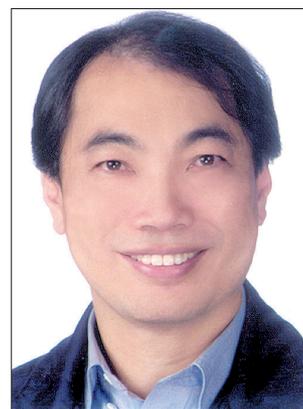


## Using Biomechanics to Improve the Surgical Technique for Internal Fixation of Intracapsular Femoral Neck Fractures

Chi-Chuan Wu, MD

Despite advances in science and technology, the success rate for the treatment of displaced intracapsular femoral neck fractures in high-energy injuries remains disappointing. The blood supply system in the femoral head of humans does not favor recovery from these fractures. Once these fractures occur, osteonecrosis and nonunion rates may be as high as 30%, even if the newest technique is used. There are some surgical techniques used to supplement internal fixation to reestablish the blood supply in the femoral head, but none have been evidently successful. After analysis of related studies, the author concludes that immediate surgical treatment using improved techniques incorporating the principles of biomechanics can improve the success rate of treatment of these fractures. Using these principles, the fracture site can achieve sufficient stability. Consequently, the blood supply in the femoral head and neck can be reestablished earlier and loss of reduction of fragments during treatment can be minimized. Thus, the chance of full recovery from these complicated fractures can be maximized. In this study, the biomechanical characteristics of these fractures and the principles associated with the surgical techniques used for treating them are reviewed and clarified. Finally, a surgical technique which is ideal from the author's viewpoint is presented. The author believes that the recommended surgical technique may become the best method for treating these complicated fractures. (*Chang Gung Med J* 2010;33:241-51)



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**Key words:** internal fixation, intracapsular femoral neck fracture, cannulated screw, biomechanics

**I**ntracapsular femoral neck fractures (subcapital or transcervical type) are common injuries. Most of these fractures occur in elderly patients and are caused by low-energy injuries such as slipping. Fractures caused by high-energy injuries are rare and usually occur in young patients as a result of motor vehicle accidents.<sup>(1-7)</sup> The principles for treating these fractures have been broadly defined. Displaced

fractures (Garden stage 3 or 4) in elderly patients ( $\geq 65$  years) are preferably treated with prosthetic replacement.<sup>(8-14)</sup> Non- or minimally displaced fractures (Garden stage 1 or 2) in elderly patients or all fractures of any Garden stage in young patients are preferably treated by closed reduction and stabilization with multiple cannulated screws.<sup>(13,15-20)</sup> However, despite advances in science and technology, the out-

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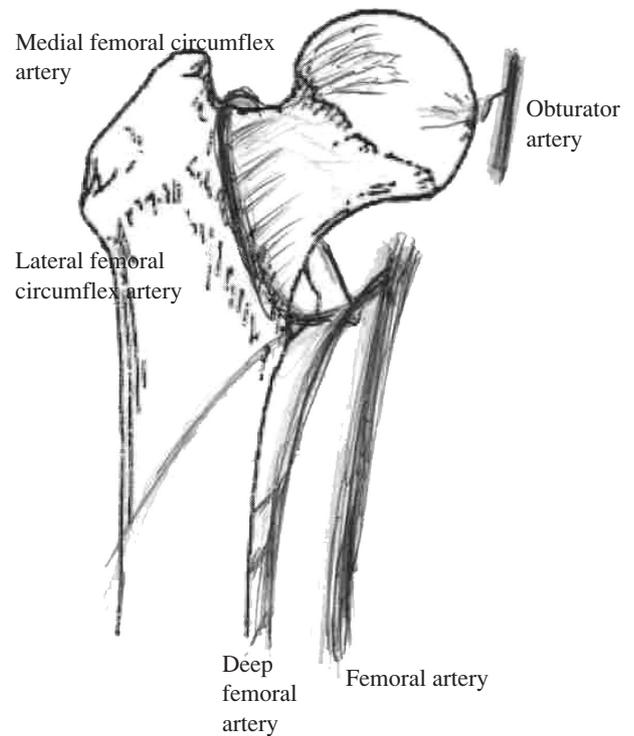
Correspondence to: Dr. Chi-Chuan Wu, Department of Orthopedics, Chang Gung Memorial Hospital, 5, Fu-Hsin St., Gueishan Township, Taoyuan County 333, Taiwan. Tel.: 886-3-3281200 ext. 2423; Fax: 886-3-3278113; E-mail: ccwu@mail.cgu.edu.tw

