5 Femoral Shaft Fractures

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5.1 Basic Theory and Concepts

5.1.1 Overview

- Femoral shaft fractures refer to the fractures between a point 5 cm distal to the femoral lesser trochanter and a point within 5 cm from the adductor tubercle of the femur.
- Femoral shaft fractures account for 36.27% of all femoral fractures in adults, mainly occurring in young males between 21 and 30 years old and females between 31 and 40 years old (Zhang 2012).
  - In the AO classification, Type A, B, and C femoral shaft fractures account for 70.26%, 18.17%, and 11.57% of all femoral shaft fractures, respectively.
  - Femoral shaft fractures most commonly occur in the middle segment of the femur.
  - Open femoral shaft fractures are rare.
- Bilateral femoral shaft fractures are often associated with injuries in other systems, reaching a mortality rate of 1.5–5.6% (Copeland et al. 1998; Nork et al. 2003).
- A small number of femoral shaft fractures are accompanied by injury of the medial vessels.

5.1.2 Applied Anatomy

- Blood supply to the femoral shaft:
  - Femoral shaft blood supply is derived mainly from the deep femoral artery.
  - One to two nutrient arteries enter the medullary cavity proximally and posteriorly from the linea aspera of the femoral shaft to supply blood to the endosteum. Therefore, the soft tissue attached to the posterior femur shaft should not be excessively stripped during fracture reduction and fixation. The steel plate should be placed on the lateral rather than the anterior femur; otherwise the screws may damage the blood vessels.
  - The outer 1/3 of the cortex receives blood from the periosteal blood vessels entering the femoral shaft along the linea aspera, and the inner 2/3 of the cortex receives blood from the endosteal blood vessels in the medullary cavity. In intramedullary nail fixation, a portion of the intramedullary blood supply is inevitably damaged during medullary reaming (Fig. 5.1).
- A great quantity of muscles are attached to the femoral shaft, and the muscles and their main functions are described below:
  - The gluteus medius and minimus are attached to the greater trochanter and participate in abduction, flexion, and external rotation of the hip joint.
  - The iliopsoas is attached to the lesser trochanter and contributes to hip flexion and slight external rotation.
  - Quadriceps femoris: The quadriceps femoris is composed of the rectus femoris, the vastus medialis, the vastus lateralis, and the vastus intermedius. The rectus femoris starts from the anterior inferior spine and the upper acetabulum and passes across the hip and knee joints, and the other three muscles start from the femur and pass across only the knee joint. The quadriceps femoris contributes mainly to knee extension.
  - Adductor muscles: These muscles are attached to the linea aspera and its medial lip, contributing mainly to hip adduction and providing an axial component for traction.
  - The posterior muscle group includes the biceps femoris and the semimembranosus and semitendinosus muscles. The main function is to extend the hip and flex the knee.
  - Because different muscle groups vary in function, femoral shaft fractures at different levels and planes are displaced in different directions (Fig. 5.2). In addi-

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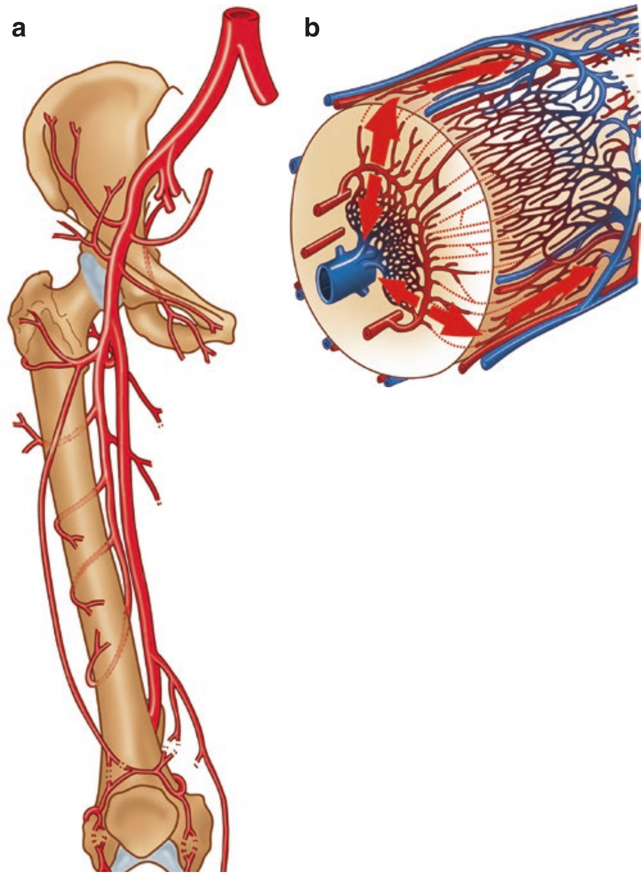

Fig. 5.1 (**a**) The blood supply of the femoral shaft comes from the nourishing periosteal arteries. (**b**) The intramedullary nourishing artery supplies blood to the inner 2/3 of the femoral cortex, and the periosteal vessels supply blood to the outer 1/3 of the femoral cortex

tion, the direction of the fracture angulation is related to the direction of the violent force (Bucholz and Court-Brown 2010).

- The femoral shaft has an anterior bow of approximately 12°–15°.
  – The intramedullary nail is arched to fit the angle of the anterior bow of the femoral shaft.
  – Steel plate-screw fixation must maintain the anterior curvature of the femoral shaft and avoid any potential backward angulation deformities (Fig. 5.3).
- The femoral isthmus (Fig. 5.4):
  – The femoral medullary cavity starts from the bottom of the lesser trochanter and stops at the level approximately 10 cm (approximately the width of the palm) above the articular surface of the distal femur.
  – Starting from the proximal 1/4 of the line connecting the femoral greater trochanter and the lateral epicondyle, the medullary cavity becomes narrower up to the level 1 cm distal to the midpoint of the connecting line, with the narrowest part at the level 2–3 cm proximal to the midpoint.
  – The diameter of the isthmus determines the size of the intramedullary nail that can be inserted into the femoral shaft.
- The linea aspera of the femur:
  – The linea aspera of the femur is an important anatomical landmark to determine the reduction of the femur.
  – To protect the blood supply to the femoral shaft, the use of large Hohman and Bennett retractors and excessive stripping of the periosteum should be avoided near the linea aspera where the nutrient vessels enter the femur.
- The mechanical characteristics of the femoral shaft (Fig. 5.5):
  – The medial cortex of the femoral shaft is subjected to compression while the lateral cortex is under tension.
  – Due to the aforementioned stress pattern, the femoral steel plate should be placed on the tension-bearing side, and the cortex in the compression-bearing side must be intact; otherwise, the fixators and fractured bone may form an unstable cantilever-like mechanical structure, resulting in bone nonunion and breaking of the steel plate.

5.1.3 Mechanism of Injury

- Direct violence:
  – High-energy violence: High-energy violence includes traffic accident collisions, crushing, or shooting. Fractures caused by high-energy violence mostly occur in young patients (Salminen et al. 2000).
  – Direct violence often causes transverse or comminuted fractures.
- Indirect violence (Court-Brown et al. 1998):
  – High-energy violence: High-energy indirect violence, such as leverage and torsion caused by a fall from a high place or marching under fatigue. Fractures caused by high-energy indirect violence mainly occur in young patients;
  – Low-energy injuries and pathological fractures occur most frequently in elderly patients.
  – Indirect violence often causes oblique or spiral fractures.

5.1.4 Classification of Femoral Shaft Fractures

- The AO-OTA classification system is commonly applied for femoral shaft fractures (Müller et al. 1990; Orthopaedic Trauma Association Committee for Coding and Classification 1996), which divides femoral shaft fractures into three types (Fig. 5.6).

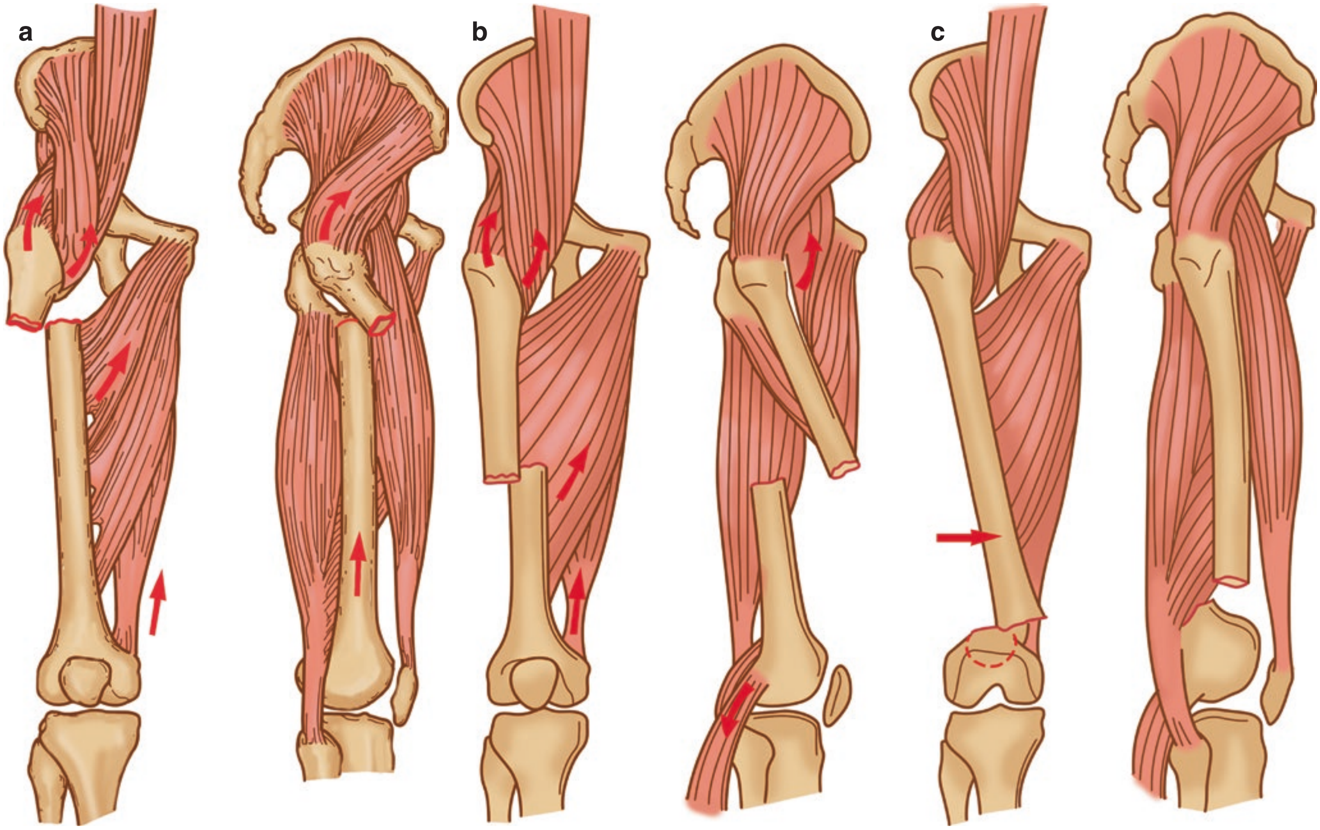

Fig. 5.2 (**a**) When the proximal femoral shaft is fractured, the proximal fragment is prone to flexion, abduction, and external rotation displacement due to pulling forces from the gluteus medius, gluteus minimus, and iliopsoas muscle; the distal fracture is pulled up by the adductor muscles, leading to a shortening deformity. (**b**) When the middle segment of the femoral shaft is fractured, the proximal fragment is flexed by the pulling forces from the iliopsoas and some adductor muscles, and the distal fragment is shortened, adduced, and inclined backward due to the pulling forces from the adductor muscles and the gastrocnemius muscle. (**c**) The proximal fragment of the distal femoral shaft fracture is adducted by the pulling of the adductor muscle, and the distal fragment inclines posteriorly due to the pulling of the gastrocnemius muscle

Fig. 5.3 There is an anterior bow of approximately 12°–15° in the femoral shaft, which should be maintained by internal fixation

- Type A includes three subtypes of simple fractures, Type A1 (spiral fractures), Type A2 (short oblique fractures), and subtype A3 (transverse fractures).
- Type B includes three subtypes of wedge fractures, Type B1 (spiral fractures with a butterfly fragment), Type B2 (oblique fractures with butterfly fragments), and Type B3 (comminuted fractures with butterfly fragments).
- Type C includes three subtypes of complex fractures, Type C1 (complex spiral fractures), Type C2 (segmental fractures), and Type C3 (complex and irregular fractures).

5.1.5 Assessment of Femoral Shaft Fractures

5.1.5.1 Clinical Assessment and Surgical Treatment

- To identify the mechanism of injury, the patient must be inquired about the medical history.
- Typical manifestations: A patient with a femoral shaft fracture often presents symptoms such as pain, deformity, swelling, limited mobility, and shortening of the affected extremity.
- For fractures caused by high-energy violence, special attention must be paid to identify the associated injuries elsewhere, including the spine, pelvis, femoral neck, femoral trochanters, parenchymal and cavitary organs in the abdominopelvic cavity, vessels, and nerves.
- The average blood loss in femoral shaft fractures is larger than 1200 mL; therefore, it is important to monitor the vital signs and assess the hemodynamic stability of the patient.

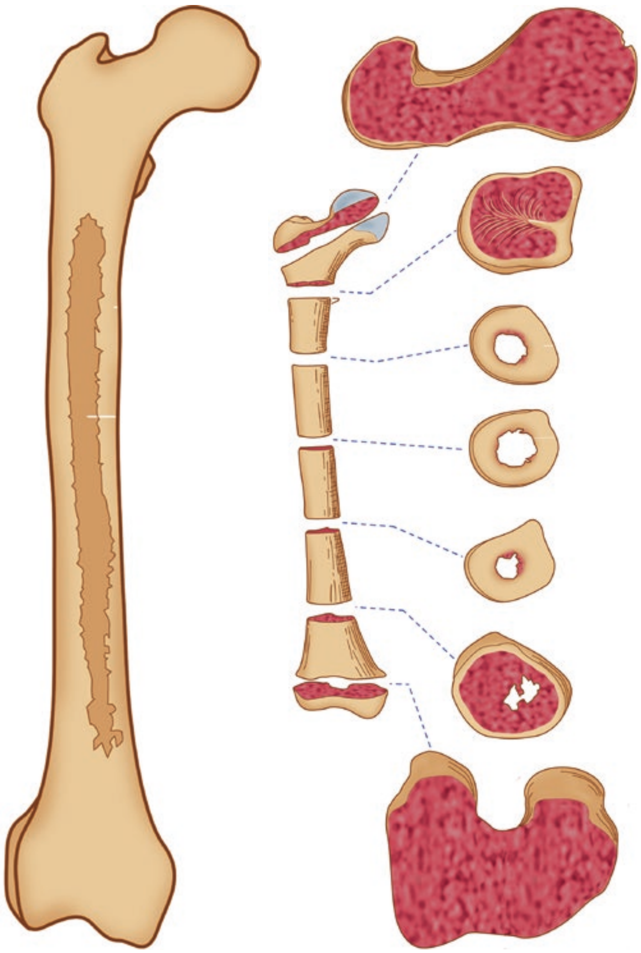

Fig. 5.4 The medullary isthmus of the femoral shaft is slightly above the midpoint of the femur. The diameter of the isthmus determines the size of the intramedullary nail to be used

- Emergency treatment for a patient with severe trauma is divided into different stages:
  - Acute stage (1–3 h after hospital admission): The core task during this period is cardiopulmonary resuscitation and assessment of the general condition of the patient, including respiratory support, anti-shock treatment, thoracentesis when necessary, and hemostasis. Orthopedic conditions requiring emergency treatment include osteofascial compartment syndrome, vascular injury, hip dislocation that cannot be reduced, and open fractures (Fig. 5.7).
  - The initial stage (1–48 h after injury): Traumatic injuries of the extremities, including fractures accompanied by vascular injury and osteofascial compartment syndrome that requires surgical decompression, are often surgically treated during this stage.
  - The second stage (2–10 days after injury): Although the general condition of the patient has improved, only limited surgical treatment (e.g., necessary debridement) rather than surgery that requires long hours of operation should be performed at this stage.
  - The third stage (weeks to months after injury): Final fracture fixation and reconstruction are performed after the patient recovers into a stable condition. Postoperative rehabilitation begins at this stage.
- Overall assessment and grading:
  - The overall condition of the patient, including the status of the circulatory system, blood coagulation, body temperature, and damage in every organ, is carefully assessed (Table 5.1) and graded into four grades: stable, marginal-stability, unstable, and near-death.

