International Orthopaedics (SICOT) (2012) 36:1191–1197
DOI 10.1007/s00264-012-1495-8

ORIGINAL PAPER

Retrograde dynamic locked nailing for valgus knee correction: a revised technique

Chi-Chuan Wu

Received: 23 November 2011 / Accepted: 13 January 2012 / Published online: 4 February 2012

Abstract
Purpose Traditionally, valgus knee deformity is predominately corrected by stabilisation with a plate inserted via the medial approach to the supracondylar region of the femur. However, this technique is unfavourable from both a biomechanical and a biological point of view. A revised retrograde dynamic locked nailing was developed to improve correction of this defect.
Method Forty-one knees with valgus deformity (average tibiofemoral angle, 22°; range, 16–29°) in 25 adult patients were treated by oblique femoral supracondylar varus osteotomy and stabilised with retrograde dynamic locked nails. Postoperatively, early ambulation with protected weight bearing and range of motion knee exercises were encouraged.
Result Thirty-five knees of 21 patients were followed-up for an average of 2.6 years (range, 1.1–4.5 years). All osteotomy sites healed with an average union period of 3.4 months (range, 2.5–5.0 months). There were no significant complications. At the latest follow-up, the average tibiofemoral angle was 7.1° valgus (range, 4–10° valgus). For all of the knees, the outcomes were satisfactory ($p<0.001$).
Conclusion The technique described here may be a feasible alternative for correction of valgus knee deformity. The advantages of this technique include the use of a biomechanically more appropriate method, a minimal complication rate and a high rate of satisfactory outcomes.

C.-C. Wu (✉)
Department of Orthopaedics, Chang Gung Memorial Hospital,
Chang Gung University,
Gueishan, Taoyuan, Taiwan
e-mail: ccwu@mail.cgu.edu.tw

Introduction

Valgus knee deformity is relatively uncommon. It may be of traumatic, degenerative or developmental origin [11, 16, 17, 35]. Biomechanically, 60–70% of the load passes through the medial compartment of the knee during stance phase in a normally aligned knee [27, 29, 34]. A knee with valgus deformity will shift the load towards the lateral compartment of the knee, leading to degenerative changes in this area [26, 27, 34]. A normal knee has been reported to have a tibiofemoral angle with 5–7° valgus [5, 18, 27, 34]. An acceptable knee alignment is considered to be within 10° of this range (i.e., 15–17° valgus) [3, 20, 34]. When the valgus deformity of the knee is progressive and symptoms appear, varus corrective osteotomy is one of the preferred treatment options [7, 17, 23]. Although relatively mild valgus deformity of the knee may be corrected by proximal tibial osteotomy, varus femoral supracondylar osteotomy is preferred for more severe cases [17, 23]. Traditionally, correction of a valgus knee is performed using the medial approach and stabilisation of fragments with a plate. A success rate of 60–86% has been reported [4, 7, 10, 17, 19, 30].

However, fixation of a plate on the medial aspect of the femur is biomechanically unfavourable owing to its contradiction of the tension band principle [2, 21]. Potentially, plate breakage with loss of fragment reduction may occur. In addition, a precise supracondylar osteotomy with the desired angle is a technically demanding procedure and placement of a plate requires a rather large incision [4, 10, 17, 19, 23, 30]. Improvement of surgical techniques is always necessary. Recently, retrograde femoral locked nailing has been used successfully to treat patients with femoral supracondylar fractures and in cases with nonunions or after osteotomy [6, 9, 12, 28, 33]. Continuing improvements in surgical techniques lead to higher rates of success. This retrospective study aimed to investigate a revised technique using retrograde dynamic locked nailing to correct valgus knee deformity and recommend a surgical technique that might yield improved results.

Materials and methods

Between February 2002 and May 2009, 25 consecutive adult patients (aged 16 or over) with valgus knee deformity were treated by femoral supracondylar varus osteotomy and stabilisation with retrograde dynamic locked nailing at the author's institution. All of the patients were operated upon and followed-up by the author. The patients were 19–52 years old (average age, 28 years) with a male-to-female ratio of 1 to 3. All of the valgus deformities had occurred since their childhood, and the patients had no memory of any injury. Surgical corrections were performed bilaterally in 16 patients and unilaterally in nine patients. Concomitant bilateral operations were not performed to allow patients post-operative ambulation. A minimum of three months was allowed between the operations. Surgical indications for the patients in this study were that they were adults, had valgus knee deformity with a tibiofemoral angle of more than 15°, and had suffered persistent aching pain in the lateral aspect of the knee for more than three months. Surgical contraindications were knee disorders involving the medial compartment, old age (≥65 years) or a deformed femoral shaft unfit for intra-medullary nail placement.