comes reported after surgical treatment of displaced intracapsular femoral neck fractures in young patients with high-energy injuries remain disappointing. The osteonecrosis rate in the femoral head is 15%-30%, and the nonunion rate in the femoral neck is 10%-30%; both rates are similar to those reported two decades ago.<sup>(4,5,21-25)</sup>

The pathomechanisms of both osteonecrosis and nonunion have been thoroughly studied, and the main complication preventing effective and early recovery has been found to be severe deprivation of blood supply in the femoral head. Therefore, rapid, effective reestablishment of the blood supply in the femoral head and the neck is considered the gold standard for successful treatment.<sup>(4,5,7,21)</sup>

#### **Blood supply in the femoral head and neck**

The blood supply in the femoral head and neck has been extensively studied. In adults, three arterial sources are believed to provide blood to this region.<sup>(3,5,26-30)</sup> The main source is the multiple retinacular arterioles that penetrate the hip capsule and reach the epiphysis of the femoral head (Fig. 1). These retinacular arterioles are the ascending branches of the arterial ring around the basal neck, which is formed by anastomosis of the medial and lateral femoral circumflex arteries. The latter two arteries are branches of the deep femoral artery, which is the biggest branch of the femoral artery (continuing from the external iliac artery). The second source of blood supply in the femoral head is the artery of the ligamentum teres, which is a branch of the obturator artery (a branch of the internal iliac artery). However, it supplies blood to only a small part of the femoral head (medioinferior portion). The third source is distal to the junction of the femoral head and neck and is from the intramedullary canal (endosteal arterioles). When the femoral neck is fractured and the fragments are displaced, almost all blood supply to the femoral head is blocked. Reestablishing blood supply is critical and should be achieved as soon as possible.<sup>(4,5,21)</sup> In the medical literature, the two most important factors determining the prognosis of intracapsular femoral neck fractures are the interval between the time of the fracture and internal fixation, and the fracture type (Garden classification).<sup>(4,5,7,21,31)</sup> There are some surgical techniques used to supplement internal fixation in order to reestablish the blood supply in the femoral head, but



**Fig. 1** Most of the blood supply in the femoral head comes from the ascending retinacular arterioles, which are branches of an arterial ring formed by the anastomosis of the medial and lateral femoral circumflex arteries. Blood supply from the obturator artery is minimal.

none have been evidently successful.<sup>(4,5,25,32-35)</sup>

Although some orthopedists advocate making an incision in the hip capsule to reduce intracapsular pressure to improve blood supply in the femoral head, others do not favor this technique.<sup>(4,5,7,31,36)</sup> Practically, it increases the operating time, creates an open fracture, and only achieves an imagined advantage (because the hip capsule may have torn during the fracture, so making an additional incision in the hip capsule is superfluous).