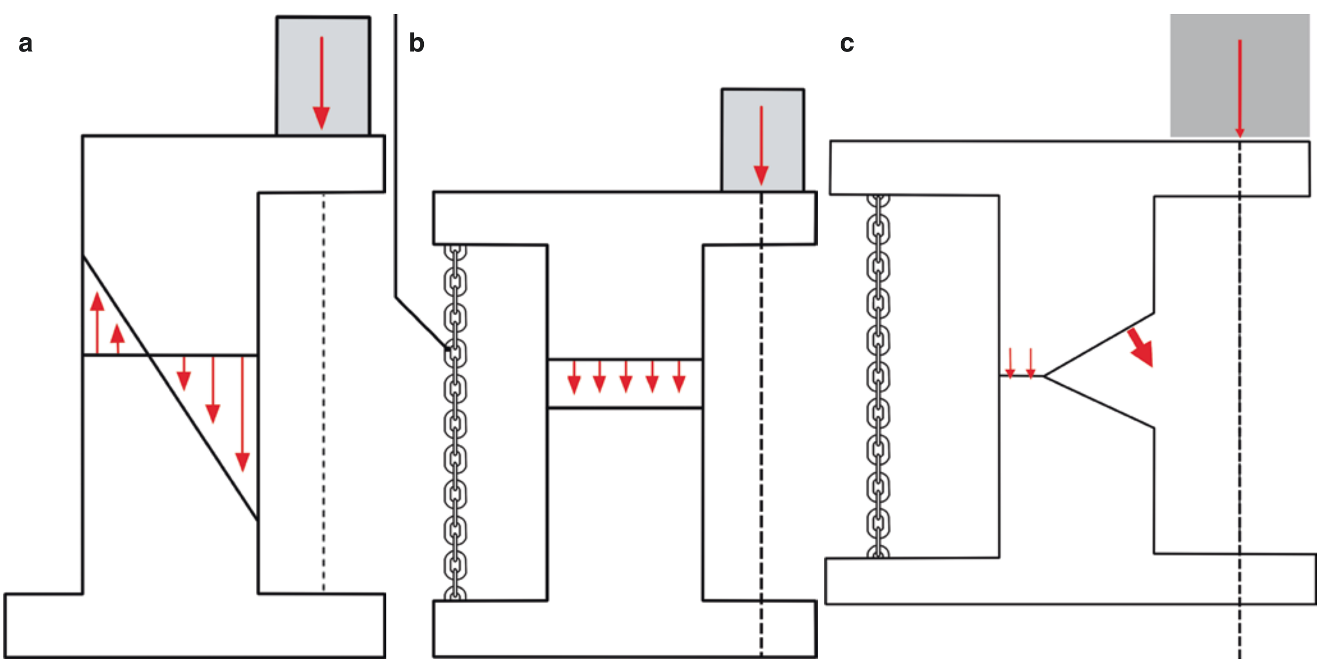

Fig. 5.5 (**a**) The lateral side of the femur is the tension-bearing side, and the medial side is the compression-bearing side. (**b**) The plate should be placed on the lateral side of the femur and act like a tension band. (**c**) The medial cortex of the femoral shaft must be intact; otherwise, the fixators and fractured bone may form an unstable cantilever-like mechanical structure, resulting in breaking of the nail and the plate

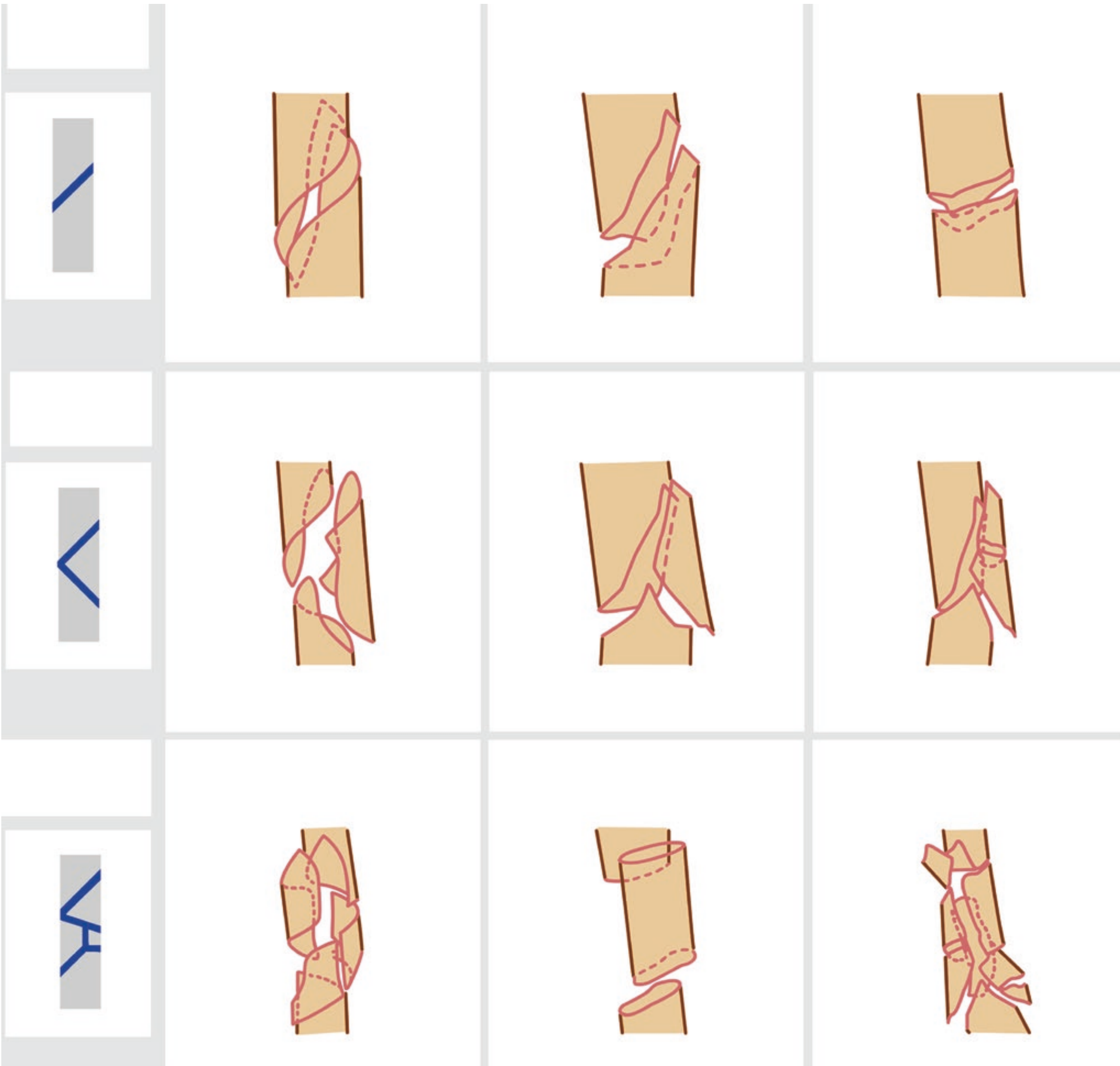

Fig. 5.6 AO classification of femoral shaft fractures. Type A includes three subtypes of simple fractures: Type A1 (spiral fractures), Type A2 (short oblique fractures), and Type A3 (transverse fractures); Type B includes three subtypes of wedge fractures: Type B1 (spiral fractures with butterfly fragments), Type B2 (oblique fractures with butterfly fragments), and Type B3 (comminuted fractures with butterfly fragments); Type C includes three subtypes of complex fractures: Type C1 (complex spiral fractures), Type C2 (segmental fractures), and Type C3 (complex and irregular fractures)

5.1.5.2 Imaging Assessment

- A femoral shaft fracture caused by a traffic accident is often accompanied by a fracture of the patella, proximal femur, and acetabulum; therefore, it is necessary to routinely conduct X-ray imaging of the full length of the femur, including the knee and hip joints.
- If X-ray of the full-length femur cannot be performed, separate radiographic examinations of the hip joint, femoral shaft, and knee joint in the AP and lateral views should be performed.
- If necessary, a CT scan of the femur can be performed to demonstrate the condition of the bone fragments in detail.
- Patients suspected of vascular injury can be diagnosed by angiography or enhanced CT vascular reconstruction (Fig. 5.8).

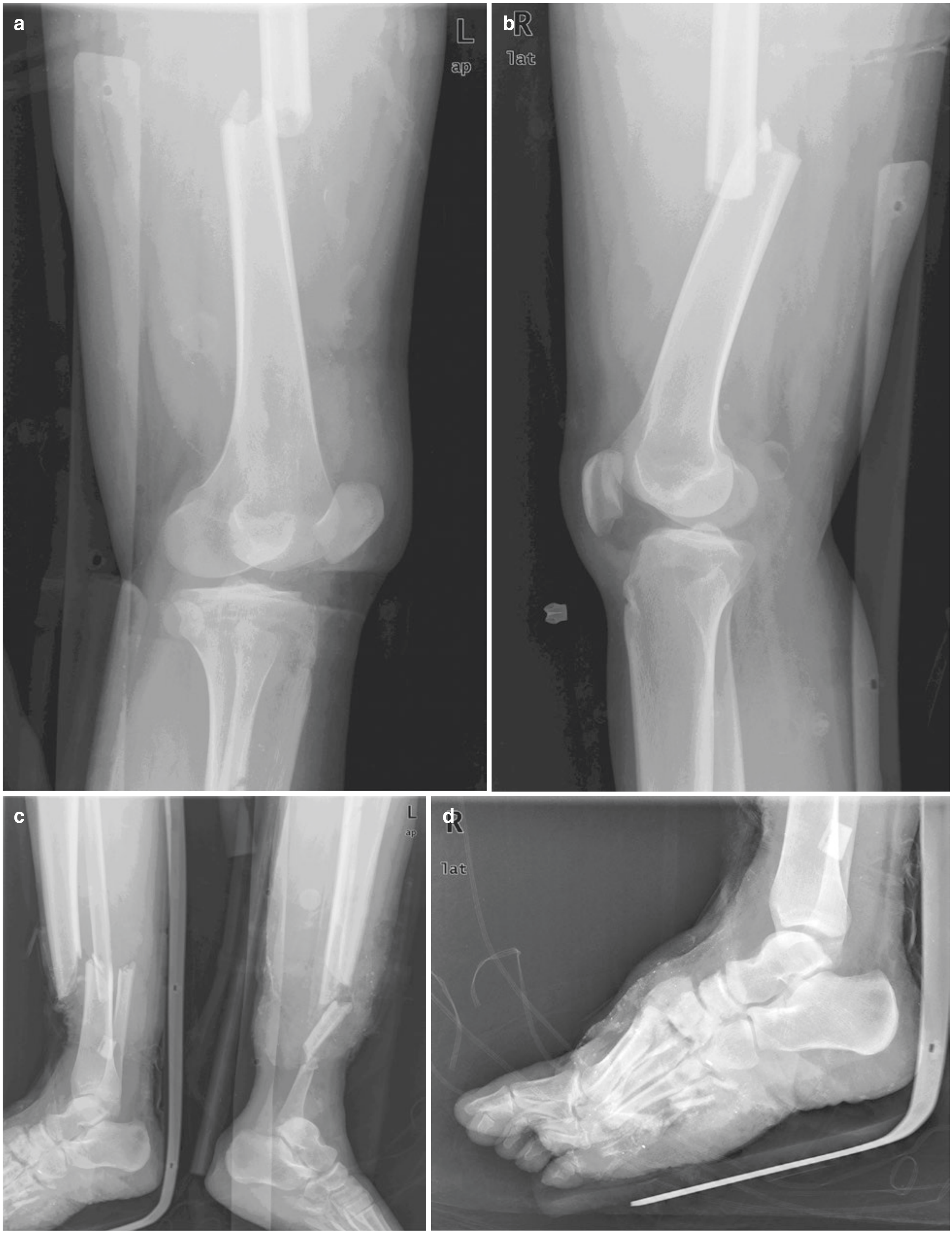

Fig. 5.7 A 19-year-old female patient with multiple trauma of the lower extremities caused by a car accident. (**a**) A radiograph showing a left femoral shaft fracture. (**b**) A radiograph showing a right femoral shaft fracture. (**c**) A radiograph showing open fractures of the tibia and fibula on both sides and loss of the lower segment of the left tibia. (**d**) A radiograph showing an open wound of the right foot and a fracture of the fifth metatarsal. (**e**) Image of the open injury of the right foot. (**f**) Image of the open injury of the left lower extremity. (**g**) As shown in the table displaying the patient's general condition, the patient was basically in the marginal-stability state at the time of hospital admission. Based on the patient condition, trauma control and surgical intervention should be started. The patient received resuscitation treatment, followed by wound debridement and external fixation of fractures, and then she was transferred to the ICU for further treatment

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blood pressure	86/59 mmHg
body temperature	35°C
hemoglobin	26.0 g/L
blood transfusion volume	7 Unit
lactate	3 mmol/L
HCO_3^-	18.6 mmol/L
platelet	159×10^9/L
FIB	0.60 g/L
D dimer	5.12μg/ml
arterial blood oxygen partial pressure	56 mmHg
fraction of inspired oxygen	40%

Fig. 5.7 (continued)

Table 5.1 Assessment chart for overall conditions

	parameter	stability level 1	boundary situation level 2	instability level 3	articulo mortis level 4
circulation	blood pressure	> 100	80-100	60-90	< 50-60
	units of blood	0-2	2-8	5-15	> 15
	lactate	normal	about 2.5	> 2.5	severe acidosis
	base defect	normal	no data	no data	> 6-8
	ATLS classification	I	II - III	III - IV	IV
cruor	PLT	> 110 000	90 000-110 00	< 70 000-90 000	< 70 000
	coagulation factor II and IV	90-100	70-80	50-70	< 50
	FIB	> 1	about 1	< 1	DIC
	d dimer	normal	abnormal	abnormal	DIC
temperature		< 33℃	33-5℃	30-32℃	30℃ or lower
organ injure	PF	350-400	300-350	200-300	< 200
	AIS	AIS I - II (abrasion)	> 2-3 rib fracture	> AIS III (severe rib fracture)	> AIS III (unstable thoracic cage)
	TTS	0	I - II	II - III	IV
	abdominal trauma	≤ II	≤ III	III	≥ III
	AO	type A	B or C	C	C (comminution)
	AIS	AIS I - II (like abrasion)	AIS II - III (like laceration > 20 cm)	AIS III - IV (like burn < 30%)	crush injuries or 30% burns