In the outpatient department, the range of motion of the knee for each patient was recorded. Anteroposterior and lateral radiographs were checked. A standing scanogram was obtained to determine the angle of deformation and the angle desired for correction. In this study, the tibiofemoral angle was 16–29° valgus (average, 22° valgus) with the required correction angle of 10–23° (average, 16°). Overcorrection was not planned owing to the relatively young age of the patients and minimal osteoarthritic change observed [7, 27].

Surgical technique

Under spinal anaesthesia, the patients were placed on the operating table in the supine position. A sterilised pneumatic tourniquet was routinely used.

A medial or lateral parapatellar tendon approach was performed. A skin incision, approximately 3-cm long, was made along the edge of the patellar tendon. With the knee bent at an angle of 45°, the intercondylar notch of the femoral condyle was identified. A bone window was made, with a power drill, over the intercondylar notch 5-mm anterior to the insertion of the posterior cruciate ligament on the medial femoral condyle.

A 5-cm skin incision was made anterolaterally over the supracondylar region of the femur. The femur was approached between the rectus femoris and the vastus lateralis. The cutting line was marked anteriorly approximately 3 cm proximal to the upper margin of the lateral femoral condyle (Fig. 1a and b) and directed upwards and medially. The angle between the cutting line and the vertical line to the lateral femoral cortex was equal to the desired angle for correction (achieved from the calculation of the standing scanogram). The femur was transected with a power saw and the anterior half of the upper medial cortex in the distal fragment was resected (Fig. 1c and d). This procedure was performed using the power saw that created a cutting line in the anterior cortex of the distal fragment perpendicular to the lateral cortex and 1 cm along the medial cortex (Fig. 1c). The posterior half of the upper medial cortex in the distal fragment was preserved as a cam.

The fragments were reduced by manipulation and the axis of the lower extremity was realigned. Usually, when the cutting line on the anterior cortex of the distal fragment closed to the medial cutting surface of the proximal fragment, the axis of planned correction was achieved. The posterior half of the bone apex in the distal fragment was countersunk into the marrow cavity of the proximal fragment to enhance stability (Fig. 1e). A rigid guide wire was subsequently inserted through the bone window in the intercondylar notch into the upper part of the femoral shaft to establish a true canal through which a flexible guide wire could be passed (Fig. 1f). After the flexible guide wire was inserted, the marrow canal was reamed as widely as possible (Fig. 1g). A 1-mm smaller femoral locked nail (Russell-Taylor femoral locked nail, Smith & Nephew, Memphis, TN, USA) with an adequate length was inserted in a retrograde fashion (Fig. 1h). Usually, the size of locked nails was 11–12 mm and the end was planned to be at the level of the lesser trochanter to avoid introduction of stress fractures [24]. The distal diagonal locked screw was inserted, but two upper transverse locked screws were not. Thus, a dynamic mode of locked nailing was used.

The angular and rotational stabilities of fragments were checked and a dynamic compression plate (Synthes, Bettlach, Switzerland) could be inserted to provide reinforcement [33]. However, this was not required in any of the cases in this study. The bone defect on the lateral aspect of the osteotomy site was packed with the resected corticocancellous bone graft (Fig. 1h). The wound was closed with absorbable sutures. Throughout the entire procedure, no image intensifier was used or radiographs taken.

Postoperatively, the patients were allowed to ambulate with protected weight bearing as early as possible. Exercise through a range of knee motion was encouraged. The patients were followed up in the outpatient department at intervals of four to six weeks. Standing scanograms were taken immediately after the operation and whenever necessary. Use of crutches was discontinued only after the healing of the fracture.