Vascularized bone grafts (vascular-pedicle or muscle-pedicle source) may be concomitantly supplemented during fracture treatment.<sup>(25,32-35)</sup> However, this procedure greatly increases the operating time and the local vulnerable vascularity may be further compromised. Furthermore, it creates an open fracture with a large surgical wound. From the viewpoint of damage control, this technique is usually impractical for the emergency care of patients with high-

energy injuries.<sup>(37,38)</sup> In the medical literature, support for simple internal fixation with multiple cannulated screws is more widespread.<sup>(4,5,21,39)</sup> Vascularized bone grafts should be used in cases of delayed treatment.<sup>(25,35)</sup>

Factors favoring fracture healing include minimal gaps, adequate stability, and sufficient nutrition supply.<sup>(40)</sup> Theoretically and practically, the most reasonable and feasible technique for treating intracapsular femoral neck fractures in young patients is closed reduction of fragments and stabilization with multiple cannulated screws as soon as possible.<sup>(4,5,21)</sup> It is hoped that the residual blood supply is not compromised further and vascular webs can be reestablished earlier. Thus, the chance of full recovery from complicated intracapsular femoral neck fractures can be maximized.

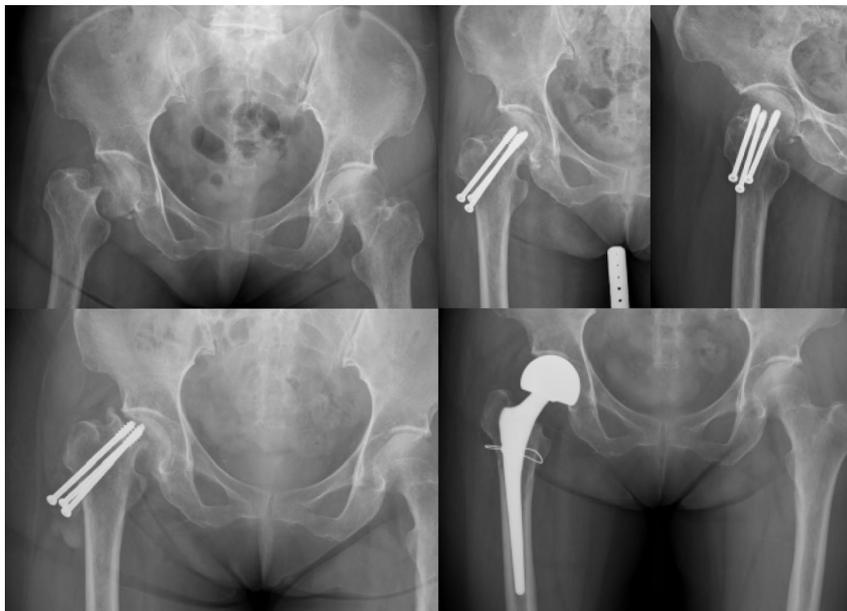
**Biomechanical considerations for improving surgical techniques to increase the success rate**

After fracture fragments are reduced by means of the closed technique, the fracture site is stabilized with three or four cannulated screws with a closed technique.<sup>(26,27)</sup> However, both procedures are technically demanding, and in some cases, they fail because the cannulated screws do not provide suffi-

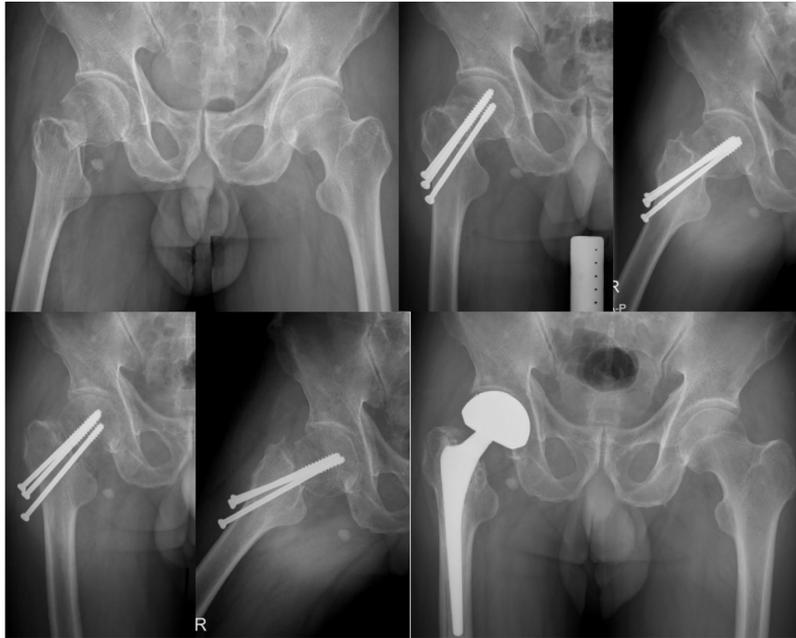
cient stability.<sup>(7,18,41-44)</sup> The unstable fragments can hinder the reestablishment of vascularity and furthermore, the unstable femoral head migrates with loss of reduction. Consequently, osteonecrosis of the femoral head and nonunion of the femoral neck can occur. More than half of failed cases at the author's institution were caused by technical errors that resulted in insufficient stability from the three or four cannulated screws used (Fig. 2-6). Therefore, improving the surgical technique so that it provides sufficient stability is a crucial step in increasing the success rate.<sup>(4,5,7,36,41-43,45)</sup>

