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Biomechanical analysis of the dynamic hip screw in the treatment of intertrochanteric fractures

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Summary. A prospective study was performed in 148 elderly patients (over 60 years old) whose intertrochanteric fractures were caused by moderate trauma. The patients were treated with dynamic hip screws and followed up for at least 2 years (average 34 months). The lag screw was placed as the biomechanical analysis favored. Follow-up showed that the majority achieved good union and were without mechanical failure. The authors conclude that a lag screw should ideally be placed inferiorly toward the medial margin in the frontal plane and centrally in the sagittal plane. The length of the lag screw should be such as to extend from 1.0 cm beneath the subchondral bone to the lateral femoral cortex. At least four cortical screws (piercing the cortex at eight points) should be inserted on the distal femoral fragment.

Intertrochanteric fractures are common injuries caused by two different etiologies. The majority of patients with these injuries are in the older age group and the fractures are caused by a moderate injury (such as slipping and falling). The other group is younger and the injuries are caused by high-energy trauma (such as traffic accidents). Following the advances of modern medicine, the life span of humankind has become significantly longer. Thus, the numbers of intertrochanteric fractures due to senile and menopausal causes have also risen markedly [3]. Once such disability occurs, the treatment now tendentially favored is operation [16]. Early postoperative ambulation can effectively lessen the mortality and morbidity rate. Furthermore, a dynamic hip screw (DHS) has been the treatment of choice all over the world [2, 8].

An intertrochanteric fracture is an extracapsular lesion, and the incidence of osteonecrosis of the femoral head is very low [5, 13]. Due to the cancellous bone of the metaphysis nonunion is also infrequent [5, 18]. The most significant complication during the course of treatment is mechanical failure, which includes cutting out or penetration of the lag screw and breakage of the side plate [15]. The biomechanical characteristics of the DHS have been well studied, but the most adequate placement of the lag screw is still a matter of controversy [6]. Particularly, there is the problem that the osteoporotic bony stock of an aged femoral head cannot stabilize the lag screw well, and cutting out or penetration of the screw becomes not unusual.

This was a prospective study. The authors analyzed the biomechanical characteristics of the DHS, then utilized it in the fixation of intertrochanteric fractures in elderly patients. The theoretically most satisfactory location of the lag screw was assessed and identified. The authors' intention was to find the most ideal location for the placement of the lag screw.

Patients, materials and methods

From June 1986 to May 1988, 320 consecutive elderly patients (older than 60 years) with intertrochanteric fractures caused by moderate trauma were treated with a DHS at the authors' institution. They were aged from 60 years to 95 years (average 74 years) and the male to female ratio was one to four. No simultaneous bilateral fractures were seen. All fractures were closed and the majority were unstable (loss of abutment of medial cortex) [5, 19]. The causes of fracture were simple falls or slipping while walking, and falls from a sitting position or from bed.

More than half the patients had associated medical problems, mostly hypertension and diabetes mellitus. If diagnosis and treatment were delayed for a couple of days, impaired renal function due to dehydration was usually evident. The principles of treatment were immediate control of the systemic condition and performance of DHS as early as possible.

The favored surgical procedure was closed reduction of the fracture fragment using an image intensifier first under spinal anesthesia. The favored placement of the lag screw was inferiorly and toward the medial margin of the femoral head in the frontal plane, with central placement in the sagittal plane. The tip of the lag screw was 1.0 cm beneath the subchondral bone (Fig. 1). The length of the lag screw was such that it extended beyond the lateral femoral cortex. No initial osteotomy procedure to stabilize the unstable fracture was performed. At least four cortical screws (piercing the cortex at eight points) were inserted on the distal fragment. If the cortical screws could not be screwed tightly, circumferential wiring was added. Postoperatively, patients were permitted ambulation with a walker or a wheelchair as early as possible.

Patients were followed up at the outpatients department at 4- to 6-week intervals and the healing processes recorded clinically and roentgenographically. Exercise of the quadriceps as well as of the range of motion of hip and knee was encouraged. After bony union ensued, patients were advised to have regular follow-up