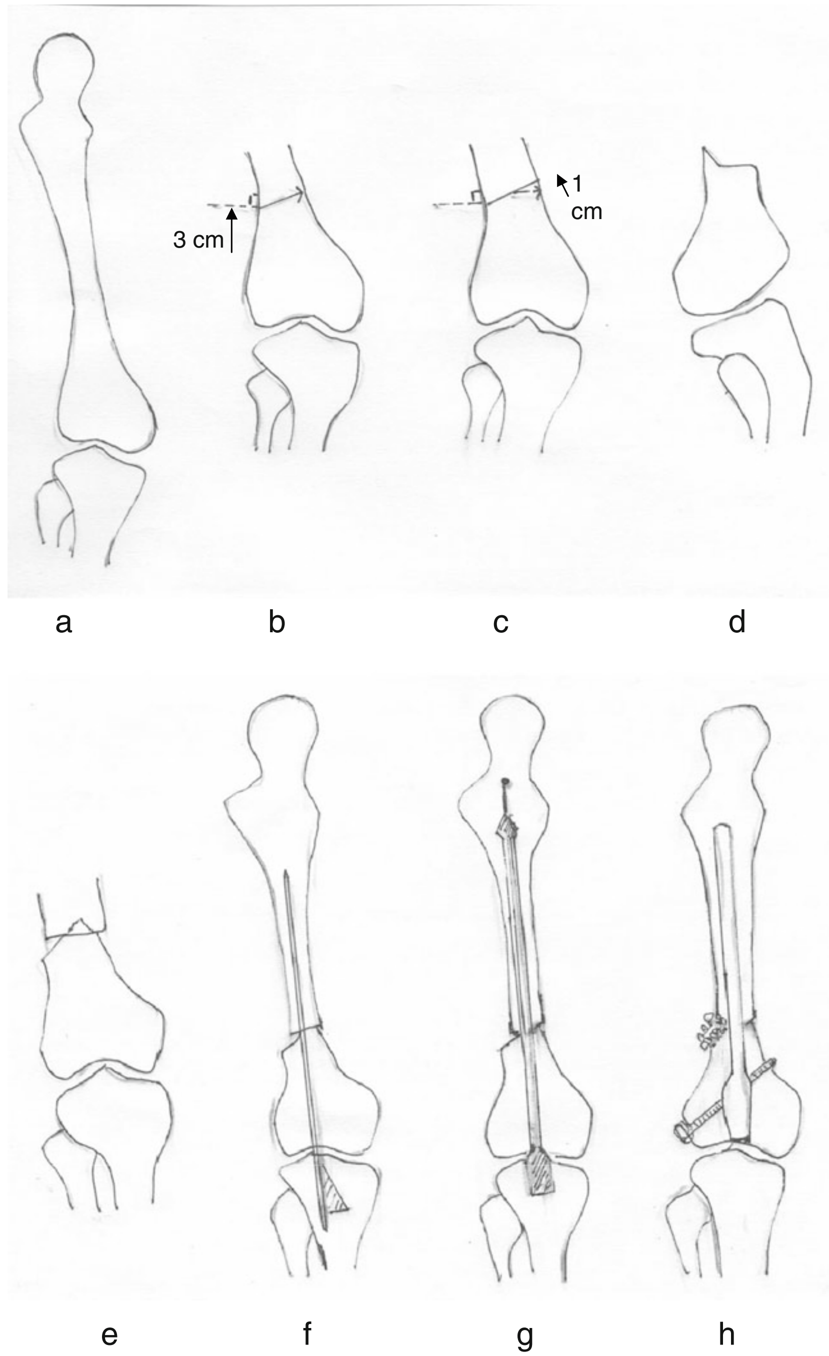

Fig. 1 The steps involved in the modified femoral supracondylar varus osteotomy technique. **a** A valgus knee requires treatment. **b** A cutting line, orientated upwards and medially, is made 3-cm proximal to the lateral femoral condylar cortex. The angle between the cutting line and a vertical line to the lateral femoral cortex is equal to the desired angle of correction. **c** A second cutting line is made in the medial part of the distal fragment. The cutting line is perpendicular to the lateral femoral cortex with the removal of 1-cm of the medial cortex. **d** The anterior portion of the medial side of distal fragment is removed. **e** The distal fragment is realigned. The posterior portion of the medial side of the distal fragment is countersunk into the proximal fragment. **f** A rigid guide wire is used to establish a precise canal. **g** After, the rigid guide wire is changed to a flexible one and the marrow cavity is reamed as widely as possible. **h** A 1-mm smaller femoral locked nail is inserted and only the distal diagonal locked screw is inserted. Corticocancellous bone graft procured from the medial side is packed into the gap on the lateral side

