main evaluation indicators in this study included the operative time, operative blood loss, fracture unioning time, shoulder range of motion, visual analog scale score, Neer score, and postoperative complications.

Results

All patients in this study underwent ''suspension bridge'' external fixation operation, 5 for primary surgery and 4 for revision surgery. In patients who underwent the procedure during the initial operation, we used a standardized deltopectoral approach, exposed the fracture end, and fixed it. At the same time, skin grafts were performed in 2 patients with skin defects. The patients who underwent revision surgery included plate removal, internal fixation, reset, and subsequent fixation. Two patients underwent bone grafting during the operation. In 1 of these patients who had skin flap necrosis, an adjacent transposition skin flap was implanted in the wound after débridement.

The mean operative time was 84.1 minutes (range: 63-120 minutes), and the intraoperative bleeding was 224.4 mL (range: 140-320 mL). The patients were followed up for 35.1 months (range: 16-72 months). All fractures

Table I Demographics and treatment outcomes of the patients included

ID	Age	Sex	Position	Causes of injury	Neer class	Case characteristics	Operative time, min	Intraoperative bleeding, mL	Follow-up, weeks	Union time, weeks	Range of motion					VAS score	Neer score
											Flex.	Ext.	Abd.	IR	ER		
1	32	M	L	Traffic accident	III	Revision/soft tissue defect	90	250	72	14	125	38	128	42	65	1	88
2	74	M	L	Fall injury	IV	Acute fracture	76	220	28	12	152	46	136	55	70	0	98
3	63	F	R	Fall injury	IV	Acute fracture/anatomic neck fracture	80	200	16	10	108	35	110	38	46	3	75
4	59	M	L	Fall injury	II	Acute fracture	65	150	36	12	142	42	126	45	62	2	91
5	38	F	R	Traffic accident	IV	Revision/infected	120	320	24	13	108	32	115	34	50	2	76
6	63	M	L	Fall injury	II	Revision/anatomic neck fracture	100	260	30	16	136	40	126	40	57	1	84
7	68	F	R	Traffic accident	IV	Acute fracture/soft tissue defect	75	200	36	14	143	45	144	46	64	1	92
8	48	F	R	Fall injury	III	Acute fracture/soft tissue defect	63	140	42	8	152	47	150	52	72	1	95
9	52	M	L	Fall injury	IV	Revision	88	280	32	15	120	34	122	43	60	1	88
Average	55.2						84.1	224.4	35.1	12.7	131.8	39.9	128.6	43.9	60.7	1.3	87.4

M, male; *F*, female; *L*, left; *R*, right; *Flex.*, flexion; *Ext.*, extension; *Abd.*, abduction; *IR*, internal rotation; *ER*, external rotation; *VAS*, visual anlog scale.

unioned, with an average unioning time of 12.7 weeks (range: 8-16 weeks).

At the final follow-up, the average flexion was 131.8° (range: 108°-152°), extension 39.9° (range: 32°-47°), abduction 128.6° (range: 110°-150°), internal rotation 43.9° (range: 34°-55°), and external rotation 60.7° (range: 46°-72°).

At the final follow-up, the mean visual analog scale score for pain was 1.3 (range: 0-3), and the mean Neer score was 87.4 points (range: 75-98 points). Efficacy was assessed as excellent in 4 patients, good in 3 patients, and acceptable in 2 patients; the excellent or good rate was 77.8% (Table I).

During the follow-up, although there were 2 cases in which the shoulder joint Neer score was rated as acceptable, there was no significant impact on the patient's daily life and work. No adverse events, such as postoperative infection, fixation failure, or nonunion, occurred during the follow-up (see Fig. 2 for typical cases).

