Original Paper

Medical Principles and Practice

Med Princ Pract 2016;25:123–129
DOI: 10.1159/000442019

Received: October 12, 2014
Accepted: October 29, 2015
Published online: October 30, 2015

The Use of Superselective Arteriography in the Evaluation of the Influence of Intracapsular Hip Joint Pressure on the Blood Flow of the Femoral Head

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Key Words
Femoral neck · Fracture · Intracapsular pressure · Angiography

Abstract
Objective: We aimed to analyze the intracapsular pressure of the hip joint following femoral neck fracture and its relationship to the position of the hip or to traction and (using superselective arteriography) to evaluate the blood supply to the femoral head and the influence of traction and hip position on the blood supply. ***Subjects and Methods:*** Twenty-six cases of fresh Garden type I–III femoral neck fractures were enrolled. After being placed in the neutral position, in internal rotation or with traction of 3 and 5 kg, respectively, intracapsular manometric changes were measured. Eight cases underwent superselective arteriography of the medial circumflex femoral artery and its branches under the manometric changes of the hip joint capsule. ***Results:*** Twenty-four to 48 h after the injury, the intracapsular pressure was significantly higher on the fractured side than on the normal side. The mean pressure was 28.41 ± 9.339 mm Hg in fully extended hips in the neutral position, 79.92 ± 12.80 mm Hg in internally rotated hips, 51.39 ± 15.41 mm Hg in hips with 3 kg of traction and 64.81 ± 13.56 mm Hg in hips with 5 kg of traction. The arteriographic findings revealed that traction and internal rotation reduced the perfusion of the femoral head at the medial circumflex femoral artery and its branches, and also negatively influenced venous reflux. ***Conclusion:*** Traction and internal rotation both caused the intracapsular pressure of the hip joint to rise considerably, which reduced the femoral head perfusion and impeded venous reflux. This could lead to avascular necrosis of the femoral head.

Introduction

Necrosis and collapse of the femoral head after femoral neck fracture is a common complication which poses a challenging problem to orthopedic surgeons [1, 2]. High intracapsular pressure resulting from intracapsular hemorrhage is known to be the most important factor for avascular necrosis (AVN); however, the exact pathogenesis of AVN of the femoral head is still not fully understood [3–7]. Traction is the traditional and most commonly used preoperative and operative method [8]. However, in the last years, the use of traction in the treatment of femoral neck fracture has been questioned as being unsafe and the source of iatrogenic injury [7, 9]. Soto-Hall et al. [7] reported that traction can cause the intracapsular

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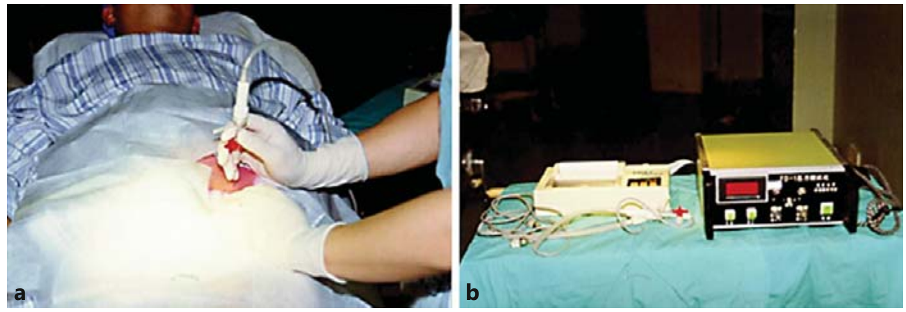

Fig. 1. a Hip needle puncture. **b** FD-1 pressure sensor.

pressure of the hip joint to rise, especially in capsules which are intact following injury, thereby reducing the blood flow to the femoral head by a tamponade-like effect. Maruenda et al. [5], on the other hand, pointed to the fact that traction of 3 kg can reduce intracapsular pressure, thereby avoiding the tamponade effect and allowing normal blood flow to the femoral head [8, 10]. This would explain why, lately, emergency puncture of the joint capsule to reduce the intracapsular pressure has slowly gained recognition among experts as a viable treatment method [3–7]. The objective of this study was to measure the intracapsular pressure of the hip joint. We also made use of digital subtraction angiography (DSA) to evaluate the vital arteries and veins involved in the blood flow to and from the femoral head and analyze the effect of different postures of the hip and of traction on the perfusion of the femoral head following femoral neck fracture.