A bone union was recognised clinically when no pain or tenderness was observed and the patients could walk without aids; radiographically, it was defined as the trabeculae having bridged the osteotomy site or a solid callus having connected the fragments [33]. Nonunion was defined as the osteotomy site still not having healed one year after treatment or requiring futher surgery to achieve a union [25].

Knee function was evaluated using a modified Mize scoring system and four grades were defined [20]. The outcome was considered satisfactory if the patients received an excellent or good grade. An excellent result included a loss of flexion of <10°, full extension, a lack of varus, valgus or rotational deformity, and absence of pain. A good result included no more than one of the following observations: >20° of flexion loss, >10° of extension loss, >5° of varus or valgus deformity, and minimal pain. This modified Mize's system was used in this study because of its simplicity and relative practicality (i.e., it did not require evaluation of the osteoarthritic situation).

To allow comparison, a Fisher's exact test or paired Student's t-test was used. A p-value of <0.05 was considered statistically significant.

Results

Thirty-five knees with valgus deformation in 21 patients were followed-up for at least one year (average, 2.6 years; range, 1.1–4.5 years). Fourteen patients underwent bilateral corrections and seven patients, unilateral correction.

All osteotomy sites healed. The union rate was 100% with an average union period of 3.4 months (range, 2.5–5.0 months). Immediately after the operation, the average tibiofemoral angle was 7.1° valgus (range, 5–9° valgus). At the latest follow-up, the average tibiofemoral angle was 7.1° valgus (range, 4–10° valgus; $p=1.0$; Table 1; Fig. 2).

There were no significant complications due to deep infection, nonunion or malunion (varus or valgus deformity >5°, shortening >2 cm). However, a technical complication occurred in one knee owing to forceful hammering of the locked nail into the marrow cavity. Mild splitting of the distal fragment was noted intraoperatively and the treatment was supplemented with a cortical screw (Synthes, Bettlach, Switzerland). All of the fractures healed uneventfully (Fig. 3).

Knee function was significantly improved postoperatively. Before the operation, all of the knees were classified as unsatisfactory; both persistent aching pain and valgus deformity were present. At the latest follow-up, all knees were classified as satisfactory ($p<0.001$). There were no knees with unacceptable valgus deformity (> 12° valgus of the tibiofemoral angle); however, nine patients experienced minimal, irregular aching pain.

Discussion

Factors favouring fracture healing are minimal gap, adequate stability, and sufficient nutrition supply [15]. After the supracondylar femur is osteotomised and realigned, fracture healing is dependent on these three factors. Normally, femoral supracondylar fractures are stabilised with a plate or nail system [8, 14, 22]. However, owing to the fact that varus osteotomy is generally performed in the lower part of the femoral supracondyle, antegrade locked nailing is unsuitable [32]. In a clinical setting, a plate is the first choice because retrograde locked nailing is not widely used [6, 7, 9].

In the literature, most orthopaedic surgeons treat valgus knee deformities by using the medial approach, wherein a plate is placed in the medial aspect of the distal femur [4, 7, 10, 17, 19, 30]. Technically, the procedure is relatively complex, and it is contrary to the tension band principle [2, 6, 13, 21]. If the patients bear the entire weight before bony union has occurred, implant failure or loss of fragment reduction may occur [31]. In this study, a retrograde femoral locked nail was used. This provides a biomechanical advantage compared to medial plating. This study showed no evidence of fixation failure.