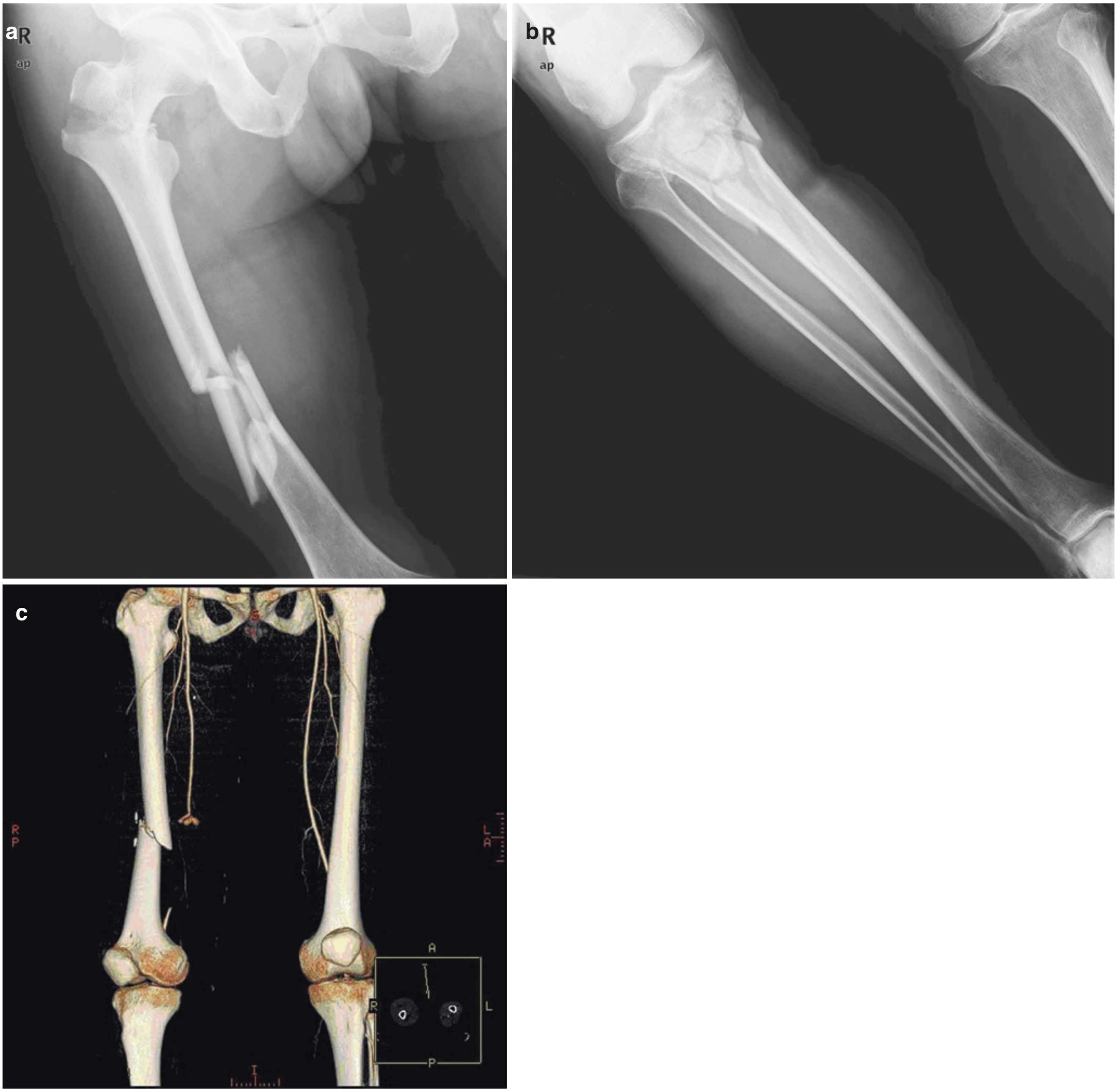

Fig. 5.8 (**a**, **b**) Radiographs of a 54-year-old male patient with multiple injuries caused by a car accident: the patient has a right femoral shaft fracture accompanied by a right intertrochanteric fracture and tibial plateau fracture. In general, a patient with a femoral shaft fracture should receive X-ray examination of the adjacent joint to rule out the potential of accompanying fractures. (**c**) The 3D reconstructed enhanced CT image of a 37-year-old male patient with a right femoral shaft fracture and absence of the right dorsalis pedis pulse: the image shows a rupture of the superficial femoral artery

5.2 Surgical Treatment

5.2.1 Surgical Indications

- All femoral shaft fractures, except for non-displaced fractures, are unstable.
- Except for patients who cannot tolerate surgery, all patients with femoral shaft fractures should be surgically treated.

5.2.2 Femoral Shaft Fractures and Surgical Treatment (Roberts et al. 2005)

- Principle of treatment for multiple trauma patients with different statuses:
  - For patients in a stable condition, the fracture can be internally fixed as the final treatment.
  - For patients in a marginal-stability status, surgery should be performed with caution, and close monitoring and intensive care are provided in combination with injury control, if necessary.
  - For patients in an unstable condition, only minimal trauma control and necessary prompt salvage surgery, including temporary fixation of the affected extremity and hemostasis, are conducted, and then the patient should be transferred to the ICU as soon as possible to further stabilize and monitor the conditions. Complex extremity reconstruction should be postponed until the patient is in a stable condition, i.e., the patient has passed the acute phase of inflammatory immune response (Fig. 5.9).
  - Patients with a near-death status usually have uncontrollable hemorrhage and remain in critical condition, even with the trauma triad of death (hypothermia, acidosis, and coagulopathy) after resuscitation; therefore, they should be immediately transferred to the ICU for invasive monitoring and simultaneously receive advanced circulatory and respiratory support, while prompt external fixation of the affected extremity can be performed at bedside.
- Effects of craniocerebral injury on patients with femoral shaft fractures:
  - Due to the reduced ability to self-regulate the blood supply and increased need for glucose in the brain after injury, head trauma causes the brain to be more sensitive to ischemia. Twelve to twenty-four hours post-trauma is the period with a high risk of blood supply declination to the brain.
  - Moreover, hypoperfusion during surgery can result in a second attack on the brain. Therefore, neurosurgeons and other relevant specialists should be consulted for craniocerebral injury assessment, and surgical treatment should be performed under close monitoring.
- Effects of chest injury on patients with femoral shaft fractures:
  - Chest injury includes rib fracture and pulmonary contusion, which should be considered during surgical treatment. The former causes reduced pulmonary ventilation and restricted respiration caused by pain, which can be treated by mechanical ventilation. The latter can cause a systemic inflammatory response, resulting in pulmonary interstitial edema and disturbed ventilation.
  - The condition of lung injury can change rapidly within a few hours after injury. Therefore, in addition to the chest X-ray and CT, arterial blood gas testing should be regularly conducted after injury.
  - A fractional inspired oxygen concentration (FiO_2) larger than 40%, an oxygenation index PaO_2/FiO_2 less than 250, or an airway pressure greater than 25 and less than 30 cm H_2O, suggests severe lung injury.
- Effects of pelvic injury on patients with femoral shaft fractures:
  - Severe pelvic injury on patients can cause hemorrhagic shock due to bleeding from the pelvic wall, presacral venous plexus, or arteries.
  - Digestive tract injury increases the risks of infection and sepsis in patients with femoral shaft fractures.
  - Patients in a stable condition can receive final fixation of the pelvis at 24–48 h after trauma; in patients with massive bleeding whose condition is unstable, a pelvic sling or external-fixation frame should be applied to reduce the volume of the true pelvis.

5.2.3 Selection of Final Internal Fixation Approaches

- Anterograde intramedullary nailing is suitable for most femoral shaft fractures.
- Retrograde intramedullary nailing is suitable for the following situations:
  - Fractures of the lower 1/3 femoral shaft.
  - Associated with fractures of the ipsilateral femoral neck, femoral trochanter, acetabulum, patella, or tibial shaft (Fig. 5.10).
  - Bilateral femoral shaft fractures.
  - Patients with pathological obesity.
  - During pregnancy.
  - Fractures near the prosthesis after total knee replacement.
  - Femoral shaft fractures in patients who have undergone an ipsilateral below-knee amputation.

Fig. 5.9 A 45-year-old male patient with multiple injuries caused by a car accident. (**a**) Right femoral shaft fracture and a left tibiofibular fracture. (**b**) Compression fracture of the second lumbar vertebra. (**c**–**e**) After hospital admission, the patient was suspected to have liver rupture and bleeding due to his unstable hemodynamics. Osteofascial compartment syndrome of the right thigh was diagnosed due to a very high tension within the right thigh. After resuscitation, emergency surgery was performed to repair the ruptured liver, temporarily fix the right femoral shaft fracture with an external fixator frame, decompress the compartments of the right thigh, roughly reduce the fractured tibia and fibula, and initiate calcaneal traction. (**f**–**h**) After the general condition of the patient improved and he became stable, the second-stage surgery was performed to ultimately fix the fracture, including internal fixation of the femoral shaft fracture with intramedullary nailing (**f**), internal fixation of the left tibial fracture with intramedullary nailing (**g**), and open reduction and internal fixation of the lumbar vertebra (**h**)

Fig. 5.9 (continued)

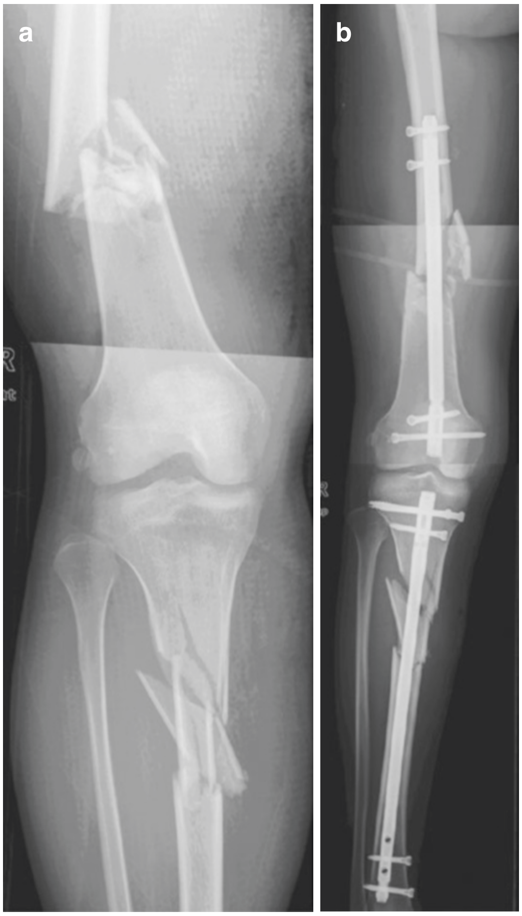

Fig. 5.10 (**a**) Femoral shaft fracture combined with ipsilateral tibial shaft fracture and floating knee injury. (**b**) Femoral shaft fracture and tibial shaft fracture are fixed by intramedullary nailing through the same incision

- Indications for internal plate fixation: Due to the biomechanical defect of eccentric fixation, the surgical indications below should be strictly followed for internal plate fixation:
  – Femoral shaft fractures with medullary stenosis that cannot or are difficult to be fixed by intramedullary nailing.
  – Patients whose second fracture is difficult to be fixed by intramedullary nailing due to a history of fracture and post-fracture healing deformities.
  – Fractures of the femoral shaft with medullary occlusion due to infection or previous conservative treatment.
  – Femoral shaft fractures that extend distally and proximally to the area around the trochanter or the condylar region and are therefore difficult to fix by intramedullary nailing.
  – Femoral shaft fractures accompanied by vascular injury, for which vessel exploration and plate fixation can be performed simultaneously.
- Indications for external fixation:
  – External fixation is often used for temporary or adjuvant fixation, or it can be used for final fixation in children;
  – For severely injured patients, external fixation is a part of the injury control operation and serves as a temporary measure before intramedullary nailing;
  – External fixation is conducted to stabilize fractures concurrently with ipsilateral arterial injury repair;
  – Severely contaminated fractures with soft tissue injuries, for which external fixation can serve as a temporary fixation measure as other fixation approaches may interfere with the second debridement operation.

5.2.4 Surgical Techniques

5.2.4.1 Internal Fixation with Antegrade Intramedullary Nailing

- Body position:
  – The patient lies in the supine position under traction on a traction table (please see Chap. 4 “Subtrochanteric Femoral Fractures” for details).
  – The patient lies in the lateral decubitus position under traction on a traction table: The patient lies in the lateral decubitus position under tibial tubercle traction, with the affected extremity on the top and both the hip and knee flexed, and the contralateral extremity is extended toward the back. C-arm fluoroscopy is conducted for both AP and lateral views (Fig. 5.11).
- Surgical techniques:
  – In addition to the described techniques in the section of intramedullary nail fixation for subtrochanteric femoral fractures, a pre-bent round-tipped guide wire (Fig. 5.12) can be applied to assist reduction under fluoroscopy (Bucholz and Court-Brown 2010; Morgan et al. 1999).
  – For internal fixation with antegrade intramedullary nailing and proximal locking, the locking methods can be chosen according to the needs and design of the intramedullary nail (Fig. 5.13).
- Experience and techniques:
  – Radiographic examination of rotational alignment:
    For femoral shaft fractures, especially type C fractures, it is very important but difficult to restore the mechanical axis and axial rotation of the affected extremity.
    Without the aid of fluoroscopy, the mechanical axis and rotation can be adjusted according to the connecting line of the anterior superior iliac spine, the patella, and the crevice between the first and second toes on the affected side conveniently drawn using an aseptic bandage or the power cord of the electric knife.

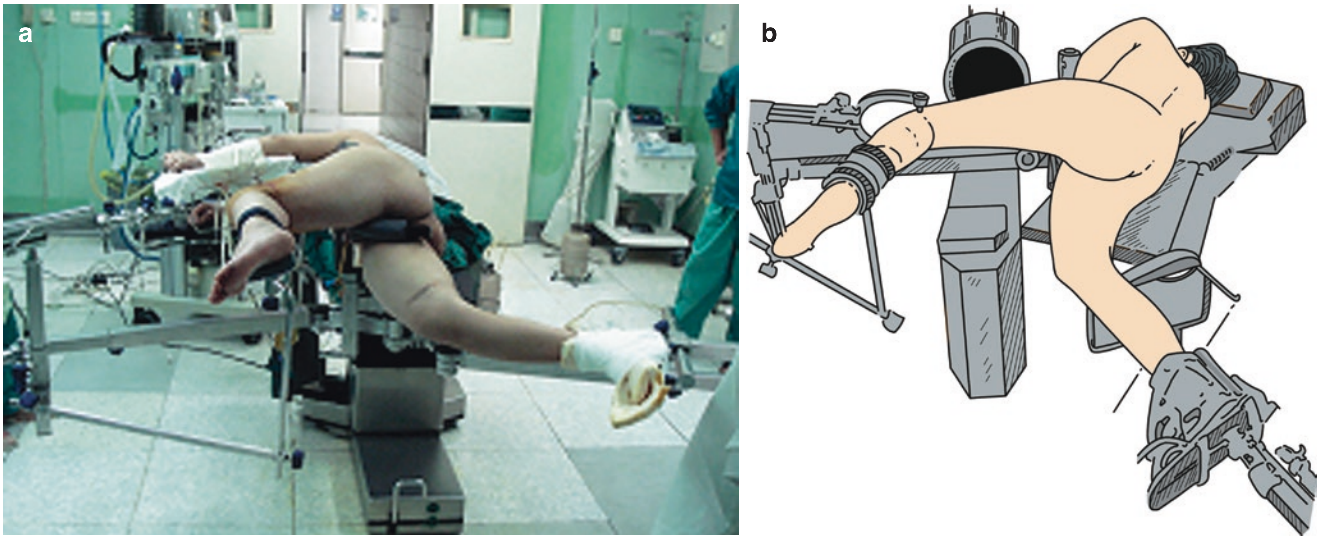

Fig. 5.11 Anterograde intramedullary nailing for femoral shaft internal fixation can be performed with the patient in the lateral decubitus position on the traction table. (**a**) The position of the patient during surgery. (**b**) Drawing of the traction table showing the position of the C-arm

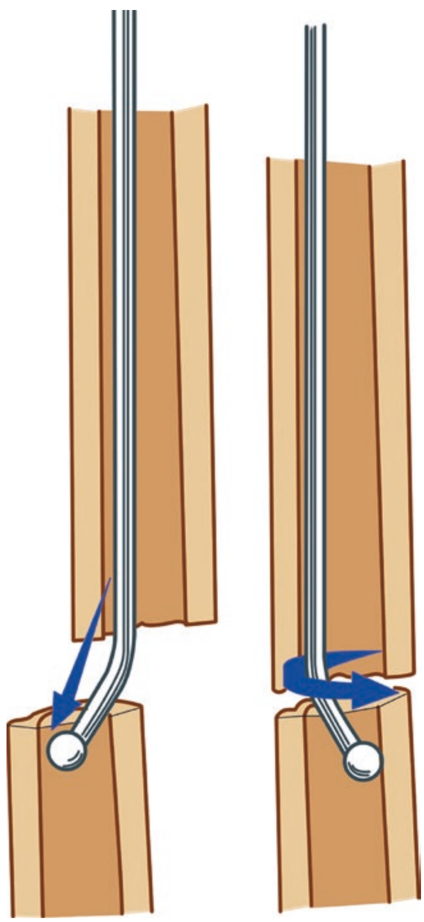

Fig. 5.12 A pre-bent round-tipped guide wire is inserted into the medullary cavity of the displaced distal fracture fragment under fluoroscopy; next, the guide wire is rotated to assist reduction

A more precise adjustment can be accomplished under fluoroscopy:

For a femoral shaft fracture with the lesser trochanter remaining intact: Both the ipsilateral and contralateral extremities are laid flat to ensure the patella is positioned facing front, and the shape of the lesser trochanter of the healthy side is compared with that of the affected side under fluoroscopy. A smaller size of the lesser trochanter on the affected side suggests an internal rotation of the proximal fragment, and a larger size suggests an external rotation of the proximal fragment. Next, rotational angle adjustment should be conducted, followed by fluoroscopy of the front-facing patella on the affected side to ensure that its size and shape are the same as that of the healthy side, confirming that the rotational deformity has been corrected (Fig. 5.14).