Subjects and Methods

General Information

A total of 26 cases (15 males and 11 females aged 28–72 years), hospitalized at our Orthopedics Center due to unilateral femoral neck fracture, were enrolled in this prospective case series. The patients were divided according to Garden classification: type I (n = 2), type II (n = 13) and type III (n = 11). Garden type IV fractures in which joint capsule ruptures could lead to a drop in intracapsular pressure were excluded from the study. The other exclusion criteria were: concomitant ipsilateral lower-extremity trauma, previous proximal femoral fracture, medical comorbidities limiting operative options and pregnancy. All the patients signed a consent form to allow us to perform preoperative hip joint capsule manometry. Only 8 patients agreed to undergo DSA due to its invasive nature. The study was approved by the Medical Ethics Committee.

Experimental Methods

Hip joint capsule manometry was performed on the fractured side for all 26 patients, while 10 patients also had the pressure of the contralateral normal side measured as a control. The intracapsular pressure was evaluated for 24–48 h under local anesthesia or continuous epidural anesthesia. Puncturing was performed lateral to the femoral artery along the inguinal fold, and the needle was inserted into the hip joint capsule. The end of the needle was connected to the FD-1 pressure sensor (Pressure Sensor Laboratory, Fudan University) and the whole system used a saline conduction system (fig. 1). The intracapsular pressure was measured with the hip in the neutral position, using skin traction of 3 or 5 kg, and also with the hip in an internally rotated position.

Superselective Angiography for the Evaluation of the Circumflex Femoral Artery Ring

After receiving regional infiltration anesthesia, 8 patients underwent selective circumflex femoral artery angiography of the fractured limb. The catheterization of 3 patients was performed through the ipsilateral femoral artery, and the remaining 5 patients were punctured via the trans-contralateral route. Later, a 5-Fr Cobra tube was introduced into the circumflex femoral artery. Superselective angiography was first done with the hip in the neutral position without traction, with traction of 3 or 5 kg and with the hip in internal rotation, respectively. In 3 cases, where the normal hip was examined, we used an SP microcatheter, which was inserted into the deep branches of the medial circumflex femoral artery and the retinacular arteries for imaging purposes. The contrast agent used was lolromide (300 mg/ml, Bayer Vital GmbH, Germany). Superselective arteriography was performed to analyze the imaging of the main arterial supply to the femoral head under different contrast-agent pressures. We hypothesized that different contrast-agent pressures (i.e. contrast-agent injection rates) would provide different arterial blood supply pressures. The standard injection rate was 0.8 ml/s; 0.6 ml/s represented low perfusion pressure and 1.2 ml/s represented high perfusion pressure. We observed the vascular imaging of the medial circumflex femoral artery, its deep branches and also the retinacular arteries along with the imaging of the venous return.

Results

The mean age of the patients was 56.4 ± 5.86 years. The outcome of manometry in the 26 cases was as follows: the fractured side had a mean intracapsular pressure of 28.41 ± 9.339 mm Hg (range 12.5–52) when placed in the neutral position. Normal hips in full extension in the neutral