Discussion

Proximal humeral fractures are a common type of fragile fracture that follows only distal radius fractures and hip fractures in its incidence rate. Approximately 75% of fractures occur in those older than 60 years.[13] Proximal humeral fractures in young adults are mostly caused by high-impact injuries. Except for simple fractures with insignificant displacement, which can be treated conservatively, complex or obvious fractures often require surgery. Surgical treatment methods mainly include plate fixation, intramedullary fixation, and humeral head replacement.[11,15] We choose different treatment methods according to the fracture type, bone condition, and the patient's age and expectations. Although these treatments have achieved good clinical results in the treatment of proximal humeral fractures,[1,6,16] there still are many surgical complications.[3,5,7,10]

For anatomic neck fracture of the humerus, it is difficult to achieve effective fixation strength because of the small volume of the humeral head and the small amount of bone. Shoulder joint replacement is an option for elderly patients with anatomic neck fractures of the humerus. However, studies have shown that the treatment effectiveness of shoulder hemiarthroplasty on proximal humeral fractures is not the same, and the overall effect is not satisfactory.[2] Although reverse shoulder replacement has some advantages over semi-shoulder replacement, it still has unique complications such as scapular notches, acromial fractures, and loosening implants.[3] In addition, for patients who need a second revision, such as due to nonunion, screw loosening, and infection, promoting rehabilitation is also a common technical difficulty. ''Suspension bridge'' external fixation technology provides a new method for the treatment of these fractures.