For a transverse femoral shaft fracture: Fluoroscopy of the fracture fragments determines whether the diameter of the medullary cavity and the thickness of the cortex of the proximal fragment are the same as those of the distal fragment. A difference between them may indicate the presence of a rotational deformity (Fig. 5.15), which would require an angle adjustment until the diameter of the medullary cavity and the thickness of the cortex of the two ends become equivalent, i.e., the rotational deformity is corrected.

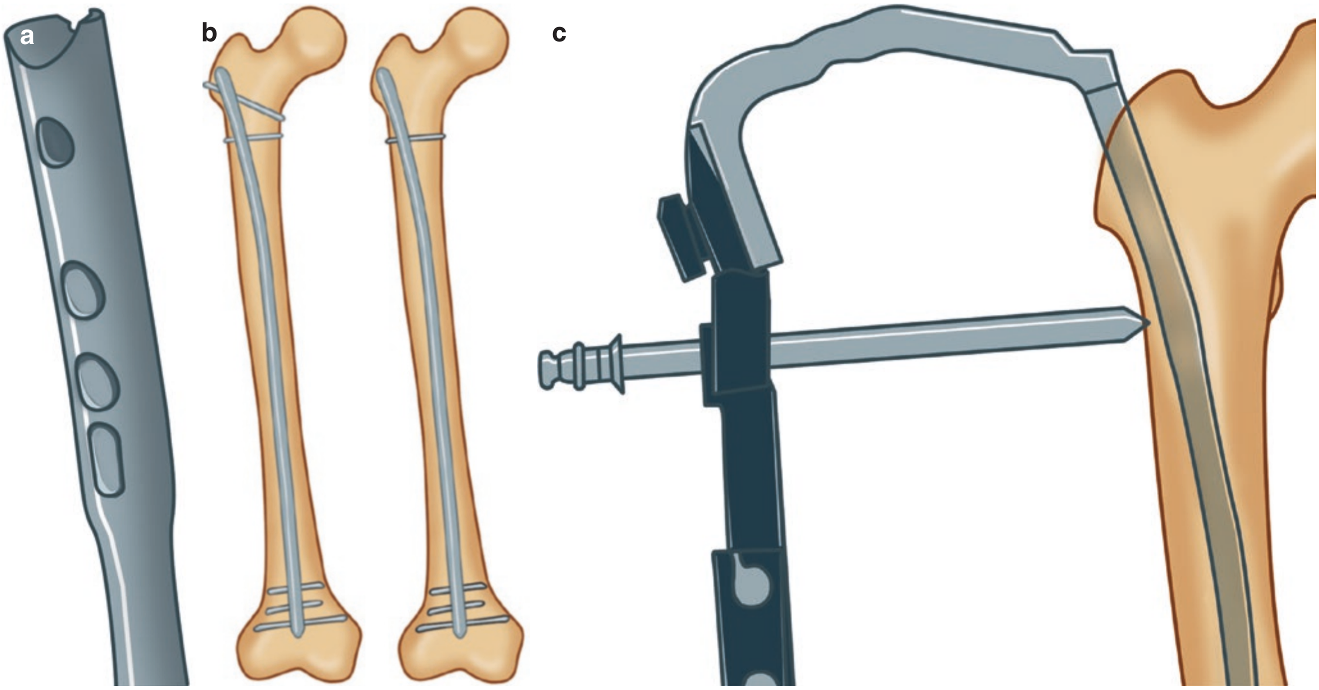

Fig. 5.13 The method for proximal locking is selected according to the needs during surgery and the design of the intramedullary nail, including 120° oblique locking, which has a better anti-rotation effect, and transverse locking, which can be either dynamic or static based on the location of the locking screw. The locking process is aided by an aiming device. (**a**) The methods for proximal femoral locking include oblique, static, and dynamic locking. (**b**) A schematic diagram showing the locking of the intramedullary nail: after locking, the use of interlocking screws can effectively control the rotation of the bone and internal fixators. (**c**) Under the aid of the aiming device, the interlocking screws are accurately placed

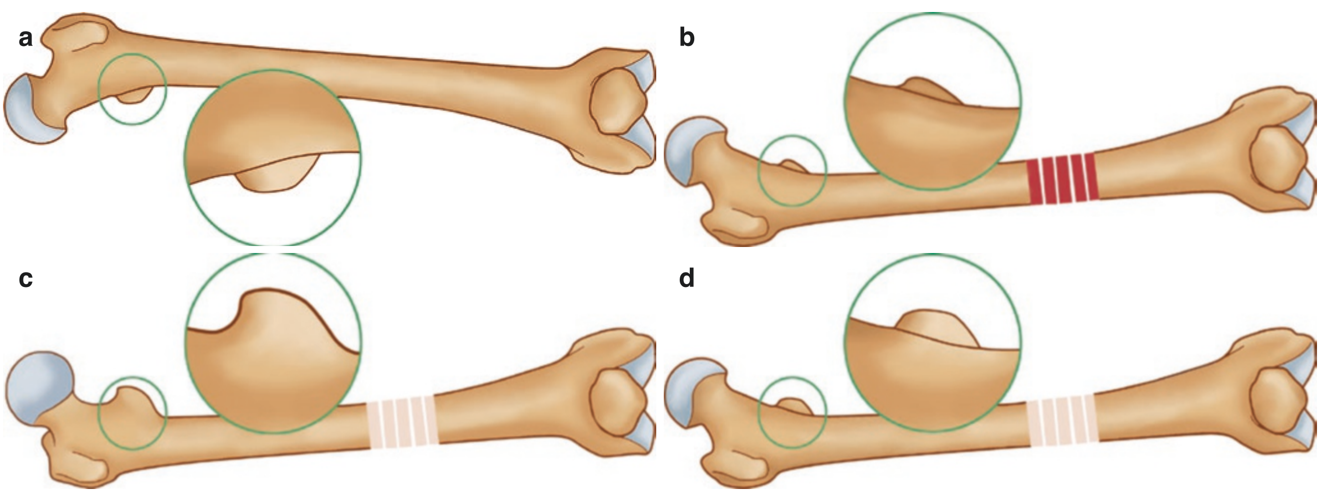

Fig. 5.14 (**a**) The morphologies of both lesser trochanters are examined under fluoroscopy, with the patella of both lower extremities facing front. (**b**) A smaller size of the lesser trochanter on the affected side compared with that of the healthy side suggests an internal rotational deformity of the proximal fragment. (**c**) In contrast, a larger size of the lesser trochanter on the affected side indicates an external rotational deformity. (**d**) The size and shape of the lesser trochanters on both sides are the same after adjustment, i.e., the rotational deformity has been corrected

For comminuted femoral shaft fractures with the lesser trochanter impaired: Both the ipsilateral and contralateral extremities are laid flat to ensure that the patella faces front, and then the anteversion angle of the femoral neck of the healthy side is examined under fluoroscopy. Using the image of the healthy side as a reference, the rotational angle of the affected extremity is adjusted until the anteversion angle of the femoral neck is the same between the two sides when the ipsilateral patella is facing front, i.e., the rotational deformity has been corrected.

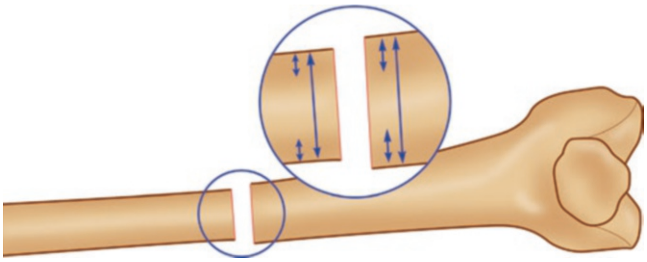

Fig. 5.15 Differences in the thickness of the cortex and the diameter of the medullary cavity between the two bone fragments indicate the presence a rotational deformity of the fractured bone

– Open intramedullary nailing:

It is rarely applied, except in patients after failed closed reduction. The use of intramedullary nailing can partially destroy the blood supply system in the femoral medulla, and the opening operation and cerclage wiring can further disrupt the blood supply to the periosteum, thus affecting fracture healing (Fig. 5.16).

It is important to prolong the duration of weight-bearing exercise for patients treated with open intramedullary nailing.

Fig. 5.16 A 39-year-old male patient with a comminuted fracture of the femoral shaft. (**a**) A preoperative radiograph showing a comminuted fracture of the femoral shaft (AO classification Type C3 fracture). (**b**) The patient received open reduction and intramedullary nailing. The comminuted bone fragments were fixed by cerclage wiring. However, a radiograph showed that the distal locking nail was not long enough to penetrate the cortex on the opposite side. (**c**) A photo of the surgical incision after surgery. (**d**) A radiograph at 7 months postoperative showing nonunion of the fracture, retreatment of the distal locking screw, and displacement of the fractured bone. (**e**) In the second surgery, the appropriate distal locking screws were placed, two plates were used to strengthen the fixation, and bone grafting was performed. (**f**) A radiograph at 20 months after the second surgery shows the healed fracture. (**g**) A radiograph after removal of all internal fixators

Fig. 5.16 (continued)

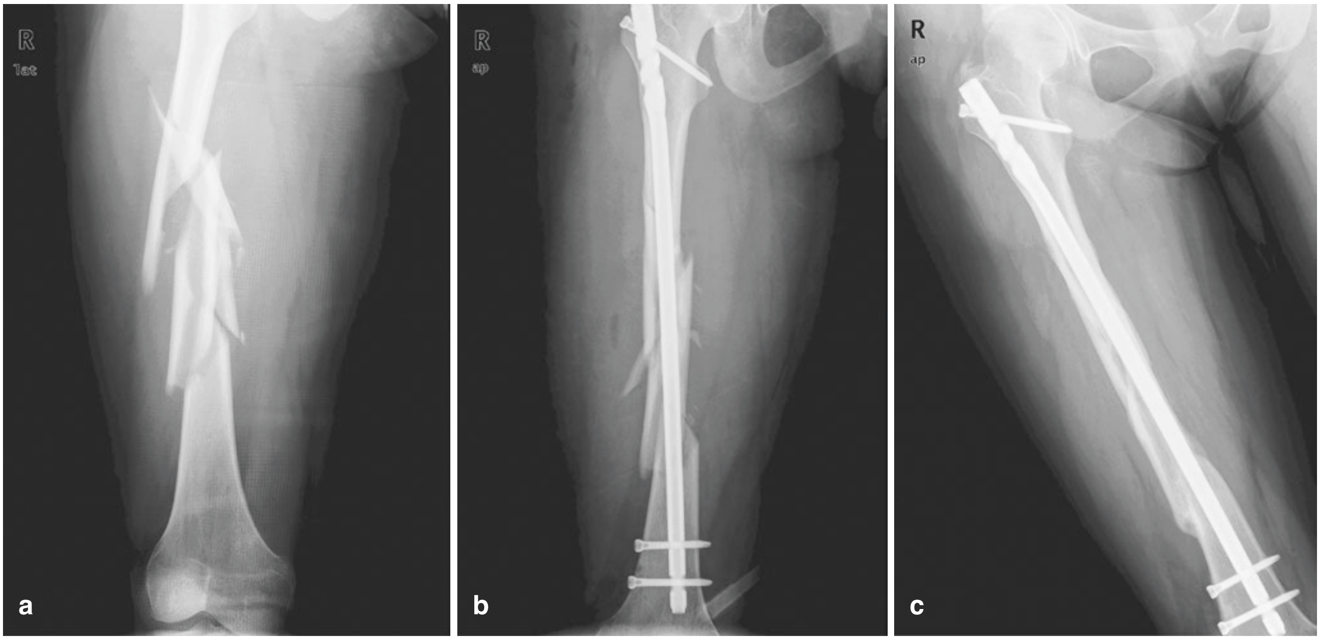

Fig. 5.17 An AO classification Type C fracture of femoral shaft fracture (**a**) a preoperative radiograph shows that the middle segment of the femur was comminuted, with most of the bone fragments in a spiral shape. (**b**) Close reduction and intramedullary nail fixation: The bone fragments were roughly reduced; the proximal end of the intramedullary nail was obliquely locked, and the distal end was locked by two screws. (**c**) A radiograph at 11 months postoperatively showed fracture healing

- Depth of the distal locking screw: The distal screw should pass through the cortex on the opposite side of the bone by two to three threads to achieve a better holding force. If the screw is too short, loosening or even retreating of the locking screw may occur after surgery, resulting in fracture displacement (Fig. 5.16); if the screw is too long, impingement on the soft tissue on the opposite side of the bone may cause pain and discomfort.
- Intramedullary nail fixation for comminuted fractures:

  For long oblique or spiral comminuted fractures with the size of the main bone fragment less than 2/3 of the initial circumference, the intramedullary nail may be displaced due to a lack of restraining force.

  In the above-described case, blocking screw technology can be applied to limit the movement of the intramedullary nail (please see Section (B) of "Retrograde intramedullary nailing for internal fixation" for details).

  For comminuted fractures, despite the absence of a requirement for anatomical reduction, fracture reduction is necessary, and the distance between bone fragments should be minimized to improve conditions for healing.

  During operations of medullary reaming, main nail insertion, and locking screw placement, attention should be paid to maintaining the fracture reduction.

  An oblique locking mechanism from the proximal fracture fragment toward the femoral neck or the lesser trochanter can provide better stability (Fig. 5.17).

5.2.4.2 Retrograde Intramedullary Nailing for Internal Fixation

- Body position and preoperative preparation:
  - The patient lies supine on a radiolucent operating table during surgery.
  - The affected knee joint is maintained in the 40°–60° flexion position by placing a cushion underneath; knee ankylosis is a contraindication for this technique.
  - With the lower extremity maintained in the neutral position by placing a soft cushion underneath the popliteal fossa, closed reduction is performed under fluoroscopy (Fig. 5.18).
- Operative incision according to the preoperative incision marks by surface projection:
  - The shape of the patella is marked with a marker pen, and a longitudinal 2–3-cm-long incision is made from the middle of the lower margin of the patella toward the distal end.
  - To enter the joint cavity and determine the entry point of the nail, the patellar ligament is longitudinally split or pulled laterally after sharply dissociating its medial side with scissors (Fig. 5.19).