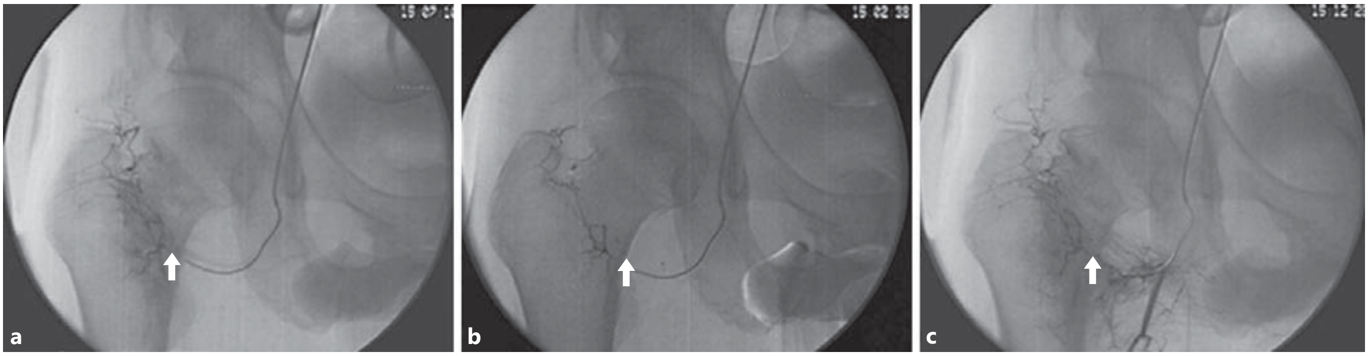

Fig. 2. a The injection rate of the contrast agent was 0.8 ml/s, and the deep branches of the medial circumflex femoral artery can be seen (arrow). **b** The injection rate of the contrast agent was 0.6 ml/s; the deep branch of the medial circumflex femoral artery is shown (arrow). **c** The injection rate of the contrast agent was 1.2 ml/s; the deep branch of the medial circumflex femoral artery is shown (arrow).

Table 1. Results of hip joint manometry

Condition	Mean ± SD	Median (IQR)	Minimum	Maximum	Z^a	p value
Neutral position (control)	28.41±9.339	25.5 (22.0–37.5)	12.5	52.0	–	–
Traction of 3 kg	51.38±15.41	49.5 (44.8–59.8)	18.0	84.0	4.293	<0.001
Traction of 5 kg	64.81±13.56	63.0 (55.8–78.3)	38.0	90.0	4.458	<0.001
Internal rotation	79.92±12.80	78.5 (71.3–88.0)	62.0	112.0	4.458	<0.001
Neutral position (normal side)	7.269±4.313	7.0 (4.0–10.0)	1.0	12.0	4.459	<0.001

The unit of pressure measurement is mm Hg.
[a] Wilcoxon signed-rank test compared with neutral position (control).

position showed mean manometric values of 7.269 ± 4.313 mm Hg (range 0–12), while the pressure on the fractured side was higher (21.14 mm Hg) than on the normal side and the difference was statistically significant ($p < 0.001$). This study found that traction of 3 or 5 kg significantly raised intracapsular pressure and the increasing pressure was much higher with the hip in an internally rotated position (table 1). The Wilcoxon signed-rank test showed statistically significant differences in pressure between the groups, i.e. the neutral position group (controls, 7.269 ± 4.313 mm Hg), traction with 3 kg (51.38 ± 15.41 mm Hg), traction with 5 kg (64.81 ± 13.56 mm Hg) and the internal rotation position group (79.92 ± 12.80 mm Hg; table 1). When compared to the systolic pressure (mean 140.6 mm Hg; range 120–170 mm Hg) and diastolic pressure (mean 88.12 mm Hg; range 74–100 mm Hg) for the same period of time, traction caused an obvious increase in intracapsular pressure (18–90 mm Hg), but this did not overtake the arterial diastolic pressure. However, in certain cases, internal rotation caused an intracapsular pressure rise (112 mm Hg) that was higher than the diastolic pressure (85 mm Hg).

Superselective Arteriography: Imaging of the Femoral Head Blood Supply with Injection of Contrast Agents under Different Pressures

Our research found that in our cohort (5 Garden II fractures and 3 Garden III fractures), when the hip was placed in the neutral position, with an intracapsular pressure of 26.46 ± 2.788 mm Hg and a contrast-agent injection rate of 0.8 ml/s, we were able to visualize 2–3 branches of the posterior superior retinacular arteries (fig. 2a). When the injection rate was decreased to 0.6 ml/s (low perfusion pressure), the contrast agent is unable to enter the joint capsule and the imaging of the intracapsular branches of the retinacular arteries is perturbed. When the venous reflux of the femoral veins was analyzed in a similar manner, the veins were not visible and the contrast agent was rerouted in the extracapsular collateral veins (fig. 2b). On the other hand, under a high injection