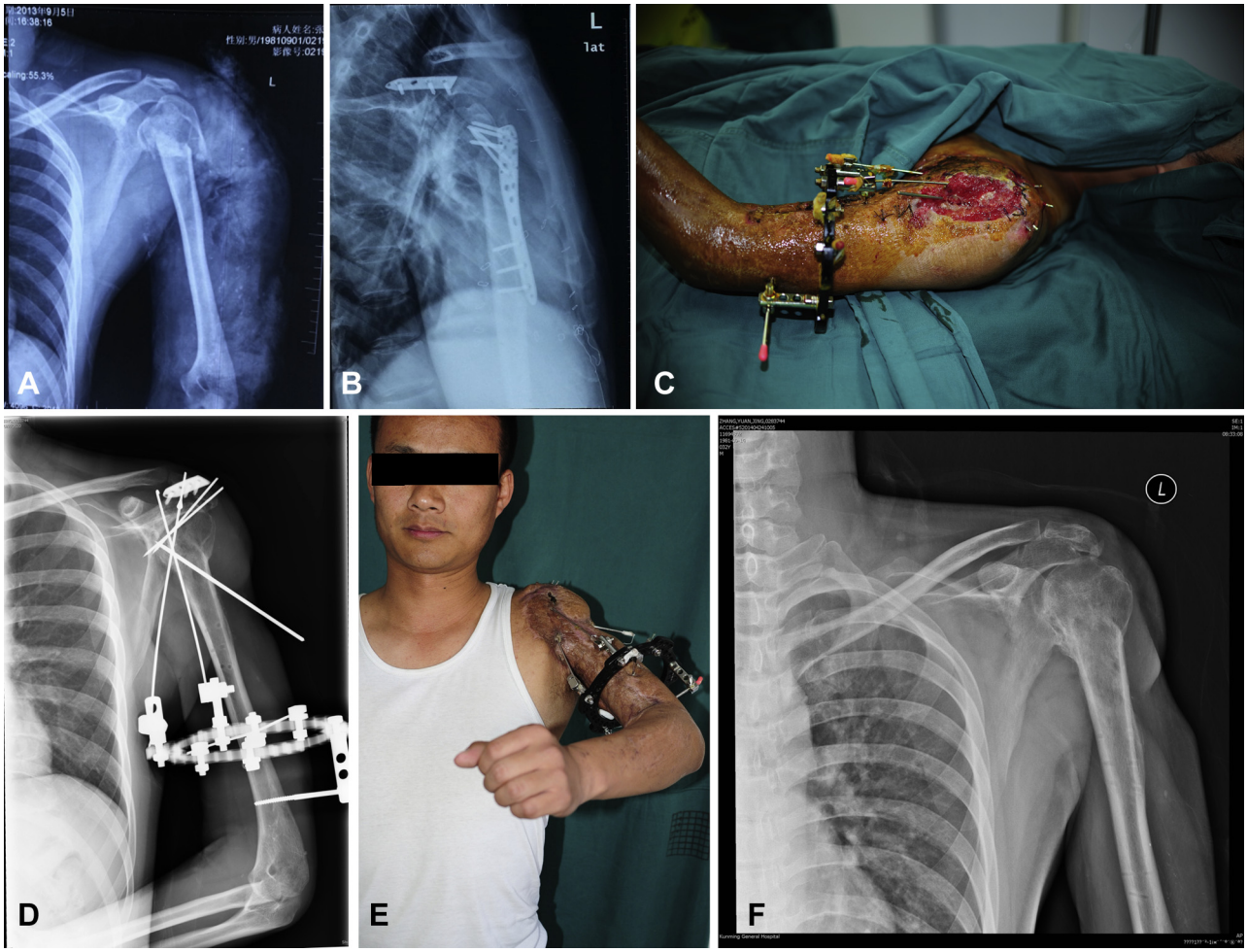

Figure 2 A 37-year-old man was diagnosed with left acromial and proximal humerus fractures with a skin defect caused by a car accident. (**A**) He underwent emergency débridement, phase 2 plate-screw internal fixation, and skin grafting. (**B**) A follow-up radiograph after surgery showed loss of proximal humerus fracture fixation and loosened screws. He transferred to our hospital 3 weeks after the surgery. The skin graft was partially necrotic after surgery. (**C**) After débridement and removal of the original internal objects, a ''suspension bridge'' external fixation was used. At the same time, the adjacent transposition skin flap was used to cover the wound. (**D**) Radiograph of the right shoulder joint after operation. (**E**) The patient could move the shoulder joint after surgery. (**F**) Radiograph of the shoulder joint after fracture unioning and removal of the external fixation.

In this study, based on the principles of ''suspension bridge'' fixation and minimally invasive surgery, ''suspension bridge'' external fixation technology was proposed. The external fixing ring is the ''pedestal'' of the suspension bridge, and the olive wires are the ''wires'' of the suspension bridge. Three-dimensional space fixation is realized through suspension and tension. We used this technique to treat proximal humeral fractures, including Neer III and IV fractures, anatomic fracture of the humerus, skin defects, infections, and revision operations.

During the operation, we chose an appropriate angle for drilling according to the anatomic relationship and the position of the bone mass. When the tip of the olive wire entered the joint cavity, the entry point and angle could be adjusted under direct visualization through the surgical opening. Under the premise of ensuring a safe and effective fixation, impact on the functional activity of the shoulder joint can be avoided as much as possible using this technique. It should be noted that the electric drill should be stopped after the olive wire has drilled out the bone, and then the olive wire should be carefully tapped and slowly moved forward at the far end. At the same time, the far end of the hand should be observed. If a nerve is touched, the far end of the hand will move, which is not safe. An alternative method is to use a sleeve tube. According to the direction of the olive wire, the sleeve tube should be inserted first, and then the olive wire should be inserted into the sleeve tube. Tension of the skin should be avoided when the olive wire is moved into and out of the skin, and nonaxial stress effects should also be avoided when the olive wire is placed for bridge fixation.

There are technical advantages and disadvantages of the ''suspension bridge''–type external fixation system.

Reduction of the fracture through incision assistance obtains better reduction effects, shortens the operation time, and reduces bleeding. The olive wire was used for different bone blocks and different directions of suspension and tension fixation to achieve a 3-dimensional space fixation that was balanced and strong. After the operation, the shoulder joint could be moved immediately to avoid joint stiffness. The method is suitable for patients with infections and skin defects. According to the condition of the fracture after the operation, the system can be adjusted in vitro and fixed with pressure at the fracture end. When the fracture is unioned, the fixation device can be removed in the office or outpatient department. The operation is simple, the technical difficulty is not high, the learning curve is short, and it is easy to master. However, because the fixation system is located outside the body surface, it may cause a superficial pin tract infection, which can be inconvenient for patients in terms of their work and life activities. Although we tried to adjust the position and angle of the olive wires, there was still some influence on the range of movement of the shoulder joint, resulting in the need to increase joint movement after fracture healing and removal of the fixation system to further improve joint function. In addition, anatomic neck fractures of the humerus will incur some damage to the articular surface when it is fixed with olive wires.

An important limitation of this study was the small number of cases and the lack of a comparison with other patients managed with different surgical techniques. Our findings need further confirmation through large comparative investigations. In future research, we will optimize and improve the fixation system according to the actual situation, improve the patients' comfort, and better promote their functional recovery.

Conclusion

The ''suspension bridge'' external fixation technique is an effective method for the treatment of proximal humerus fractures, and it can also be used for the treatment of skin defects and infections. This method is simple to operate, has low technical difficulty, and has a short learning curve. It has definite clinical application and promotion value.

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