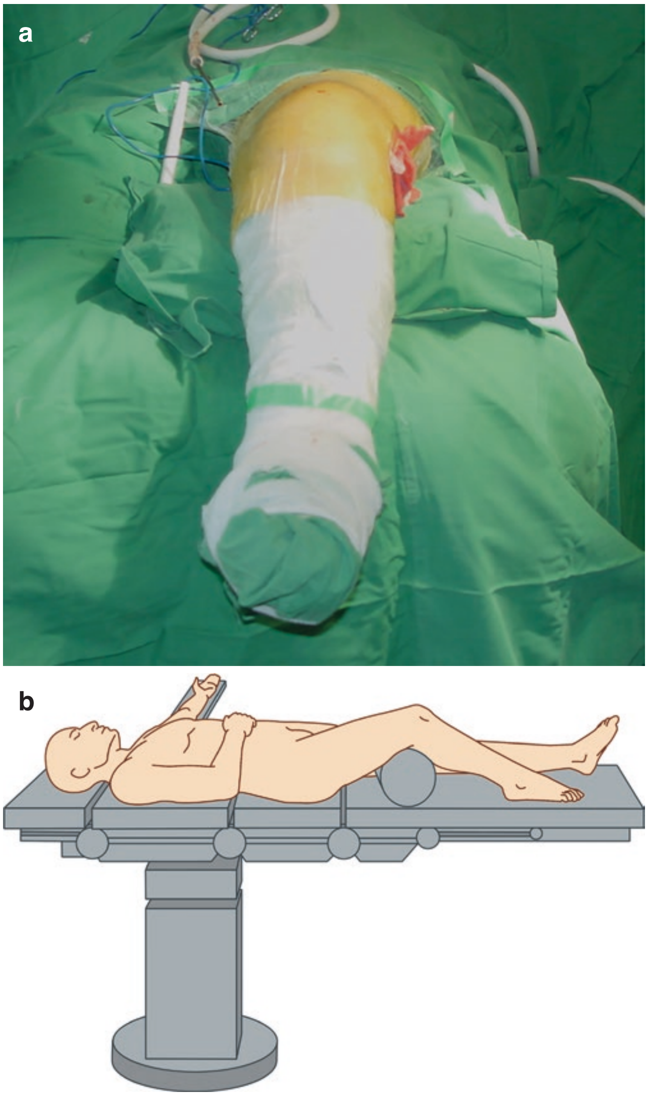

Fig. 5.18 The position for retrograde intramedullary nailing. (**a**) The patient lies in the supine position, and the affected knee joint is raised up to a 30°–60° flexion position by placing a cushion underneath. (**b**) Drawing of the body position for retrograde intramedullary nailing

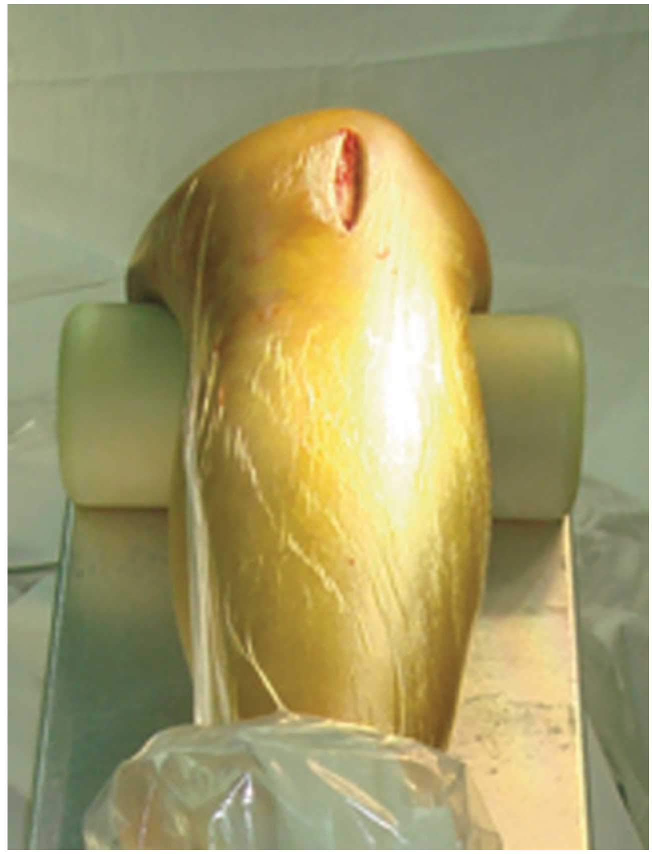

Fig. 5.19 A longitudinal incision is made at the middle of the lower margin of the patella and extended distally approximately 2–3 cm; the patellar ligament is split to enter the joint space and determine the entry point of the nail

- Fracture reduction: A gross fracture reduction must be performed before medullary reaming (please see the section on subtrochanteric femoral fractures for a detailed description of the reduction technique).
- Selection of the entry point for nailing:
  - The projection point of the distal femoral medullary cavity is in front of the ending point of the posterior cruciate ligament.
  - Therefore, a guide wire is inserted from the front of the ending point of the posterior cruciate ligament along the long axis of the femur.
  - Guided by X-ray, the entry point is in the front of the end of Blumensaat's line (the line drawn along the roof of the intercondylar fossa of the femur) in the lateral view, and in the center of the intercondylar fossa in the AP view (Figs. 5.20 and 5.21).
  - Operations including placement of the intramedullary nail guide wire and medullary reaming should be performed with the knee flexed approximately 40°. A knee flexion angle that is too small or too large would easily lead to damage to the tibial tubercle or the inferior pole of the patella, respectively.
- Placement of the intramedullary nail:
  - Along the guide wire that passes across the fracture site, the medullary cavity can be gradually enlarged up to the level of the lesser trochanter with a hollow reamer (please see Chap. 4 "Subtrochanteric Femoral Fractures" for details). Bone crumbs in the joint should be thoroughly rinsed away to eliminate the presence of any free bodies after reaming.
  - After the required length of the intramedullary nail is determined, the nail is inserted into the medullary cavity using bare hands and can be gently tapped in if necessary.

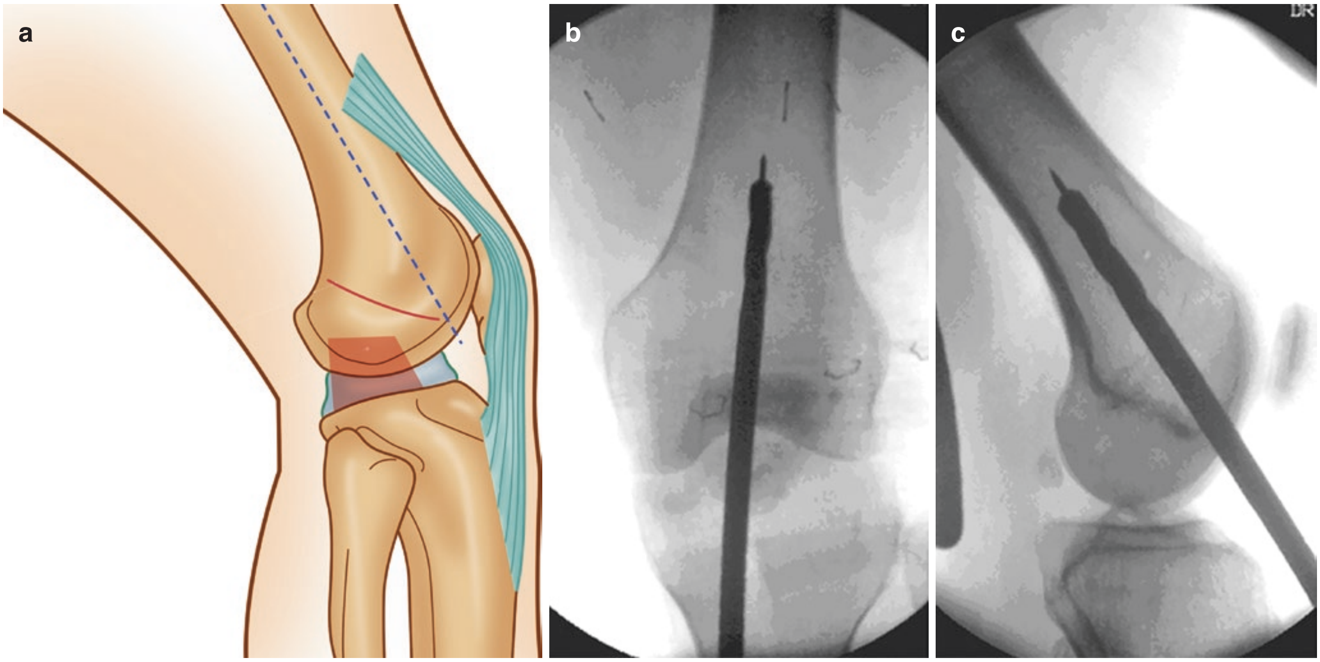

Fig. 5.20 (**a**) The entry point of the retrograde femoral nail is anterior to the end of Blumensaat's line (the line drawn along the roof of the intercondylar fossa of the femur, denoted by the orange solid line in the figure). (**b**, **c**) The entry point of the nail is determined under fluoroscopy during surgery, which is in the center of the intercondylar fossa in the AP view and anterior to the end of the cortical line of the intercondylar fossa in the lateral view

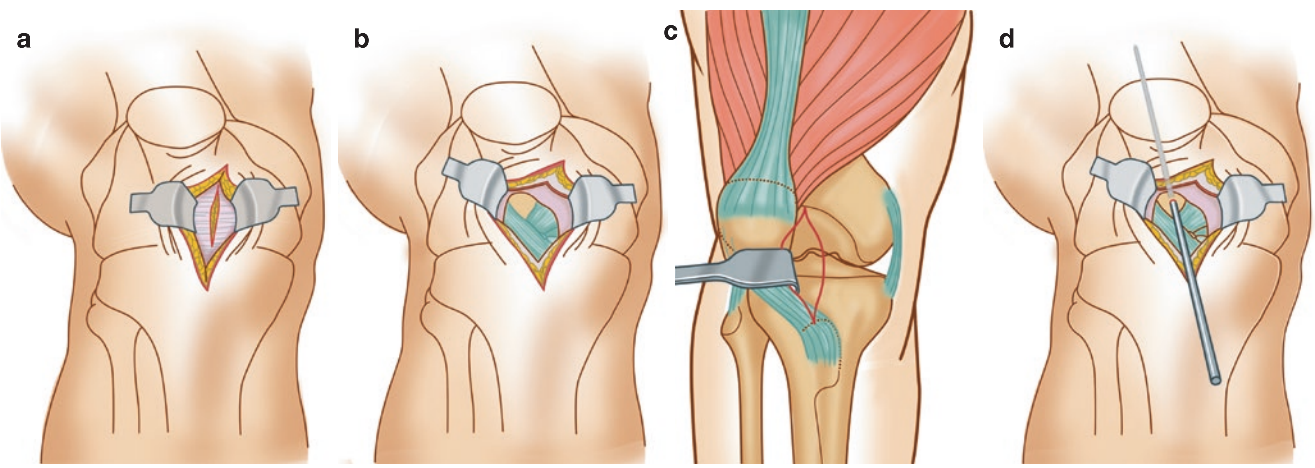

Fig. 5.21 (**a**, **b**) The patellar ligament and joint capsule are longitudinally split to expose the intercondylar fossa and posterior cruciate ligament; the guide wire is inserted directly in front of the ending point of the posterior cruciate ligament. (**c**, **d**) Alternatively, the medial side of the patellar ligament is sharply separated with scissors, and then the patellar ligament is laterally pulled aside

- Positioning of the proximal intramedullary nail: For a fracture with its fracture line at the distal femoral shaft, the intramedullary nail must pass through the femoral isthmus. For comminuted fractures of the femoral shaft, the intramedullary nail should be inserted up to the level of the lesser trochanter.
- Positioning of the distal end of the intramedullary nail: The nail tip must be embedded under the articular cartilage to avoid protrusion from the joint surface (Harwood et al. 2006); otherwise, it will damage the cartilage surface of the patella. The length of the end cap is chosen according to the sinking depth of the end of the intramedullary nail into the bone. The end cap should not be embedded too deep; otherwise, the intramedullary nail will be difficult to remove after fracture healing.

- Proximal and distal locking:
  – With the application of a distal guider, dynamic locking can be used for transverse fractures; static locking should be adopted for comminuted fractures (please see the section “Experiences and techniques” for determination of the length of the locking screw).
  – The mechanical axis and rotational deformity of the affected extremity should be adjusted using the healthy side as a reference (please see the section “Experiences and techniques” for details).
  – While fracture reduction is well maintained, 1 or 2 screws are placed for locking using a “full-circle” technique (Fig. 5.22).
- Incision closure:
  – After placement and locking of internal fixators, the joint capsule and patellar ligament are sutured.
  – The incision is closed following routine procedures.
- Postoperative management:
  – At postoperative day 1, isometric contraction exercise and passive training of the knee of the affected extremity can be performed.

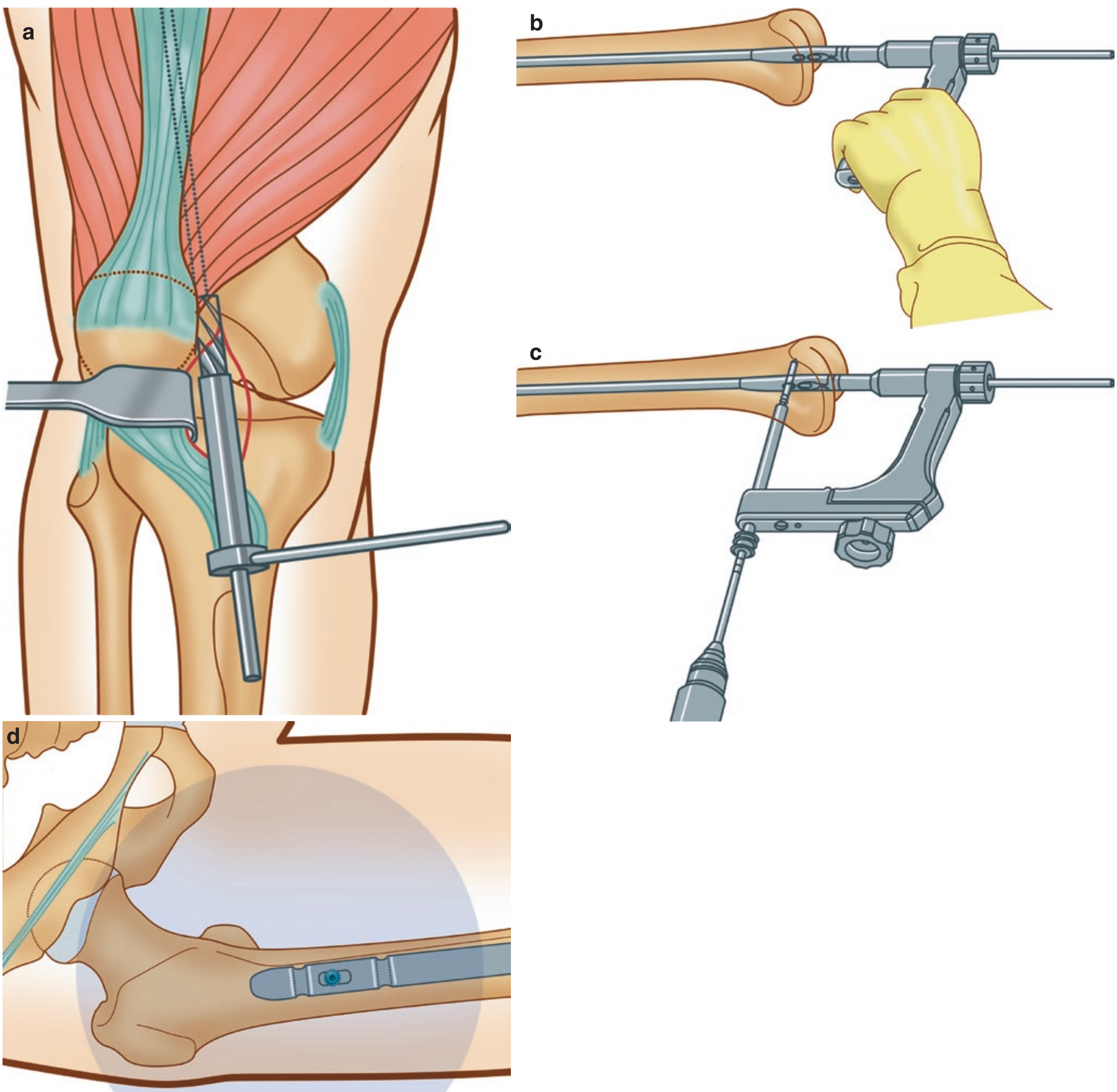

Fig. 5.22 (**a**) The medullary cavity is gradually reamed along the direction of the guide wire. (**b**) The nail is inserted into the medullary cavity using bare hands and gentle tapping. (**c**) Distal locking. (**d**) The proximal end is locked by one or two screws using a “full-circle” technique

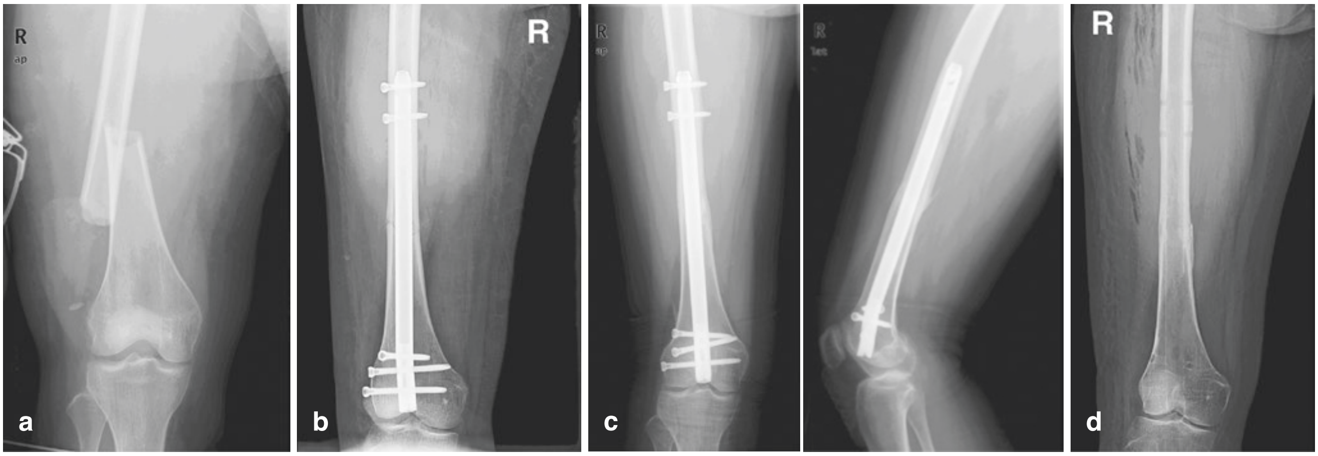

Fig. 5.23 A type A3 fracture of the femoral shaft. (**a**) A preoperative radiograph showing a transverse fracture of the middle-to-lower segment of the femoral shaft. (**b**) The patient received the treatment of closed reduction and retrograde intramedullary nailing, with the proximal end of the main nail locked by two screws and the distal end locked by three screws on multiple planes. (**c**) A radiograph at 2 years postoperatively showing fracture healing. (**d**) A radiograph at 2 years postoperatively after removal of internal fixators

- At postoperative week 1–2, functional non-weight-bearing exercise of the knee can be performed beside the bed.
- At postoperative week 3–4, the patient is encouraged to stand on crutches for partial weight-bearing exercise of the affected extremity and continue the functional exercise of the knee joint.
- If fracture fixation is stable, the weight-bearing exercise can be gradually intensified according to the tolerance level of the patient.
- In patients receiving statically locked fracture fixation, the affected extremity should not bear a load exceeding 50% of the body weight.
- The weight-bearing exercise can be gradually intensified after the fracture healing is confirmed by radiographic examination; otherwise, full weight-bearing should be postponed if the radiograph indicates a delayed fracture healing (Fig. 5.23).