To minimise the gap between the two fragments in closed wedge osteotomy, impaction is required when using the plating technique [4, 10, 17, 19, 30]. However, minimising the gap in a wedge osteotomy is technically difficult. It is more practical to fill the gap with a cancellous bone graft [10, 14, 30]. In this study, the posterior half of the upper part of the distal fragment is countersunk into the marrow cavity

Table 1 Comparison of various techniques of femoral supracondylar varus osteotomy

Surgical technique	Knee no.	Etiology	Initial valgus angle (°)	Latest valgus angle (°)	Union period (months)	Major complications	Satisfactory rate (%)	Follow-up (years)
Plating								
Medially								
Healy et al. (1988) [10]	23	15 OA	18	2	–	2 nonunions	83	4
Wang and Hsu (2005) [30]	30	30 OA	18	1.2	4.7	1 nonunion	83	8.3
Backstein et al. (2007) [4]	38	–	11.6	−7.2	–	–	60	10.3
Kosashvili et al. (2010) [17]	33	33 OA	–	–	–	–	30	15.1
Laterally								
Jacobi et al. (2011) [13]	14	14 OA	–	–	–	1 nonunion	–	3.8
Casting								
Aglietti et al. (1987) [1]	14	9 OA	21	2.3	2.1	no	71	2
Mathews et al. (1998) [19]	15	15 OA	15	5	–	7 stiffness 3 nonunions	33	3
Nailing								
Gugenheim and Brinker (2003) [9]	14	Multiple	–	–	3.3	No	69	2.8
This study (2011)	35	Devel	22	7.1	3.4	No	100	2.6

Devel developmental, *OA* osteoarthritis, – unavailable

Fig. 2 A 25-year-old woman with bilateral knee deformities and a tibiofemoral angle of 29° valgus was treated. Bilateral knee deformities were treated by the technique described. Both osteotomy sites healed at 3.5 months, and excellent outcomes were achieved at a 3.6-year follow-up. The tibiofemoral angle at the latest follow-up was 8° valgus

of the proximal fragment. Thus, gaps in the medial aspect of the osteotomy site disappear. This technique may have the additional advantage of enhancing local stability. Additionally, corticocancellous bone graft harvested from the medial aspect of the distal fragment is packed into the lateral aspect of the osteotomy site to minimise the gap. A dynamic mode of intramedullary nailing can also reduce the gap [33]. In this study, the rate of healing of all of the fractures was higher than that reported in studies that used the plating techniques (Table 1).

A sufficient supply of nutrients to the site is normally maintained by the preservation of the local vasculature. Placing of a traditional plate usually requires extensive soft tissue dissection. Placing of a locked plate, using a minimally invasive technique, is theoretically difficult owing to the contour of the medial femoral condyle. Until now, no clinical studies have reported the use of a locked plate to treat valgus knee deformity. The use of a retrograde locked nail minimises soft tissue dissection at the osteotomy site. In this study, all fractures healed uneventfully.

In an attempt to stabilise fragments with a plate for correction of valgus knee osteoarthritis, Backstein et al. achieved a 60% satisfactory rate at a ten-year follow-up and Wang et al. achieved an 83% satisfactory rate at a 99-month follow-up [4,

Fig. 3 A 52-year-old woman with a right knee deformity and a tibiofemoral angle of 24° valgus was treated. The knee deformity was treated with the technique described. A tibiofemoral angle of 7° valgus was achieved immediately after the operation. A cortical screw was used to treat the cortical splitting, which occurred during nail hammering. The osteotomy site healed at 4.0 months and an excellent outcome was achieved at the four-year follow-up. The tibiofemoral angle at the latest follow-up was 6° valgus

30]. Aglietti et al. achieved a 71% satisfactory rate at a two-year follow-up by using supracondylar V-osteotomy and immobilization by a long-leg cylinder cast [1]. Although, in our study, the average follow-up period was only 2.6 years, a 100% success rate was achieved (Table 1). The lower satisfactory rate reported in previous studies may be attributable to more severe knee degeneration occurring during the longer follow-up period. However, the main aim of our study was to develop a simple surgical technique to treat valgus knee deformity, as long as its satisfactory rate is acceptable. The angle after correction is considered the main determinant of prognosis [1, 4, 7, 10, 30].

The use of retrograde locked nails to correct varus or valgus knee deformities has been reported previously [9]. Gugenheim and Brinker treated 14 deformed knees with a temporary external fixation after dome osteotomy to correct deformity. Consequently, a classic retrograde static supracondylar femoral nail was inserted. After an average of a 33-month follow-up, all of the fractures had healed with a union period of 3.2 months. Pain was reduced in all patients and walking ability improved in 69% of the patients. In our study, external fixation was unnecessary and traditional femoral locked nails with a dynamic mode were inserted in a retrograde fashion. All of the fractures healed and all of the patients were able to walk normally. Technically, the revised technique is greatly simplified, and a high rate of satisfactory outcomes was achieved.