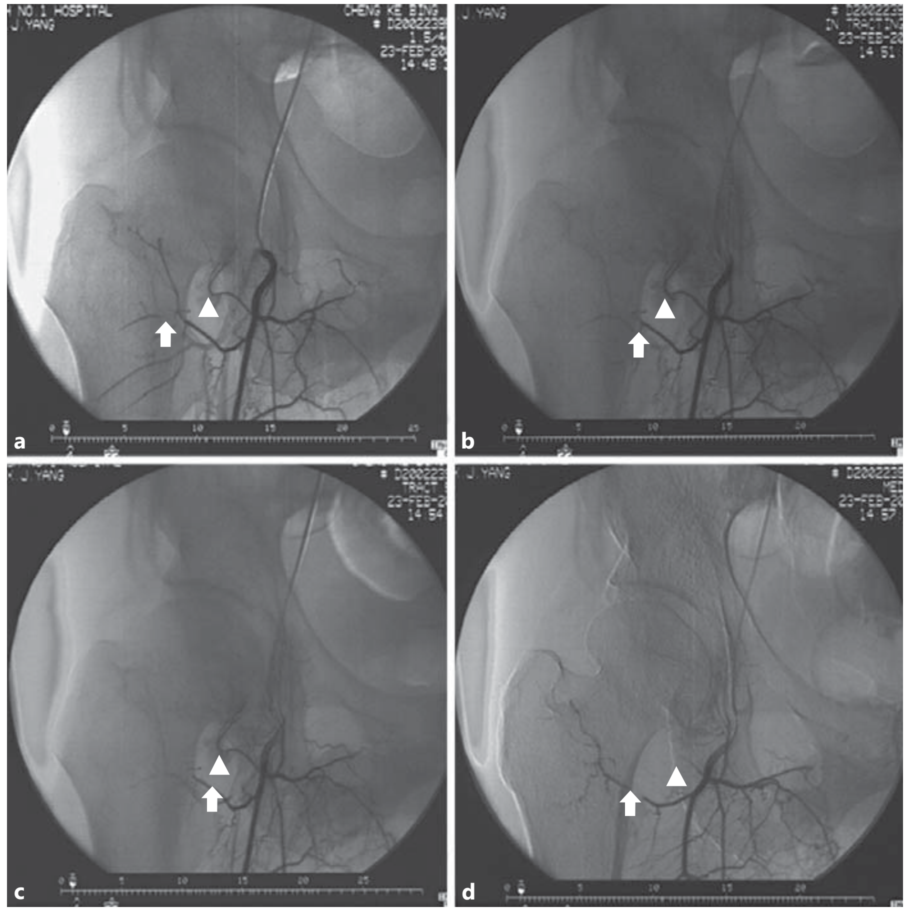

Fig. 3. a Images of the medial circumflex femoral artery, its deep branches and the retinacular arteries when the hip was in the neutral position (**a**), when 3 kg of traction was used (**b**), when 5 kg of traction was used (**c**) and when the hip was placed in internal rotation (**d**). The inferior retinacular arteries are shown with an arrowhead and the medial circumflex femoral artery is shown with an arrow.

rate (high perfusion pressure), during the arterial phase, the intracapsular retinacular artery and its branches were fully visible, and in the venous phase, the retinacular artery, medial and lateral circumflex femoral arteries and deep femoral veins were all visible. When compared to low perfusion pressure, the arterial phase was much shorter than the venous phase with the perfusion in the femoral neck being more abundant. In a few cases, the branches of the posterior and anterior superior arteries were found to form communicating branches at the base of the femoral neck (fig. 2c).

Femoral Head Perfusion following Traction or Internal Rotation

In 8 patients in whom the fractured hips were placed in 3 kg traction, the measured intracapsular manometric values rose up to 52.18 mm Hg, when compared to the hip in the neutral position without traction (fig. 3a). The medial and lateral circumflex femoral arteries were all visible, but the branches of the posterior inferior and retinacular arteries were only partly visible and even showed signs of reflux. In the venous phase, the retinacular veins were also not clearly visible and were almost not imaged (fig. 3b). The time spent by the contrast agent in the circulation in the femoral head was increased from 5 to 15 s in hips without traction and to between 15 and 20 s in hips with traction. When the traction weight was increased to 5 kg, only the main branch or initial part of the medial and lateral circumflex femoral artery could be seen and the reflux phenomenon of the contrast agent was also more obvious. The retinacular veins and the circumflex femoral vein ring showed delayed imaging. The total time the contrast agent spent in the internal circulation of the femoral head was increased to above 25 s.