**Stresses on the femoral head during daily activity**

Humans are bipedal and the femoral head normally sustains huge stresses during the stance phase of a gait cycle.<sup>(46)</sup> The stresses include axial, bending, and torsional forces. The total stresses during daily activity are considered to be 3-6 times the body weight (180-360 kg) and the orientation of the forces is 17° downwards and laterally.<sup>(47)</sup> Therefore, cannulated screws must be inserted so that they can withstand the three-dimensional stresses. In other words, multiple screws cannot be convergent. A divergent configuration is superior to a convergent configuration and can provide sufficient stability.<sup>(13)</sup>



**Fig. 2** A Garden stage 4 right femoral neck fracture treated with closed reduction and fixation with three cannulated screws. The screw purchase of all three screws is insufficient, resulting in insufficient stability with loss of reduction. Finally, a bipolar hip arthroplasty was performed.



**Fig. 3** A Garden stage 3 right femoral neck fracture treated with closed reduction and fixation with three cannulated screws. The three screws were too close to each other, resulting in insufficient stability and inability to withstand rotational stresses. Nonunion with loss of reduction of the femoral neck forced treatment with a bipolar hip arthroplasty.



**Fig. 4** A Garden stage 4 left femoral neck fracture treated with closed reduction and fixation with three cannulated screws. The non-parallel screws could not provide sufficient stability, resulting in loss of reduction, A total hip arthroplasty was finally performed.



**Fig. 5** A Garden stage 3 right femoral neck fracture treated with closed reduction and fixation with three cannulated screws. The screws were too proximal close to each other, which caused cutting out from the femoral head. A bipolar hip arthroplasty was finally performed.



**Fig. 6** A Garden stage 3 left femoral neck fracture treated with closed reduction and fixation with three cannulated screws. The three screws were too central and close, and could not achieve stable support from the femoral neck cortex. The fracture healed with a varus deformity.

Fractured fragments are normally reduced by a closed technique under the guidance of an image intensifier. The acceptable range of reduction reported in the medical literature is a 160°-180° angle of the primary compressive trabeculae to the medial femoral cortex in the anteroposterior view and the same angle for the pure primary compressive trabeculae in the lateral view.<sup>(5,26,27)</sup> However, there may still be a gap in the fracture site after closed reduction, and this gap will hinder the fracture healing process.<sup>(40)</sup> Therefore, if three or four cannulated screws are inserted in a parallel fashion, local compression can eliminate the gap, enforcing fracture healing (Fig. 4).<sup>(4,5,21,48)</sup>

#### ***Local stability provided by three or four cannulated screws***

Screws engaged in both the proximal and distal fragments might provide sufficient stability to withstand large three-dimensional stresses. Therefore, the screw end should reach the subchondral bone area.<sup>(26,27)</sup> A cannulated screw has a wide thread, which can provide a larger bone purchase than a Knowles pin.<sup>(15,41,44,49-52)</sup> Theoretically, cannulated screws enable a higher success rate. However, in terms of biomechanics, cannulated screws are not different from Knowles pins.<sup>(53)</sup> Similarly, this deduction is not consistent with the results of a study conducted at our institution 18 years ago.<sup>(49)</sup> The success rate in that study (using multiple Knowles pins) was similar to present reports with cannulated screw treatment.<sup>(4,5,21)</sup> Thus, presently, technical errors and not devices may determine the outcomes of these complicated fractures. In other words, improving surgical techniques can increase the success rate in treatment.