It is recommended that the end of a retrograde locked nail reaches the level of the lesser trochanter [24]. A short classic femoral supracondylar nail may induce a stress riser leading to a stress fracture. In this study, a traditional femoral locked nail was used and no stress fractures were observed.

When the osteotomy is performed, the angle between the cutting line and the vertical line to the lateral femoral cortex is equal to the desired angle of correction. When the anterior half of the medial cortex of the distal fragment is removed, the second cutting line is also vertical to the lateral femoral cortex. Therefore, the two cutting lines are parallel and the two angles are equal. Once the second cutting line closes to the first cutting line, the desired correction is achieved. Moreover, in the osteotomy site, the local tissues are fresh and loose. The desired alignment is normally easy to be kept for insertion and stabilisation with retrograde locked nails.

There are several limitations to this study and these should be taken into account when interpreting the results: (1) The follow-up period was short. A 2.6-year period may be insufficient to predict the long-term outcomes of this technique. Normally, the success rate will decrease during the follow-up period. However, this does not change the fact that a new surgical technique, which ameliorates the disadvantages of current techniques of plating, has been developed. (2) The sample size is small. It was not possible to divide the patients into two groups to compare different angles of correction. In the literature, this issue is still controversial because the number of cases available is always small. With our technique, the angle of correction can be achieved as planned. (3) The age of the patients in this study may be relatively young. Hence, this technique may not be applicable to older patients. In cases with local osteoporosis, plate or cement augmentation may be required [33]. (4) The modified Mize's scoring system is not commonly used [20]. Hence, it is difficult to compare knee function determined in this study with that determined in other studies. This system is used in this case for its simplicity and relative practicality. As described above, the aim of this study was to develop a better surgical technique, not to improve the long-term treatment of osteoarthritis.

In conclusion, the described technique may be a feasible alternative for the correction of valgus knee deformity. The advantages of this technique include the use of a biomechanically more appropriate method, a minimal complication rate, and a high rate of satisfactory outcomes.

References

1. Aglietti P, Stringa G, Buzzi R, Pisaneschi A, Windsor RE (1987) Correction of valgus knee deformity with a supracondylar V osteotomy. Clin Orthop Relat Res 217:214–220
2. Albright JA, Johnson TR, Saha S (1978) Principles of internal fixation. In: Ghista DN, Roaf R (eds) Orthopedic mechanics: procedures and devices. Academic, London, pp 123–229
3. Andriacchi TP (1994) Dynamics of knee malalignment. Orthop Clin North Am 25:395–403
4. Backstein D, Morag G, Hanna S, Safir O, Gross A (2007) Long-term follow-up of distal femoral osteotomy of the knee. J Arthroplasty 22:2–6
5. Chao EYS, Neluheni EVD, Hsu RWW, Paley D (1994) Biomechanics of malalignment. Orthop Clin North Am 25:379–386
6. Chen SH, Yu TC, Chang CH, Lu YC (2008) Biomechanical analysis of retrograde intramedullary nail fixation in distal femoral fractures. Knee 15:384–389
7. Dabov GD (2008) Miscellaneous nontraumatic disorders. In: Canale ST, Beaty JH (eds) Campbell's operative orthopedics. Mosby, Philadelphia, pp 987–1060
8. Foster TE, Healy WL (1991) Operative management of distal femoral fractures. Orthop Rev 20:962–969
9. Gugenheim JJ Jr, Brinker MR (2003) Bone realignment with use of temporary external fixation for distal femoral valgus and varus deformities. J Bone Joint Surg Am 85:1229–1237
10. Healy WL, Anglen JO, Wasilewski SA, Krackow KA (1988) Distal femoral varus osteotomy. J Bone Joint Surg Am 70:102–109
11. Healy WL, Iorio R, Lemos DW (1998) Medial reconstruction during total knee arthroplasty for severe valgus deformity. Clin Orthop Relat Res 356:161–169
12. Henry SL, Trager S, Green S, Seligson D (1991) Management of supracondylar fractures of the femur with the GSH intramedullary nail: preliminary report. Contemp Orthop 22:631–640
13. Jacobi M, Wahl P, Bouaicha S, Jakob RP, Gautier E (2011) Distal femoral varus osteotomy: problems associated with the lateral open-wedge technique. Arch Orthop Trauma Surg 131:725–728
14. Johnson KD, Hicken G (1987) Distal femoral fractures. Orthop Clin North Am 18:115–132