This study also investigated the imaging of the retinacular arteries with the hip in an internal rotation. The main branch of the medial circumflex artery was visible, but in the neutral position, the imaging of the retinacular artery was delayed or not clear. As shown in figure 3c, the originally imaged medial inferior retinacular arteries were discontinuous with refluxing of the contrast agent. The imaging of the medial and lateral circumflex femoral artery was delayed and the time spent by the contrast agent inside the circulation of the femoral head oscillated between 25 and 30 s.

Discussion

In this study, we found that the intracapsular pressure was significantly higher on the fractured side than on the normal side. This increase was more evident when the hip was in an internally rotated position or in traction. Superselective arteriography also demonstrated that traction and internal rotation reduced the perfusion of the femoral head. As far as research on the intracapsular hip joint pressure is concerned, in the past, radionuclide imaging, dynamic MRI and laser Doppler flowmetry were used to investigate how changes in intracapsular pressure affect the blood flow of the femoral head [11–13]. Our study mainly aimed at analyzing the effect of different postures of the hip and of different traction weights on the intracapsular pressure, while using DSA to image the retinacular arteries.

The pathogenesis of the necrosis of the femoral head following femoral neck fracture remains controversial. Previously, the widely accepted reason for this complication was that the violence of the fracture would directly damage the blood vessels. However, this theory was incapable of explaining how in certain cases of nondisplaced femoral head fracture, years after receiving conventional therapy, patients still witnessed femoral head necrosis despite the fact that radiographic evidence showed that the blood flow to the femoral head was not completely interrupted [3–7]. This suggests that there are other factors that are responsible for this problem whereby, after fracture of the femoral neck, the blood supply is affected, aggravating the problem of decreased blood supply to the femoral head and resulting in AVN of the femoral head. In addition to this, anatomical studies have shown that the medial circumflex femoral artery branches out to form 2–4 retinacular arteries, also known as posterior superior retinacular arteries, which are responsible for the blood supply to the femoral head. These aforementioned blood vessels are distributed along the intertrochanteric line; they enter the hip joint capsule to find themselves in the subsynovial space before inserting into the femoral head and femoral neck [14–16]. On the basis of this, some studies have theorized that intracapsular bleeding due femoral neck fracture leads to a tamponade effect which causes an increase in intracapsular pressure and interruption of the blood circulation in the retinacular blood vessels, which eventually results in femoral head necrosis. These last few years have seen reports of femoral head necrosis following hip arthroscopic surgery, which could also be evidence of the fact that a rise in intracapsular pressure could lead to femoral head necrosis [17, 18]. Although our study and previous studies have shown that the blood supply to the femoral head may be occluded transiently by the elevated intracapsular pressure, the degree and duration of this impairment remains unknown. Woodhouse [19] reported that if the intracapsular tamponade lasted for >12 h, the process of osteonecrosis in animal models would subsequently begin. Beck et al. [4] also demonstrated that the adverse effect of intracapsular tamponade was reversible if the correction was done early. To date, there has been no direct epidemiological evidence of a link between the elevated intracapsular pressure and femoral head necrosis. The intracapsular tamponade may be partly responsible for the subsequent development of femoral head necrosis.

We found that the fractured side of the hip had higher intracapsular pressure when compared to the normal side. However, the minimal intracapsular pressure which is required to influence the blood flow of the femoral head is yet to be determined. According to Drake and Meyers [20], if the pressure is >80 mm Hg, i.e. more or less equal to the diastolic pressure, the perfusion of the femoral head decreases considerably. Strömqvist et al. [21] reported that when the hip is placed in the neutral position, the mean intracapsular pressure is 67 mm Hg. A retrospective study by Maruenda et al. [5] on 34 cases, with the patients on analgesics, measured a mean intracapsular pressure of 44.4 mm Hg. Beck et al. [4] injected saline solution into hip joints without fractures and measured the intracapsular pressure as well as making use of laser Doppler flowmetry to evaluate the blood flow to the femoral head. They found that when the intracapsular pressure reached 58 mm Hg, the pulse signal of the blood flow to the femoral head disappeared. In our study, with the measurement taken under analgesic conditions, the range of the intra-articular pressure was found to be between 12.5 and 52 mm Hg, much lower than the diastolic pressure. Superselective arteriography of the deep branches of the medial circumflex femoral artery showed that the remaining retinacular arteries are still visible under such intra-articular pressure. This poses the question whether there are other conditions that may cause a rise in the intracapsular pressure and therefore disturb the blood flow to the femoral head.

