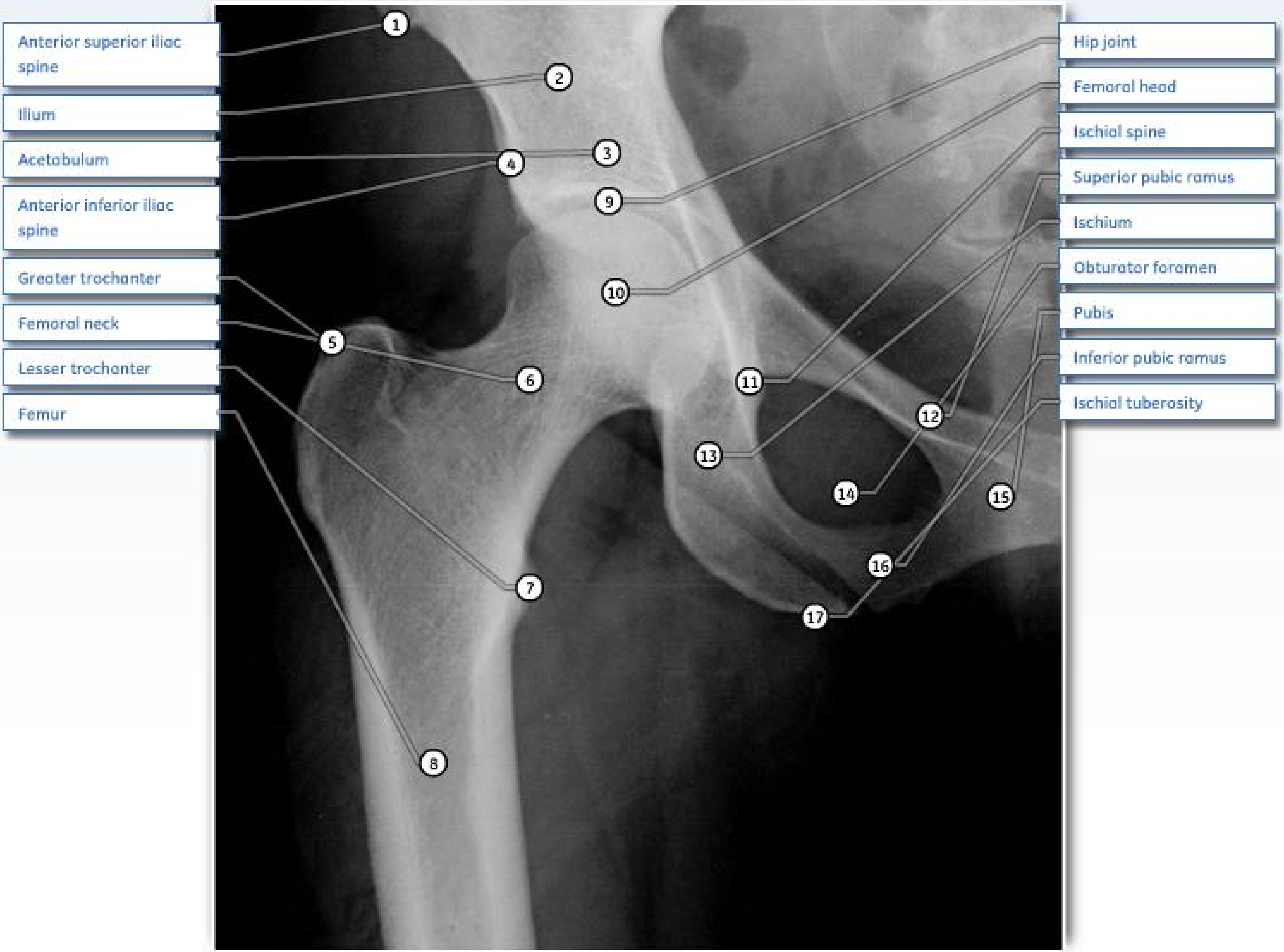