15. Karlstrom G, Olerud S (1974) Fractures of the tibial shaft: a critical evaluation of treatment alternatives. Clin Orthop Relat Res 105:82–111
16. Kettelkamp DB, Hillberry BM, Murrish DE, Heck DA (1988) Degenerative arthritis of the knee secondary to fracture malunion. Clin Orthop Relat Res 234:159–169
17. Kosashvili Y, Safir O, Gross A, Morag G, Lakstein D, Backstein D (2010) Distal femoral varus osteotomy for lateral osteoarthritis of the knee: a minimum ten-year follow-up. Int Orthop 34:249–254
18. Learmonth ID (1990) A simple technique for varus supracondylar osteotomy in genu valgum. J Bone Joint Surg Br 72:235–237
19. Mathews J, Cobb AG, Richardson S, Bentley G (1998) Distal femoral osteotomy for lateral compartment osteoarthritis of the knee. Orthopedics 21:437–440
20. Mize RD, Bucholz RW, Grogan DP (1982) Surgical treatment of displaced, comminuted fractures of the distal end of the femur. J Bone Joint Surg Am 64:871–879
21. Perren SM (1989) The biomechanics and biology of internal fixation using plates and nails. Orthopedics 12:21–34
22. Pritchett JW (1984) Supracondylar fractures of the femur. Clin Orthop Relat Res 184:173–177
23. Puddu G, Cipolla M, Cerullo G, Franco V, Gianni E (2010) Which osteotomy for a valgus knee? Int Orthop 34:239–247
24. Ricci WM (2005) Femur: trauma. In: Vaccaro AR (ed) Orthopedic knowledge update: 8. American Academy of Orthopedic Surgeons, Rosemont, pp 425–431
25. Seinsheimer F (1978) Subtrochanteric fractures of the femur. J Bone Joint Surg Am 60:300–306
26. Sharma L, Song J, Felson DT, Cahue S, Shamiyeh E, Dunlop DD (2001) The role of knee alignment in disease progression and functional decline in knee osteoarthritis. JAMA 286:188–195
27. Sherman C, Cabanela ME (2010) Closing wedge osteotomy of the tibia and the femur in the treatment of gonarthrosis. Int Orthop 34:173–184
28. Tejwani NC, Park S, Iesaka K, Kummer F (2005) The effect of locked distal screws in retrograde nailing of osteoporotic distal femur fractures: a laboratory study using cadaver femurs. J Orthop Trauma 19:380–383
29. Tetsworth K, Paley D (1994) Malalignment and degenerative arthropathy. Orthop Clin North Am 25:367–377
30. Wang JW, Hsu CC (2005) Distal femoral varus osteotomy for osteoarthritis of the knee. J Bone Joint Surg Am 87:127–133
31. Wang JW, Hsu CC (2006) Distal femoral osteotomy for osteoarthritis of the knee: surgical technique. J Bone Joint Surg Am 88:100–108
32. Wu CC (1991) Interlocking nailing of distal femoral fractures: 28 patents followed for 1-2 years. Acta Orthop Scand 62:342–345
33. Wu CC (2009) Retrograde dynamic locked nailing for femoral supracondylar nonunions after plating. J Trauma 66:195–199
34. Yang NH, Nayeb-Hashemi H, Canavan PK, Vaziri A (2010) Effect of frontal plane tibiofemoral angle on the stress and strain at the knee cartilage during the stance phase of gait. J Orthop Res 28:1539–1547
35. Zhang AL, Exner GU, Wenger DR (2008) Progressive genu valgum resulting from idiopathic lateral distal femoral physeal growth suppression in adolescents. J Pediatr Orthop 28:752–756