Traction is a conventional treatment method for femoral neck fracture, and has always been regarded as safe and efficient. However, lately, some indirect evidence has shown that when treating Legg-Calvé-Perthes disease and developmental dysplasia of the hip, the use of traction can result in more complications than no traction, including AVN of the head of the femur [22, 23]. This has led several surgeons to remark that the use of traction as treatment for fracture of the femoral neck also carries some risks. According to the results of the DSA, we demonstrated that traction can affect blood perfusion to the femoral head in different ways. Spastic twisting of the medial circumflex femoral artery causing a decrease in the amount of blood entering the hip joint capsule is one of the direct effects of traction on the joint capsule. Another effect is the rise of the intracapsular pressure, which directly causes a decrease in the perfusion of the femoral head via the retinacular arteries. Furthermore, traction causes an augmentation in pressure inside the veins blocking normal venous return and causing oxygen deprivation of the femoral head. An animal experiment conducted by Woodhouse [19] showed that by keeping the intracapsular pressure at 50 mm Hg for >12 h, femoral head necrosis can be induced. In 2010, an experiment by Yang et al. [24] gave further evidence that traction causes a decrease in the perfusion of the femoral head, leads to an increased blood circulation time in the femoral head of canines, and that this procedure was irreversible. This may point to the fact that, with the increase in the amount of traction time, the femoral head blood flow is worse and that, even when traction is removed, it is difficult for the blood flow to be completely restored and the restoration to normal blood flow takes a longer time. In agreement with the results of our study, deciding whether a femoral neck fracture patient requires traction is best decided on a case-to-case basis. When the hip is placed in internal rotation, the intracapsular pressure of the hip increases significantly, and is higher than when traction is used or when the hip is placed in the neutral position. The pressure in the medial and lateral circumflex femoral arteries is between 40 and 80 mm Hg; Strömqvist et al. [21], measuring intra-articular pressure with the hips in full extension and in internal rotation, obtained values as high as 280–320 mm Hg. With these above-systolic-pressure intracapsular manometric values, even if the retinacular arteries are intact, it is unthinkable that the extracapsular blood flow will be able to overcome the resistance and flow into the joint capsule. This is why it is clinically important to place the hip of patients suffering from a fracture of the femoral neck in an externally rotated position instead of an internally rotated one.

Even though placing the hip in an internally rotated position for reduction or in continuous traction are considered conventional therapy of femoral neck fracture, in this study, these have both been shown to lead to an increase of the intracapsular pressure of the hip joint. It is therefore reasonable to state that we would expect these two treatment methods to influence the normal blood flow of the femoral head. In contrast to other studies done in the past, which utilized laser Doppler flowmetry, radionuclide imaging or MRI, we made use of DSA, which was more straightforward for the evaluation of the blood supply to the femoral head. The advantage of the DSA technique is that it allowed us to observe the blood flow of the regions concerned during the arterial, capillary and venous phases. However, the utilization of DSA is weighted down by its invasive nature and its attached risks which may not be easily acceptable to some patients, by its relatively high cost and by its ethical liabilities, which limited our ability to collect cases and caused a potential unwanted deviation regarding the data obtained. Based on this study, it is still too early to ascertain whether it is safe to continue using traction in the treatment of femoral neck fracture or whether it potentially leads to hospital-acquired trauma. However, according to our results and those published in other studies, extreme caution is advised when using traction. The use of traction in cases where it is planned that the patient will receive emergency open reduction and internal fixation is questionable, and it could result in femoral head necrosis at a later stage.

Conclusion

In this study, there was a significant increase in the intracapsular pressure of the hip joint when traction or internal rotation was applied to the leg ipsilateral to a femoral neck fracture. This reduced the femoral head perfusion and impeded venous reflux. The results of our study may provide a new clue for discovering the pathogenesis of AVN.

Disclosure Statement

There were no conflicts of interest.

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