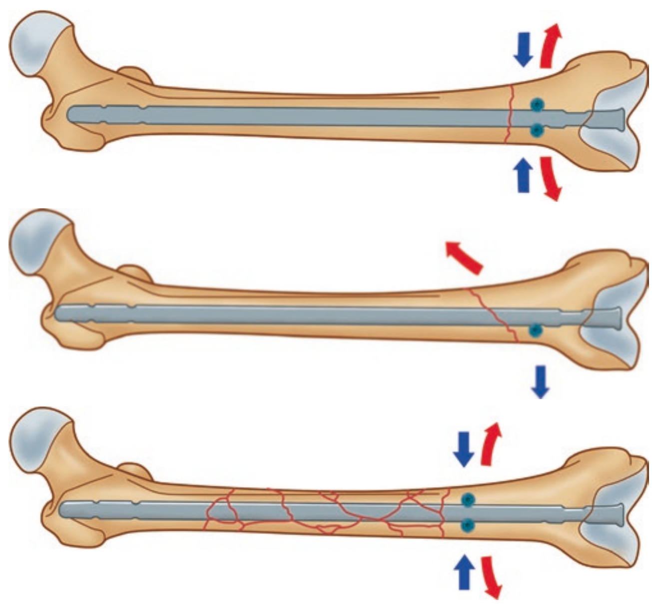

Fig. 5.24 Blocking screw techniques for different fracture types: for transverse fractures, two blocking screws can be used; for oblique fractures, one blocking screw can be used according to the direction of fracture displacement; for comminuted fractures, the blocking screw technique can also be applied according to the possible direction of fracture displacement and size of the medullary cavity. Direction of displacement of unstable fractures (red arrow). Reaction direction of blocking screw (blue arrow)

Experience and techniques

- Blocking screw technique (Fig. 5.24):
- The purpose of using blocking screws is to prevent the displacement caused by oblique fracture. Therefore, blocking screws should be placed on the shorter side of the distal fracture fragment in oblique fractures, and two blocking screws should be placed within the segment where the medullary cavity is broader.
- The blocking screw should be placed before intramedullary reaming because it creates a path for main nail placement that may compromise the effectiveness of screw blocking.
- Common screws or locking screws can be used as blocking screws. After insertion of the blocking screws, attention should be paid to avoid damaging the tip of the intramedullary reamer during medullary reaming.
- Determination of the length of the distal locking screw under fluoroscopic guidance (taking transverse locking as an example).
  - Because the cross-section of the distal femur is trapezoid, it is possible that a locking screw with an appropriate length appears shorter than the width of the distal femur and embedded inside the bone in the AP view.

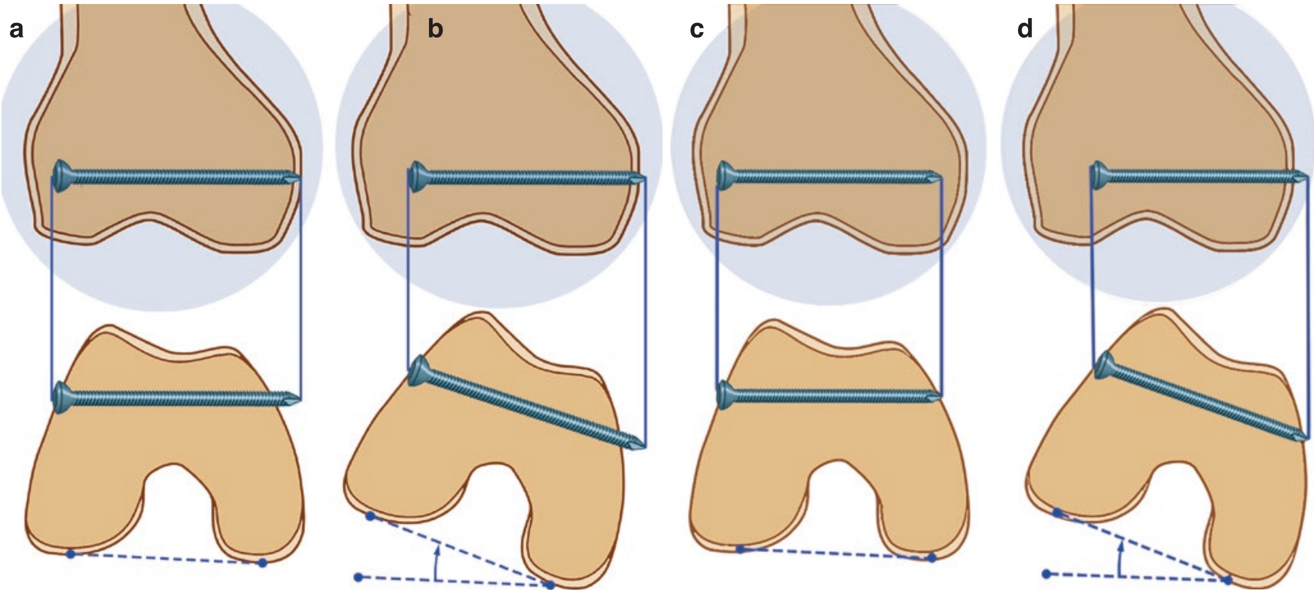

Fig. 5.25 (**a**) The tip of the locking screw is within the cortex in the AP view. (**b**) In the radiograph taken when the distal end of the affected extremity is internally rotated by 30° to show the tangential position of the screw tip, the tip of the screw protrudes from the cortex on the opposite side, which may cause pain and other symptoms after surgery. (**c**, **d**) To avoid incorrect judgment regarding the length of the locking screw (e.g., the screw is too long), the X-ray beam should be projected along the direction tangential to the cortex of the medial condyle, namely, at the position when the distal end of the affected extremity is internally rotated by 30°

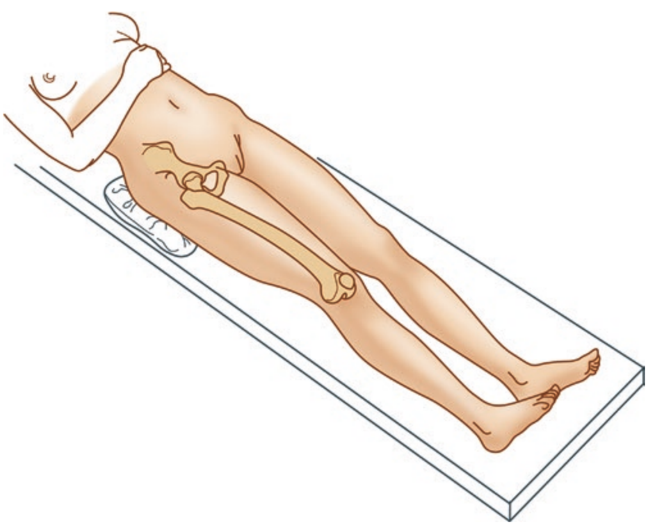

Fig. 5.26 The patient lies in a supine position with the affected extremity raised up by placing a cushion beneath the hip

- If the locking screw is placed too far into the femur and enters the cortex under the AP view, then it is likely that the screw is too long and will penetrate the medial cortex, which would cause impingement-associated pain in the future.
- Therefore, the locking screw should be placed under fluoroscopic guidance when the distal end of the affected extremity is internally rotated by 30° and the X-ray beam is projected along the direction tangential to the cortex of the medial condyle (Fig. 5.25).

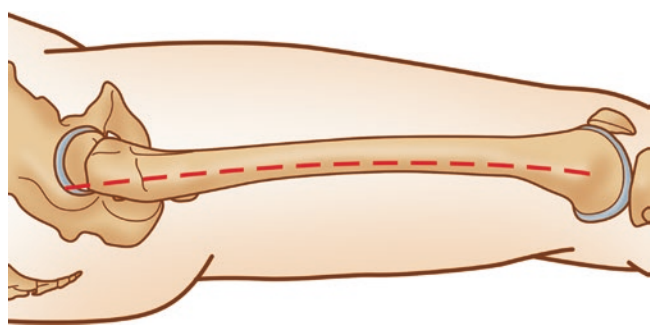

Fig. 5.27 An arc-shaped skin incision is made along the long axis of the femur, and its length is determined according to the location and affected area of the fracture

5.2.4.3 Open Reduction and Internal Fixation of Femoral Shaft Fractures (The Lateral Approach)

- Body position and preoperative preparation: Epidural anesthesia or general anesthesia is applied, and preparations for possible blood transfusion are performed. The patient lies in a radiolucent operating table or a traction table, with the affected extremity raised up by placing a cushion beneath the hip (Fig. 5.26).
- Operative incision according to the preoperative incision marks by surface projection: An incision is created according to an arc-shaped curve drawn along the long axis of the femur on the lateral side of the thigh using a marker pen. The length of the incision is determined according to the location of the fracture (Fig. 5.27).

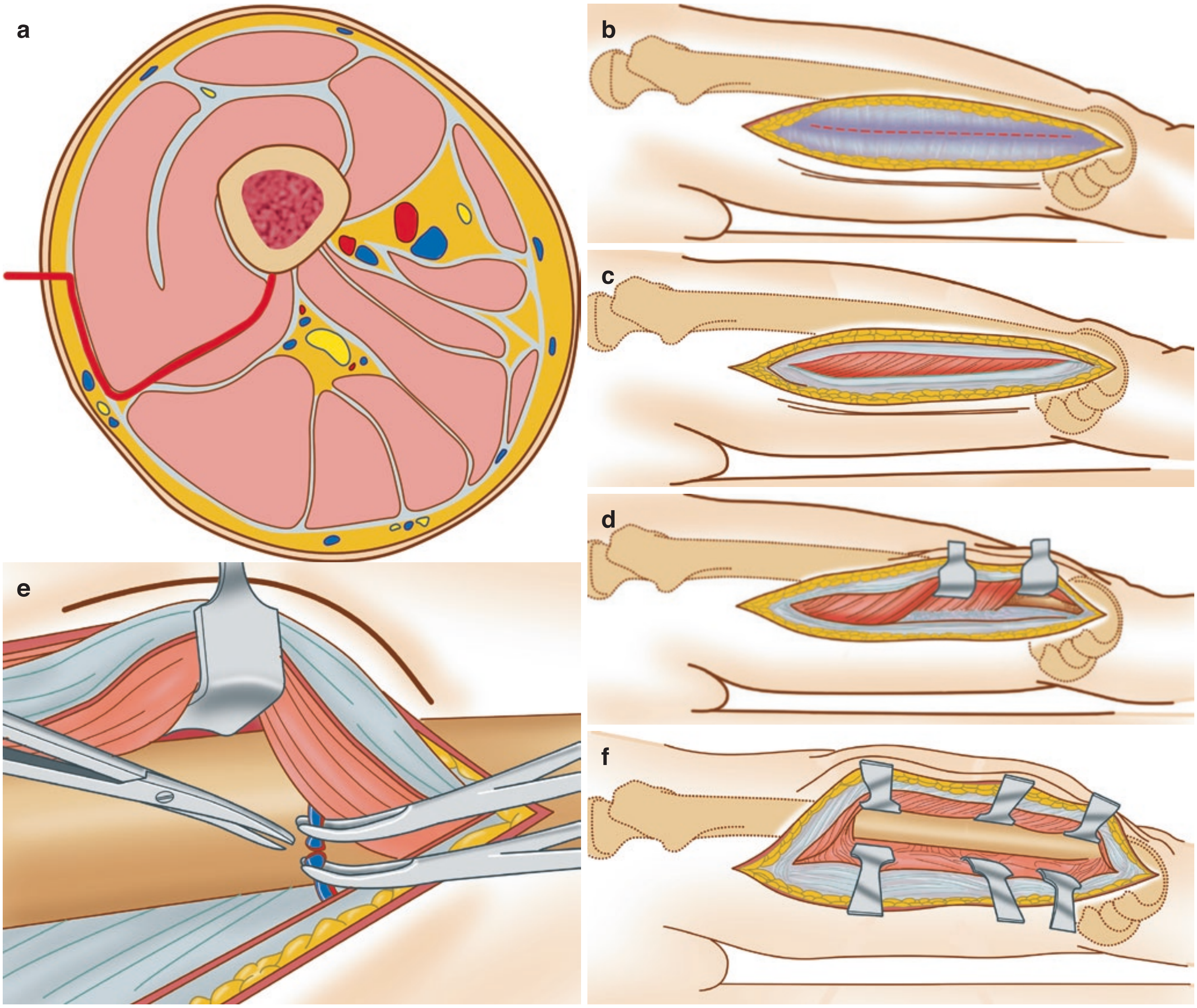

Fig. 5.28 (**a**) The cross-section diagram of the femoral shaft shows access to the femur via the lateral approach. (**b**, **c**) The fascia latae is longitudinally split. (**d**) The vastus lateralis muscle is separated along the lateral intermuscular septum. (**e**) The perforator vessels in the area from the intermuscular septum to the femur must be ligated. (**f**) The femur is exposed

- Surgical approach (Fig. 5.28):
  - Incisions are created in the skin and subcutaneous tissues along the projection line on the body surface to expose the fascia latae, which is then longitudinally split. The vastus lateralis muscle is separated along the fascia latae toward the hip up to the lateral intermuscular septum. During this process, splitting of the vastus lateralis muscle should be avoided to reduce intraoperative blood loss.
  - Separation of the vastus lateralis muscle along the lateral intermuscular septum is continued up to the femur. It is important that the separation should be conducted maximally close to the intermuscular septum to reduce bleeding.
  - When separation reaches the area near the femur, special attention should be paid to avoid breaking the perforator vessels penetrating the posterior part of the lateral muscular septum, which should be carefully ligated.
- For different types of fractures, different strategies should be adopted for reduction and fixation.
  - According to the force-loading pattern of the femur, the steel plate should be placed on the lateral tension side to allow it to play a role similar to the tension band.
  - Moreover, the medial cortex on the compression side must remain intact. Therefore, reduction of the medial cortical fragment is critical for Type B and Type C fractures.