The location of multiple cannulated screws has been studied biomechanically.<sup>(39,48,50-52)</sup> Inserting the screws in an inverted triangle configuration is considered ideal.<sup>(4,5,21,54)</sup> There are reports that using three or four cannulated screws provides similar stability in the femoral head.<sup>(4,5,21)</sup> However, a normal triangle configuration was found to be better than an inverted triangle configuration in single vertical load testing.<sup>(48)</sup> The difference between the two models was up to 22.5% in terms of the applied loads. The reason for this difference is that an inverted triangle in the lower hemisphere of the femoral head has support from only one screw compared to two screws in a

normal triangle configuration. However, during daily activity the loads on the femoral head alternate anteriorly and posteriorly. The wider side of the inverted triangle in the upper part of the lower hemisphere has a longer lever arm, allowing the configuration to withstand femoral head rotation.<sup>(13,55)</sup>

The location of all cannulated screws is important. In a gait cycle the center of gravity of the human body alternates anteriorly and posteriorly. Therefore, the two cannulated screws in the upper corner of the inverted triangle should not be inserted too close to the articular surface.<sup>(46)</sup> This precaution is taken to avoid the screw from cutting out anteriorly or posteriorly. The forces from the acetabulum are transferred to the femoral head at 17° downwards and laterally. A single lower cannulated screw inserted in the lower part of the femoral head can prevent the screw from migrating upwards. The two upper cannulated screws, should not be placed too superiorly, as this positioning prevents the screws from cutting out superiorly (Fig. 5). Importantly, the three cannulated screws cannot be placed too close because the wider side of a triangle has a longer lever arm, enabling the configuration to better withstand femoral head rotation (Fig. 3).<sup>(48,55)</sup>

Because the marrow cavity of the femoral neck is not dense, connecting the femoral head and lateral femoral cortex with three cannulated screws does not achieve a rigid framework.<sup>(4,5,21)</sup> Although spikes in the fracture line can prevent fragments from sliding, cannulated screws are displaced in the direction of force (Fig. 6).<sup>(2,56)</sup> To prevent their displacement, all screws should be inserted close to the neck cortex. Thus, the neck cortex becomes the fulcrum of the cannulated screws, which is required for the three-point fixation to be effective.<sup>(56)</sup>

#### **Techniques recommended by the author at Chang Gung Memorial Hospital, Linkou**

After administering spinal anesthesia, the patient is placed in the supine position on a fracture table. An image intensifier is then prepared.

The footplate provides traction while the distal fracture fragment is pulled distally. The lower extremity is internally rotated 20°-30° and then, the traction is released slowly.<sup>(26,27)</sup> The fracture site is examined in the image intensifier. An acceptable range of reduction is from 160° to 180° between the primary compressive trabeculae and the medial

femoral cortex in the anteroposterior view and the pure primary compressive trabeculae in the lateral view or an anterior and posterior angulation of less than  $10^\circ$ .<sup>(4,5,21)</sup> If an acceptable range cannot be achieved, the procedure is repeated by manipulating the hip area. If the closed reduction fails repeatedly, open reduction with a small incision on the fracture site should be performed under the guidance of an image intensifier. A wide open wound is unnecessary (Fig. 7A).