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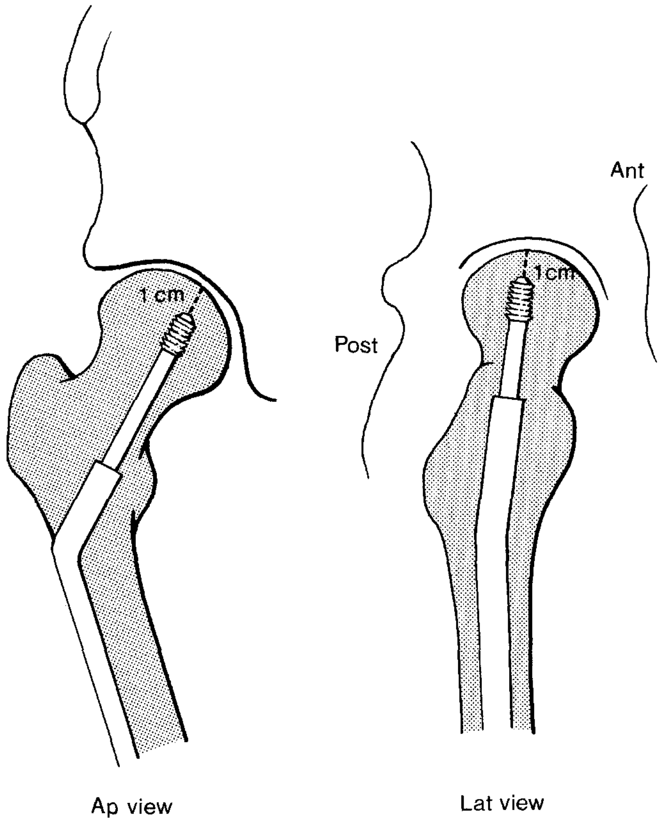

Fig. 1. The favored placement of the lag screw is inferior and toward the medial margin in the frontal plane, with central placement in the sagittal plane. The tip of the lag screw is 1.0 cm short of the subchondral bone

every year. Usually, the implant was not removed unless it caused significant complications.

Results

Of the 320 patients, 285 were followed up until bony union occurred and 148 patients completed a follow-up period of at least 2 years (average 34 months). The causes of loss to follow-up were death, inconvenience of transportation to the clinic, and inability of the hospital to contact the patients. We defined bony union clinically by absence of pain and tenderness, and the patient's walking without aids; the roentgenographic criterion was evidence of intramedullary trabeculi bridging the fragments [7]. Nonunion was the verdict when the fracture was still ununited after a 1-year follow-up period [22]. Delayed union was union achieved after 6 months [7].

The 285 patients followed up to union had an average period to union of 2.5 ± 0.6 months (Fig. 2). Only one delayed union was noted. The 148 patients with complete follow-up sustained no osteonecrosis of the femoral head in at least 2 years of follow-up.

Complications

One deep infection was noted 5 days postoperatively and was treated with debridement, local drainage, and septopal chain insertion. Bony union ensued in 7 months. Then the implant was removed and there was no recurrence.

No cutting out or penetration of the lag screw nor any side plate breakage was noted.

Six DHSs needed to be removed after bony union ensued due to intolerable irritation of the soft tissue by the sliding lag screw (telescoping effect).

Discussion

Although we have complete follow-ups for at least 2 years for only 46.3% (148/320) of patients, 89.1% (285/320) of patients were followed up until bony union occurred. The authors consider 285 cases enough to allow conclusions as to the mechanical failure rate. Theoretically, implant failure should very rarely occur after the fracture has healed, given the usually low daily activity of the elderly [25]. Therefore, the results of 148 cases are analyzed here to represent 285 cases, despite the fact that delayed infections may theoretically occur.

Humans are bipedal animals. In the stationary bipedal support position, the center of gravity of the body is lo-

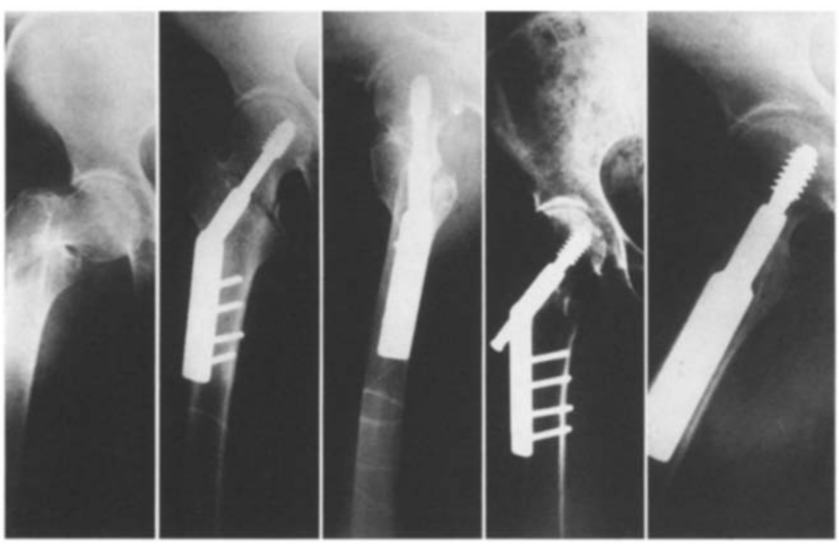

Fig. 2. A 85-year-old woman sustained a right intertrochanteric fracture from a fall while walking. A dynamic hip screw (DHS) was inserted in the planned manner. Bony union ensued in 2 months. The implant was still in a satisfactory position at 3-year follow-up