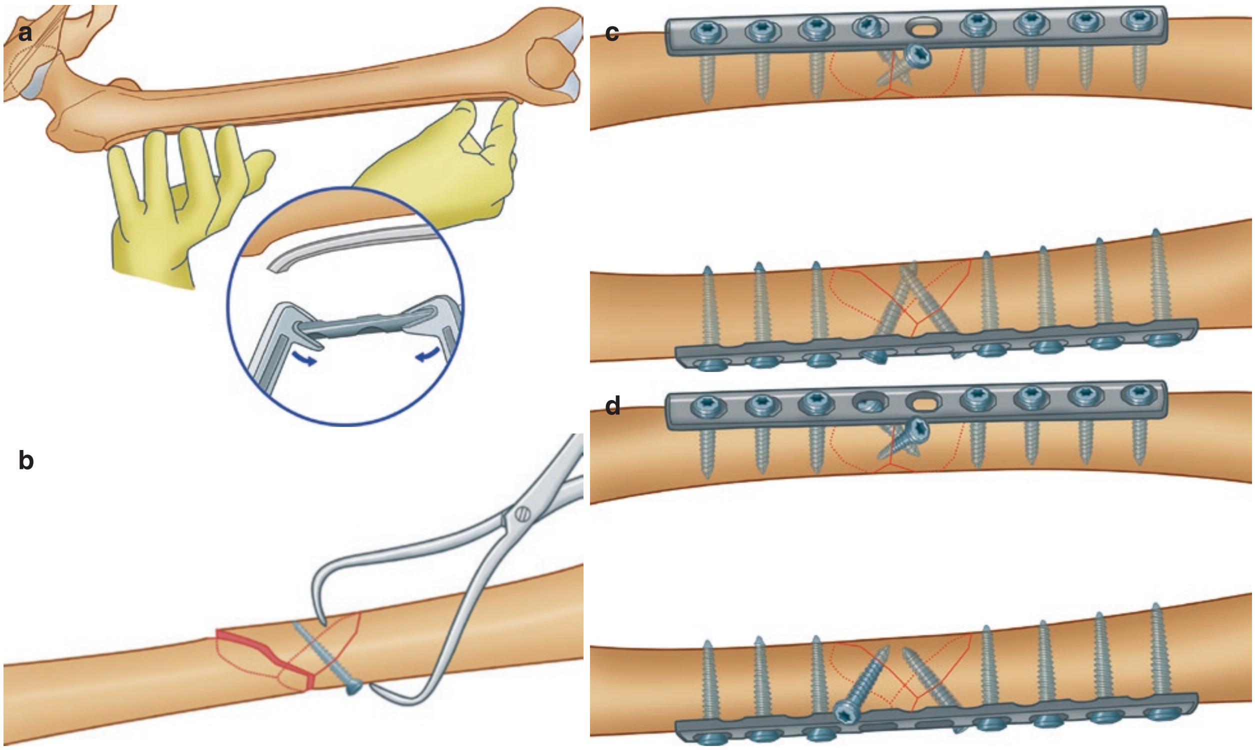

Fig. 5.29 (**a**) The plate is pre-shaped based on the shape of the femur. (**b**) The butterfly fragment is reduced and fixed with a lag screw, and the hole is drilled into the side of the main bone fragment to minimize the disturbance in the blood supply to the butterfly fragment. (**c**, **d**) At least three bicortical screws are placed on each side of the fracture for fixation, and one lag screw passes through the plate if possible

– Fixation with lag screws and a protective plate can be used for type A fractures (Fig. 5.31) (please see the section "Open Reduction and Internal Fixation for Humeral Shaft Fractures" for details).
– Fixation with lag screws and a protective plate can be used for types B1 and B2 fractures (Fig. 5.29):

  The plate is pre-shaped based on the shape of the femur.

  A Type B fracture should first be converted into a Type A fracture with lag screws.

  To protect the soft tissue attachment of the butterfly fragment and avoid extensive dissection, the fragment should be reduced with a pointed reduction clamp.

  The lag screws are screwed into the holes drilled perpendicular to the fracture plane from the side of the main bone fragment. Ideally, one lag screw should pass through the steel plate, if possible; however, if the fracture shape does not allow, the placement of two lag screws without passing through the plate is acceptable.

  At least three bicortical screws are placed in each fracture fragment.
– Bridge plate fixation can be used for Type B3 and C fractures (Fig. 5.30).

  First, the fragments are roughly reduced using traction, a femoral retractor, and other methods.

  Any large butterfly fragment can first be fixed using the lag screw technique.

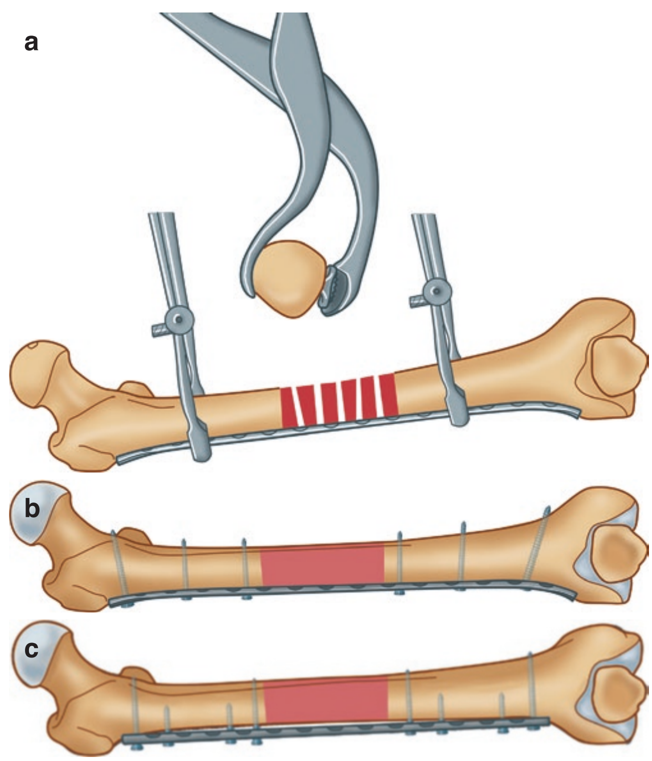

Fig. 5.30 (**a**) The plate is pre-shaped according to the shape of the proximal and distal femur, and the reduction is maintained by using a bone-holding clamp. (**b**) At least three screws are placed in each fracture fragment. (**c**) A locking plate is used to establish an internal fixation frame, during which pre-shaping of the plate and full bone-plate contact are unnecessary

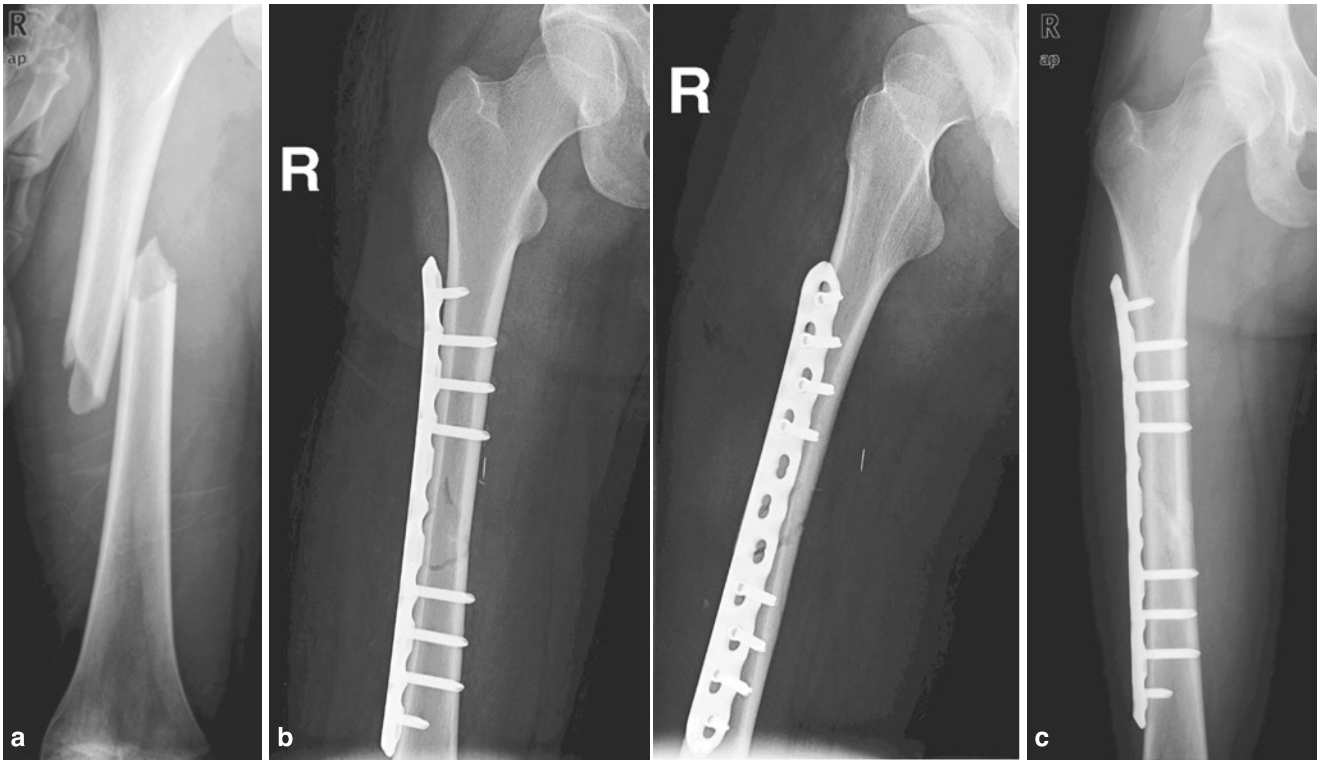

Fig. 5.31 (**a**) An AO classification Type A2 fracture of the femoral shaft. (**b**) The fracture was treated by open reduction and internal fixation, with seven cortices fixed with screws on each side of the fracture and having a sufficient working distance in between the screws. (**c**) A radiograph at 3 months postoperatively showed fracture heading

For Type B3 and C fractures, anatomic reduction of the fracture-affected segment is not required. However, attention should be paid to restoring the mechanical axis, length and rotation of the affected extremity (please see the section “intramedullary nail fixation” for specific methods). The reduction must be maintained using a bone-holding clamp after adjustment of the position.

Shapeable plate fixation can be applied with at least three screws to secure each fracture fragment. Alternatively, internal locking plate fixation can be used without pre-shaping the steel plate.

- After hemostatic treatment, the fascia latae is sutured to prevent the formation of a muscle hernia, followed by suturing of the incision.

Postoperative management

- At postoperative day 1, isometric contraction exercise and passive training of the knee of the affected extremity can be performed.
- Afterward, both active and passive non-weight-bearing functional exercises of the knee are performed until fracture healing.
- Internal plate fixation achieves lateral eccentric fixation, and the plate bears high tensile stress; therefore, the timing of weight-bearing exercise should be determined according to the fracture healing status.

Experiences and techniques

- Femoral shaft fractures accompanied by femoral neck and knee joint ligament injuries:
- Please see the relevant content in the chapter on femoral neck fractures for treatment principles and strategies for concurrent ipsilateral femoral shaft and neck fractures.
- A retrospective study found that 27–48% of femoral shaft fractures are associated with knee ligament injury, and the average time of knee instability diagnosis is more than 1 year after injury (Walker and Kennedy 1980).
- For patients with a femoral shaft fracture accompanied by a knee ligament injury who cannot immediately receive a relevant physical examination due to pain, the stability of the knee joint should be examined after surgical fixation of the femoral shaft fracture.
- Multi-dimensional cross locking plate can be used as an anterior augmentation plate via anterior approach to treat femoral shaft nonunion with or without exchanging intramedullary nailing.

Femoral shaft nonunion has been a big challenge for orthopedic trauma surgeon and a disaster for patients (Rockwood et al. 2019). Numerous methods, such as screw dynamization, exchanging nail (EN), double plates (DP), the Ilizarov technique, or an augmentation plate (AP), have been followed to treat nonunion with bone healing rate of 47–100% (Rommens and Hessmann 2015; Marti and Kloen 2011; Zhang et al. 2018a). However, all kinds of complications and concerns often occurred. Nail dynamization is a simple and safe method, but it has the potential of extremity length shortening, especially for the patients with comminuted fracture (Gelalis et al. 2012). Besides, exchanging larger diameter nail has been preferred by many surgeons, but with variable healing rates due to potential heat injury or considerable vascular damage to blood circulation (Gelalis et al. 2012). Double plates could also provide rigid stability for nonunion site, but extensive soft tissue dissection and blood supply disruption at the nonunion site could not be avoided (Zhang et al. 2018b). Although Ilizarov technique might be a minimally invasive option, many patients are not tolerant to external fixator with the potential of pin-tract infections, or inconvenience in daily life (Zhang et al. 2017a, b).

Compared with above-mentioned surgical treatment, augmentation plate (AP) over nail has been reported to manage femoral shaft nonunion as the first line treatment option, with higher healing rate (Garnavos 2017; Rupp et al. 2018). However, unicortical screw and single-dimensional fixation are inadequate to afford enough anti-rotational stability for the nonunion site (Wei et al. 2019). In addition, the incision length of lateral or posterolateral approach used commonly, was so long due to the interference with fascia lata that we could fully expose nonunion site for thorough debridement and bone grafting, especially in the medial side of nonunion site, and created massive destruction of soft tissue around nonunion site, which might lead to delayed union, limb dysfunction, and poor quality of life (Wei et al. 2019; Chapman and Finkemeier 1999). It seemed that fracture healing needed much more time and the functions of the affected limb or quality of life of the patient did not get improved. Hence, how to achieve the improvement of mechanical stability and biological environment is still a big problem for femoral shaft nonunion with augmentation technique.

A new augmentation plate system, which is designed and termed as multidimensional cross-locking plate (MDC-LP) by Pro. Tang and chen, could provide multidimensional stability and bicortical screw fixation when combined with IMN to treat femoral shaft nonunion (Zhang et al. 2020). The MDC-LP is a 3.5 mm wide plate that is divided into two types: 8 cm long with six-row holes and 10 cm long with eight-row holes (Fig. 5.32). In the sagittal plane, the direction of the locking screw forms an angle of 30° with the long axis of the medullary cavity and with the proximal row of screws pointing proximally and the distal row of screws pointing distally. In the transverse section, the direction of the locking screw forms an angle of 45° with the vector line of the medullary cavity and with the outboard screws pointing outward and the inboard screws pointing inward. The MDC-LP can be located on the anterior surface of the femoral shaft, with the locking screws inserted from the anterior cortices to the posterior cortices, sandwiching a nail. The results of biomechanical research and clinical study have shown that the MDC-LP could provide better mechanical stability over nail for femoral shaft nonunion compared with the traditional locking compression plate.

Conventional lateral and posterolateral approaches are associated with severe soft tissue and muscle damage, difficulty in exposure, and inadequate debridement of nonunion site, which may lead to prolonged fracture healing and poor function of the affected limb and quality of life (Wei et al. 2019). Chapman and Finkemeier (1999) treated 14 femoral supracondylar nonunion via anterior approach, and achieved

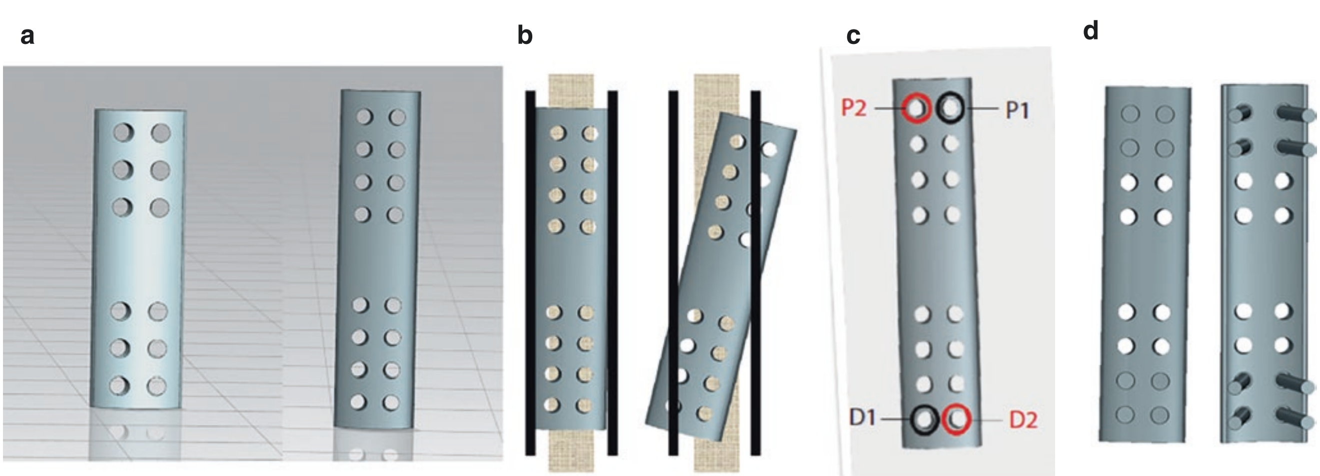

Fig. 5.32 Schematic representation of MDC-LP. (**a**) MDC-LP with six and eight holes. (**b**) The plate should be placed concentrically, that is, in keeping with the long axis of the femoral shaft and nail. (**c**) First choice of two holes fixation in a diagonal relationship, P1 and D1, or P2 and D2. (**d**) Four bicortical screws should be fixed bilaterally around the nonunion site