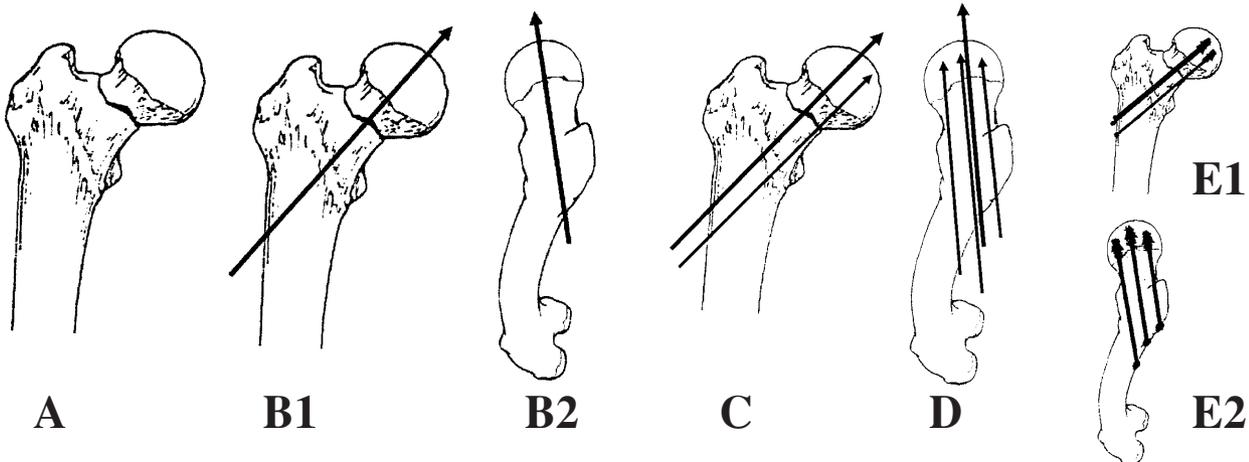
A 2.4- mm Kirschner wire (Mizuho, Tokyo, Japan) should be inserted from the subtrochanteric area into the central-central point of the femoral head in the anteroposterior and lateral views under the guidance of the image intensifier. The end of the Kirschner wire penetrates the acetabular fossa, fixing the femoral head temporarily (Fig. 7B1, B2). In the anteroposterior view, a 2- mm Kirschner wire should be inserted along the lowest cortex of the femoral neck, parallel to the 2.4- mm Kirschner wire. Both Kirschner wires are in the same frontal plane. The end of the 2- mm Kirschner wire is 2-3 mm from the articular surface (Fig. 7C). Then, in the lateral view, a 2- mm Kirschner wire is inserted along the anterior cortex and another 2- mm Kirschner wire is inserted along the posterior cortex of the femoral neck, parallel to the 2.4- mm Kirschner wire. The levels of the

two 2- mm Kirschner wires are in the same horizontal plane as the 2.4 mm Kirschner wire. Similarly, the ends of the two Kirschner wires are 2-3 mm from the articular surface (Fig. 7D). Adequate lengths for the three cannulated screws (7- mm; Synthes, Bettlach, Switzerland) are determined, and all three screws are inserted. All Kirschner wires should then be removed. Finally, the insertion of the three cannulated screws in an inverted triangle configuration is completed (Fig. 7E1, E2). For femoral neck fractures with posterior comminution, a fourth cannulated screw is used.<sup>(57)</sup> Acrylic bone cement is normally unnecessary to reinforce the stability.

Postoperatively, patients treated with this procedure are capable of ambulation with protected weight bearing. It is advised that the gait stride not be too wide. Thus, the rotational torque of the femoral head can be greatly reduced.<sup>(46)</sup>

**Superiority of the recommended surgical technique over traditional surgical techniques**

Inserting one relatively rigid 2.4- mm Kirschner wire in the central-central point of the femoral head as a guide permits convenient and accurate insertion of three 2- mm Kirschner wires later. The anteroposterior or lateral views can be checked on an image intensifier a minimal number of times after the three