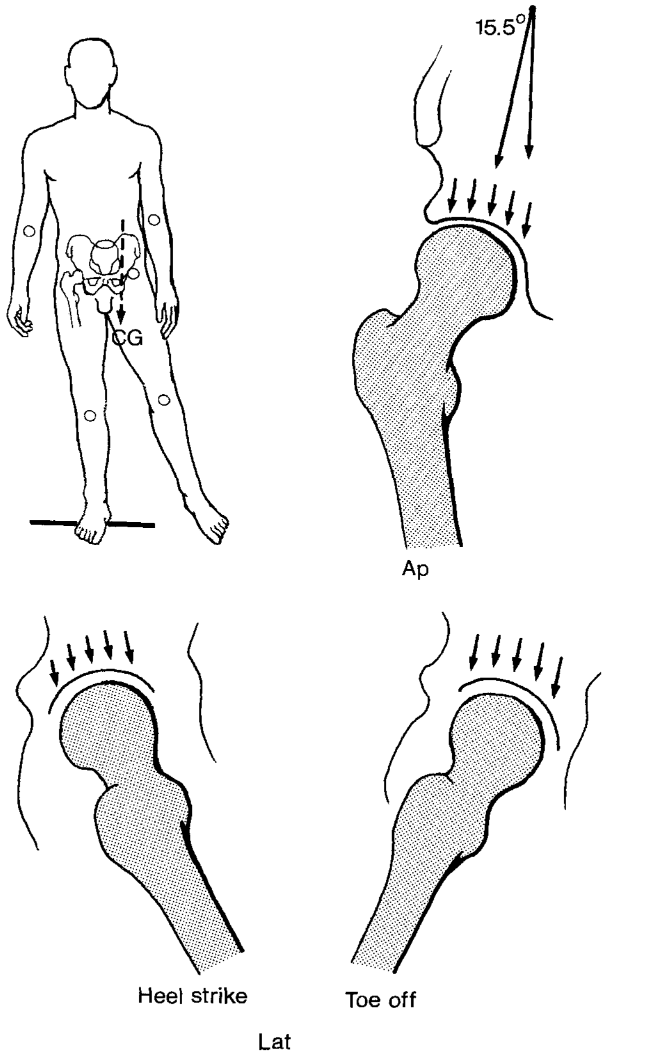

Fig. 3. In monopedal support, the center of gravity (CG) moves toward the contralateral side. The increased lever arm produces markedly increased stress on the femoral head. The resultant force is directed 15.5° inferolaterally in the frontal plane and at various angles inferoanteriorally to inferoposteriorally in the sagittal plane

cated in the midsagittal plane and in a coronal plane passing through the disk between T10 and T11. Only one-third of the body weight bears on each femoral head. However, the situation is very different in the monopedal support position. The body's center of gravity moves 2 inch toward the unsupported side and down to the level of the disk between L3 and L4. The increase in length of the lever arm produces a marked rise in the load on the femoral head to three times the body weight. In addition, the resultant force is directed 15.5° inferolaterally in the frontal plane. During gait, the center of gravity changes to various positions according to the particular phase of the stride in the sagittal plane [4, 17]; after all, the body contour of humans is narrower in the sagittal plane and broader in the frontal plane. The lever arm of counteractor muscles which produce markedly increasing loading on the femoral head has much less effect in the sagittal plane. In addition, the resultant force has an inferoanterior or inferoposterior direction at various angles [4] (Fig. 3).

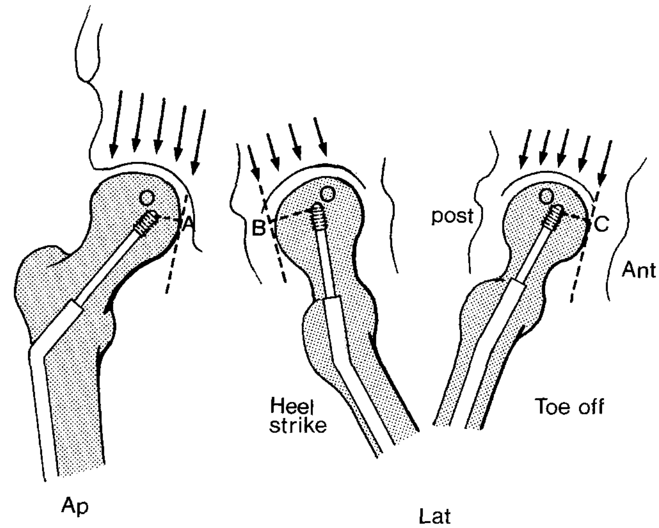

Fig. 4. The rotatory moment of the femoral head is decided by the lever arm (OA in the frontal plane, *OB* or *OC* in the sagittal plane). Inferior placement of the lag screw can shorten *OA* in the frontal plane. For avoidance of an unfavourable *OB* or *OC,* the lag screw is best inserted centrally in the sagittal plane