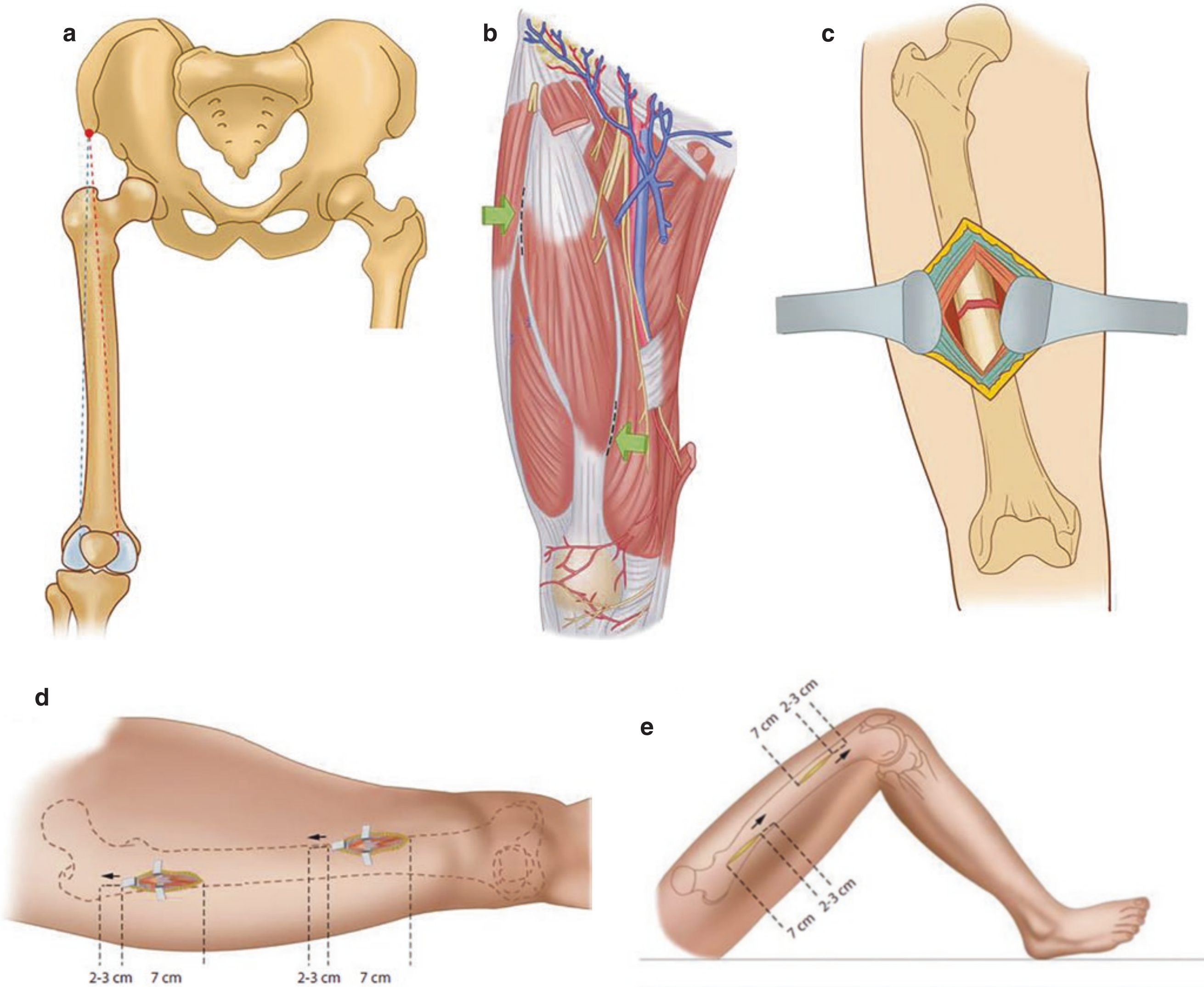

Fig. 5.33 Schematic diagram of anterior approaches. (**a**) Body surface projection of anteromedial approach (red line) and anterolateral approach (blue line). (**b**) The intermuscular space of lateral or medial rectus femoris is identified (green arrow). (**c**) The anterior, medial, and lateral aspects of the nonunion site could achieve bright exposure via the anterior approach. (**d**) When hip and knee are extended, the incision is pulled 2–3 cm proximally with the retractor. (**e**) Flexing both hip and knee to contract the quadriceps, the incision could slide 2–3 cm distally. Black arrow: incisions sliding direction

satisfactory fracture-healing outcomes. Moreover, he also found that if the anterior approach was chosen, the nonunion site could be clearly exposed, bone grafting and fixation could be facilitated, and postoperative knee function was satisfactory. Hoppenfeld et al. (2009) and Morrey and Morrey (2008) showed that the anterior approach, through the medial and lateral intermuscular spaces of rectus femoris, could be used to expose the full length of the femoral shaft. Therefore, treatment of femoral shaft nonunion via the anterior approach might provide another new option (Fig. 5.33). The surgical incision used for anterior approach could automatically shift with flexion and extension of hip and knee, and thus, a longer plate can be placed through this shorter incision. The smaller surgical trauma and tissue dissection can also reduce the healing time. In addition, the nonunion site was exposed through the intermuscular space via anterior approach with little interference with the quadriceps femoris, and achieved better functional outcome by earlier clinical practice in our trauma center (Fig. 5.34).

- Surgical procedure

The patient was placed in a supine position with extension of the affected hip and knee. A longitudinal marking line was made by surface projection to connect the anterior inferior iliac spine (AIIS) and the superior pole of patella, and a transverse marking line was made at the nonunion site identified by image intensifier. An incision of 5–10 cm was made along the longitudinal marking line with its center on the intersection point of the longitudinal and transverse marking

Fig. 5.34 A 29-year-old female with right nonisthmal femoral shaft nonunion after nailing. (**a**, **b**) X-ray showed no breakage of nail and hypertrophic nonunion without obvious deformity and bone defect preoperatively. (**c**, **d**) The MDC-LP as AP was performed without removal of the previous nail via anterior approach, and all screws achieved bicortical fixation. Three months postoperatively, X-ray showed that fracture uneventfully healed. (**e**) The incision (5 cm) was seen in front of the thigh (red arrow). (**f**, **g**) The function of the affected extremity was good

lines. The skin, subcutaneous tissue, and fascia were sequentially incised to visualize the medial or lateral intermuscular space of the rectus femoris. After the vastus intermedius was exposed through this space, the vastus intermedius and the periosteum were incised sharply along the longitudinal axis of the limb. Then, the vastus intermedius was stripped together with the periosteum to visualize the nonunion site, and the decortication and autogenous bone grafting was performed.

For augmentation plate via this approach, knee and hip were placed at the extension position to relax the quadriceps femoris. Then, a retractor was used to retract the muscle proximally and shift the incision 3 cm proximally, which created a space that was available for proximal screws insertion. After this, knee and hip were placed at the flexion position to stress the quadriceps femoris, and the incision was automatically shifted 3 cm distally to obtain a space for distal screws insertion.

When the MDC-LP was chosen as the augmentation plate, screw holes on both ends of the plate that are farthest from the nonunion end should be fixed firstly. Secondly, of these four screw holes, two holes fixation in a diagonal relationship, P1 and D1, or P2 and D2, should be chosen. This mode of fixation is advantageous in determining the long axis congruence of plate and nail. After complete fixation of these four screw holes, fixation of additional screw holes is

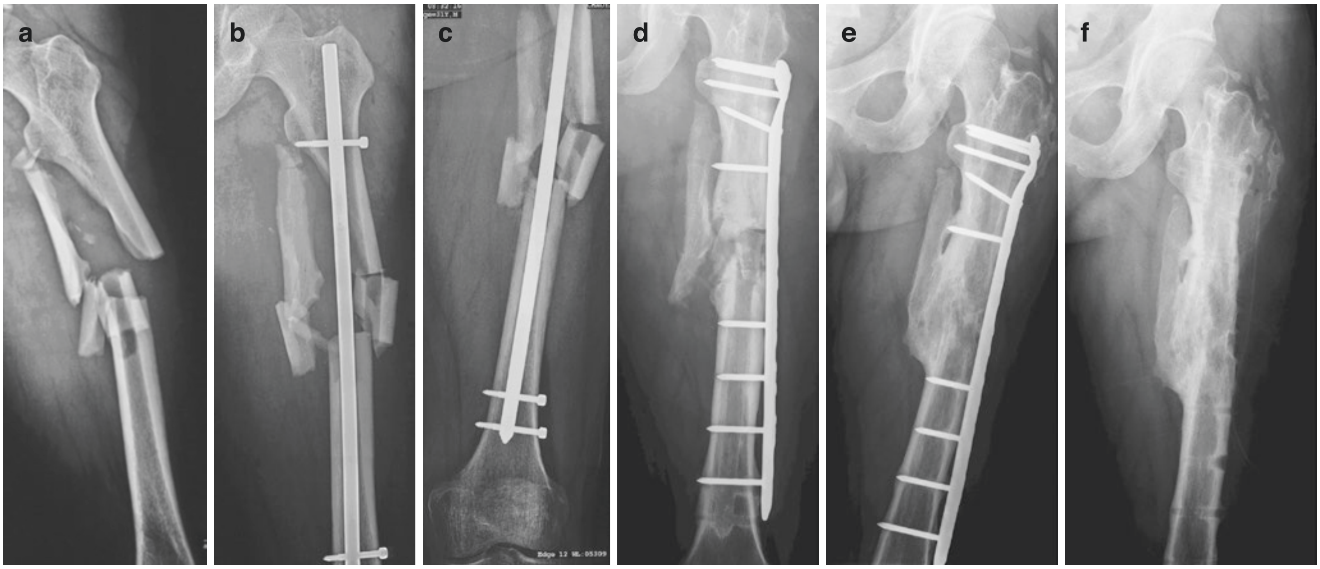

Fig. 5.35 A 36-year-old male patient with a femoral shaft fracture. (**a**) A preoperative AP radiograph showed a comminuted AO Type C3 femoral shaft fracture, with an oblique fracture at the proximal end and less than 1/2 of the initial circumference remaining in the main bone fragment. (**b**) The patient received closed reduction and intramedullary nailing; however, poor intraoperative fracture reduction caused a varus deformity, and the intramedullary nail was not constrained and held in position firmly. (**c**) A radiograph at 3 months postoperatively showed malreduction (the proximal bone fragment had a varus deformity) and bone nonunion (the fragments were separate from each other at the medial side). (**d**) Two years after the first surgery, the second surgery for open reduction, plate-screw fixation, and bone grafting at the fracture site were performed. (**e**) A radiograph 3 years after the second surgery showed healing of the fracture. (**f**) A radiograph after removing the internal fixator

indicated. It is recommended that the nonunion site should be fixated with four bicortical screws bilaterally, that is, eight layers of cortical bone bilaterally. If bicortical fixation is not achieved with partial screws, more screw holes can be fixed to achieve the reasonable number of cortical bone fixations. The drainage tube was placed after suture of the periosteum and the vastus intermedius, then the incision was closed in layers.

5.2.5 Postoperative Complications and Their Prevention and Treatment Strategies

- Prevention and treatment for complications after intramedullary nailing for femoral shaft fractures:
  - Obesity might increase the risk of fracture healing with malformation or nonunion due to an inaccurate entry point of the guide wire caused by soft tissue interference (Szalay et al. 1990; Ricci et al. 2006).
  - In a fracture of the proximal 1/3 of the femoral shaft, the proximal fragment may be abducted, flexed, and externally rotated due to the imbalanced pulling forces from the gluteus medius, gluteus minimus, and iliopsoas muscles. Special attention should be paid to the reduction before medullary reaming and the accuracy of the entry point of the guide wire; the entry of the guide wire deviated laterally may cause a varus deformity (Fig. 5.35).
  - It is critical to maintain the reduction during medullary reaming; otherwise, new fractures may occur, or the intramedullary nail is inserted in an eccentric direction, resulting in malunion.
  - For comminuted fractures with long oblique or long spiral bone fragments, if the main bone fragment has less than 2/3 of the initial circumference remained, then intramedullary nailing yields poor stability (Tucker et al. 2007; Hak et al. 2000).
- An improper plate-screw fixation strategy may cause fracture nonunion (Fig. 5.36):
  - For a simple fracture, compression on the broken ends can achieve absolute stability and ultimate fracture healing.
  - Bridging plate fixation of simple fractures requires a sufficient working distance to ensure that the distance between the nearest screws on each side of the transverse fracture line is eight to ten times the width of the fracture line.
  - When using a bridging plate to fix comminuted fractures, the length of the steel plate should be more than three times that of the fractured zone, and no screw is placed in the fractured zone to obtain relative stability and reduce stress concentration (Weresh et al. 2000).
- The absence of the medial cortex may lead to breaking of the plate and screws and ultimately fixation failure (Ruedi and Luscher 1979; Riemer et al. 1992; Beaupre et al. 1988) (Fig. 5.37):

Fig. 5.36 A femoral shaft fracture (Type B1). (**a**) A preoperative radiograph showed a type B1 fracture in the middle segment of the femoral shaft. (**b**) The patient received locking plate fixation; however, the fragments were not compressed effectively, and the fracture was not absolutely stabilized. In addition, the screws were too concentrated in the fracture area, and thereby the fractured part was not relatively stabilized. (**c**) As shown in the radiograph taken at 8 months postoperatively, the bone was absorbed near the fracture site, the fracture line was clearly visible, and the fracture did not heal. (**d**) The patient received the second surgery for removal of the excessive screws and for double-plate fixation and autologous bone grafting

– As mentioned previously, because the medial femur bears compression and the lateral femur bears tension, the steel plate placed on the tension side can act as a tension band, but the medial bone cortex must gain sufficient support.

– Otherwise, the steel plate acts like a cantilever-like force-bearing structure that is prone to metal fatigue during weight bearing, eventually leading to breakage of the plate and screws.

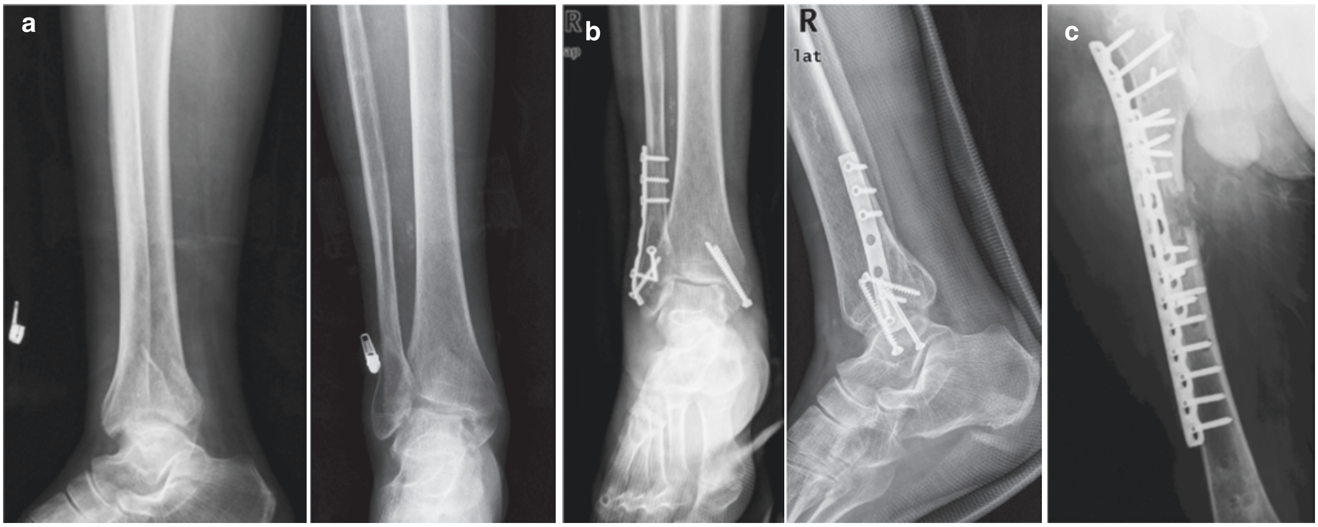

Fig. 5.37 (**a**) A femoral shaft fracture was fixed with plate and screws, and a portion of bone in the medial side was absent. (**b**) A radiograph at 3 months postoperatively showed the broken plate. (**c**) Double-plate fixation and bone grafting at the fracture site were performed

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