**Fig. 7** The recommended surgical technique (A) A right subcapital femoral neck fracture is reduced with a closed technique. (B1, B2) A 2.4- mm Kirschner wire is inserted under the guidance of an image intensifier in the central-central point of the femoral head in the anteroposterior and lateral views. The end of the 2.4- mm Kirschner wire penetrates the acetabular fossa temporarily. (C) In the anteroposterior view, a 2- mm Kirschner wire is inserted along the lowest cortex of the femoral neck, parallel to the 2.4- mm Kirschner wire. (D) In the lateral view, two additional 2- mm Kirschner wires are inserted along the anterior and posterior cortex of the neck, parallel to the 2.4- mm Kirschner wire. (E1, E2) Three cannulated screws of adequate length are placed and all Kirschner wires are removed.

2- mm Kirschner wires are placed.

Usually, it is impossible to stabilize the femoral neck fracture with three cannulated screws so that it is absolutely rigid. This is because of the cancellous bone characteristics of the marrow canal in the femoral neck and limited engagement of the cannulated screws on the femoral cortex.<sup>(4,5,21)</sup> Consequently, the fracture site wobbles following load application. The traditional technique completely disregards this defect. It has been pointed out that if cannulated screws are inserted along the femoral neck cortex, displacement of the femoral neck can be prevented.<sup>(5)</sup> In the recommended technique, all three cannulated screws are inserted according to this principle.

The cannulated screws engaged in the femoral head must be inserted to a sufficient depth. If the insertion into the femoral head is too shallow, the holding power of the screws is reduced (Fig. 2). The traditional technique does not emphasize the importance of an appropriate depth.<sup>(4,5,57)</sup> In the recommended technique, inserting the screws until they are 2-3 mm from the articular surface greatly improves their holding power.

Inserting three cannulated screws in an inverted triangle has been reported as the most stable configuration for fracture fixation in terms of biomechanics.<sup>(4,5,21,57)</sup> It is more suitable for use in a clinical setting than the normal triangular configuration used in the traditional technique.<sup>(26,27,36)</sup>

## Conclusion

Intracapsular femoral neck fractures in high-energy injuries are not common. Complete recovery from these fractures is often not achieved even when these fractures are treated using the newest techniques. Currently, the most convincing and practical treatment technique involves closed reduction with internal fixation as soon as possible, providing sufficient stability for vascular regeneration, and preventing fixation failure. The author has presented a surgical technique that considers biomechanics. The author believes that the proposed technique is the most reasonable and feasible method for treating complicated intracapsular femoral neck fractures.

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## 關節囊內股骨頸骨折的內固定手術治療： 從生物力學上的考量去改善手術技巧以提高治療的成功率

吳基銓

儘管科學及工程學上有重大的進展，治療高能量引起的關節囊內股骨頸骨折的成功率卻仍然令人失望。人類股骨頭的血液供應系統不利於此種骨折的復原。一旦此種骨折發生，即便使用最新的方法去治療；股骨頭缺血性壞死及骨折不癒合的發生率，仍可能各高達 30%。許多手術方法被附加使用，以重建股骨頭的血液供應來幫助內固定手術治療，但仍未能明確地成功。在仔細地分析大量有關的研究後，作者有個結論：想提升治療關節囊內股骨頸骨折的成功率，最令人信服及可行的方法是隨即施行經過生物力學上改良過的手術方式去治療。假如此種骨折能夠遵循生物力學的原則去治療，骨折處即可得到足夠的穩定度。然後，股骨頭的血液供應可即早恢復，同時骨折處滑脫的可能性被大大降低。因而，從此種骨折完全復原的機會就大大增加。在本研究中，此種骨折的生物力學上特徵以及有關治療方法上的原則被詳細回顧及澄清。最後，根據作者觀點發展出來的手術技巧被提出。作者相信：本研究推薦的手術技巧，可能成為治療關節囊內股骨頸骨折中最好的方法。(長庚醫誌 2010;33:241-51)

**關鍵詞：**內固定手術，關節囊內股骨頸骨折，中空型螺釘，生物力學

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