When an implant is inserted in the femoral head, it becomes the support of the proximal fragment. The tip of the implant is the fulcrum and center of rotation. To reduce the lever arm of rotatory force and increase the stress-bearing surface of the lag screw, theoretically, the tip should be placed as medially as possible in the frontal plane. On a similar principle, the tip should be placed centrally near the subchondral bone in the sagittal plane. Therefore, to prevent cutting out of the lag screw, theoretically, the tip should be inserted medially in the frontal plane and centrally and deeply in the sagittal plane. Clinically, to achieve this purpose, the lag screw can be inferiorly placed in the frontal plane and centrally and deeply in the sagittal plane (Fig. 4).

Koch's biomechanical study of 1917 shows that the major compressive stress is borne by the proximal medial femoral cortex, and is maximal at a point about 7.5 cm distal to the lesser trochanter [12]. An unstable intertrochanteric fracture is one with loss of abutment of the medial cortex, due to which the bending force that arises in weight bearing will produce fixation failure. Due to the poor, osteoporotic bony stock of the proximal fragment in elderly patients, an implant usually does not break, but cutting out usually results instead. In the past, osteotomy was advocated to stabilize and prevent such a complication in unstable fractures [19, 20]. However, its main importance is for angle plate fixation, which does not produce dynamic compression in the fracture site. The compressive load can not be transferred to the distal fragment due to the medial cortical gap and will produce fragment migration in the osteoporotic fragment. The invention of the DHS reduces the incidence of implant failure. By the telescoping effect during weight bearing, interfragmental compression can transfer the proximal stress into the distal fragment. A well-known study by Kyle et al. [14] revealed that for facilitating the sliding effect of a lag screw, the engaged screw in the barrel should be maximal. Another condition was utilizing a higher angle side plate. The disadvantage was the technical difficulty of performance and the impossibility of medial-ward insertion. Should the lag screw be jammed, it may cut out or penetrate the hip joint. For this reason, the placement of the lag screw should not be too near the subchondral bone. Clinically, inferior placement of the lag screw in the frontal plane has the advantages of being both far from the subchondral bone and a deep medial placement.

Although an intramedullary nail can lessen the lever arm of the femoral shaft to the center of gravity [21, 24], it has no interfragmental compressive effect. For an unstable intertrochanteric fracture, an intramedullary nail is always a load-bearing device. However, with the telescoping effect, a DHS becomes a tension band plate and can promote the healing process [1, 9]. Nevertheless, a DHS must be performed with open reduction and the surgical risk is higher [11]. In osteoporotic bone, fixation of the side plate to the lateral femoral cortex with cortical screws is usually challenging. Four cortical screw fixations are advocated if stability can be achieved [23], otherwise a longer plate to reach the distal thicker femoral cortex or supplementary circumferential wire must be utilized. Failure of side plate fixation should be less likely in older patients who are less active. So far, there still exists no surgical technique which can offer both advantages. A DHS is still the treatment of choice for intertrochanteric fractures.

A review of earlier literature reveals the various recommendations for the placement of the lag screw [6]. The incidence of mechanical failure is reported as 0–19% [6, 10, 16, 19]. The present series reveals a relatively high union rate and no fixation failure. The most probable difference between this series and other might be adequate placement of the lag screw, which can then tolerate greater loading during the healing process. Thus, the most serious postoperative complication will be deep infection. The causes of this are multiple and management with local drainage until bony union is the most reasonable and practicable procedure.

On the basis of the theoretical and clinical considerations, the present authors conclude that a DHS is still the treatment of choice for intertrochanteric fractures in the elderly. The lag screw should be placed inferiorly and toward the medial margin of the femoral head in the frontal plane and centrally in the sagittal plane. The tip should be about 1.0 cm from the subchondral bone. The length of the lag screw should be such that it extends beyond the lateral femoral cortex. The side plate should have at least four cortical screw insertions on the distal fragment. This offers the maximum guarantee against implant failure.

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