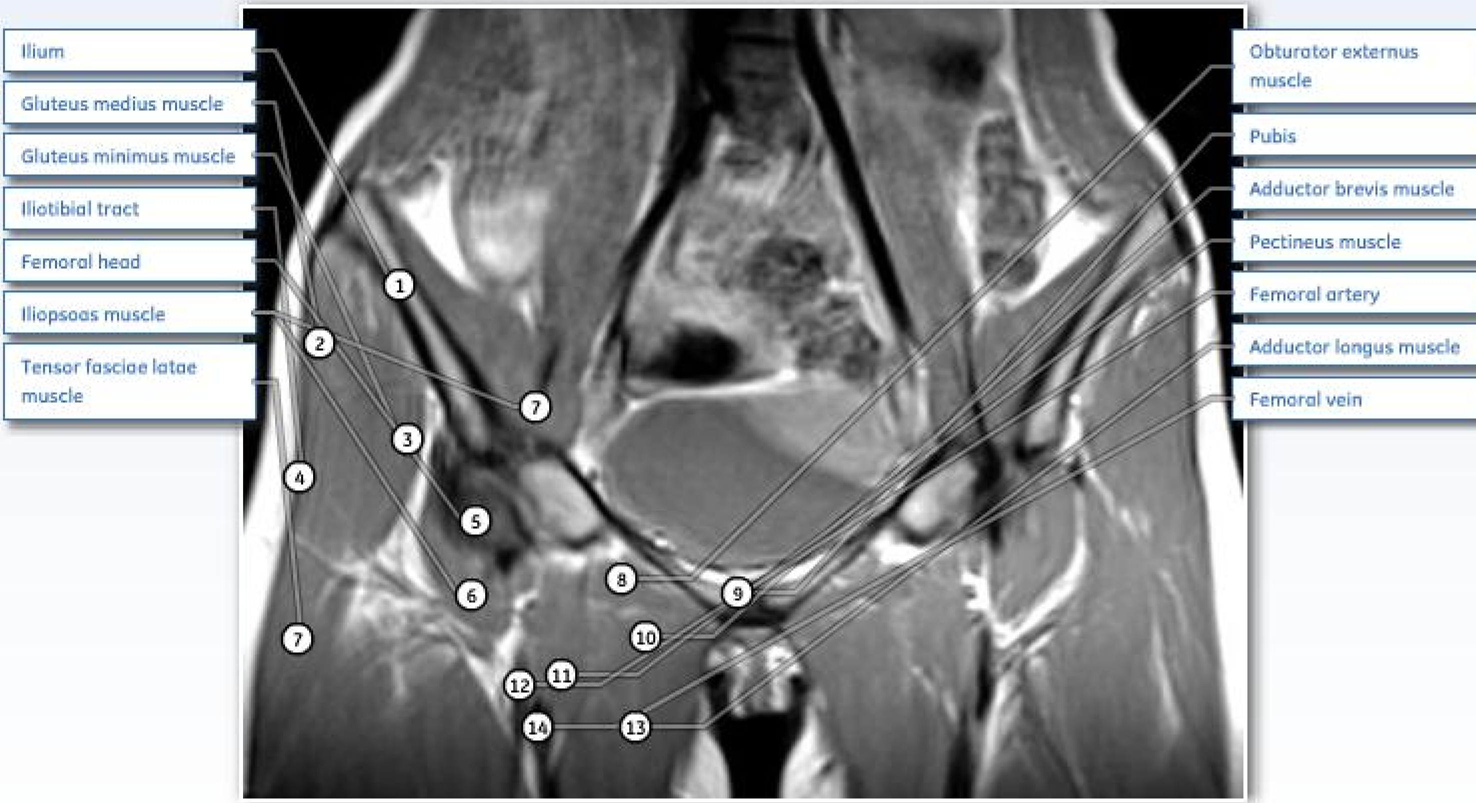
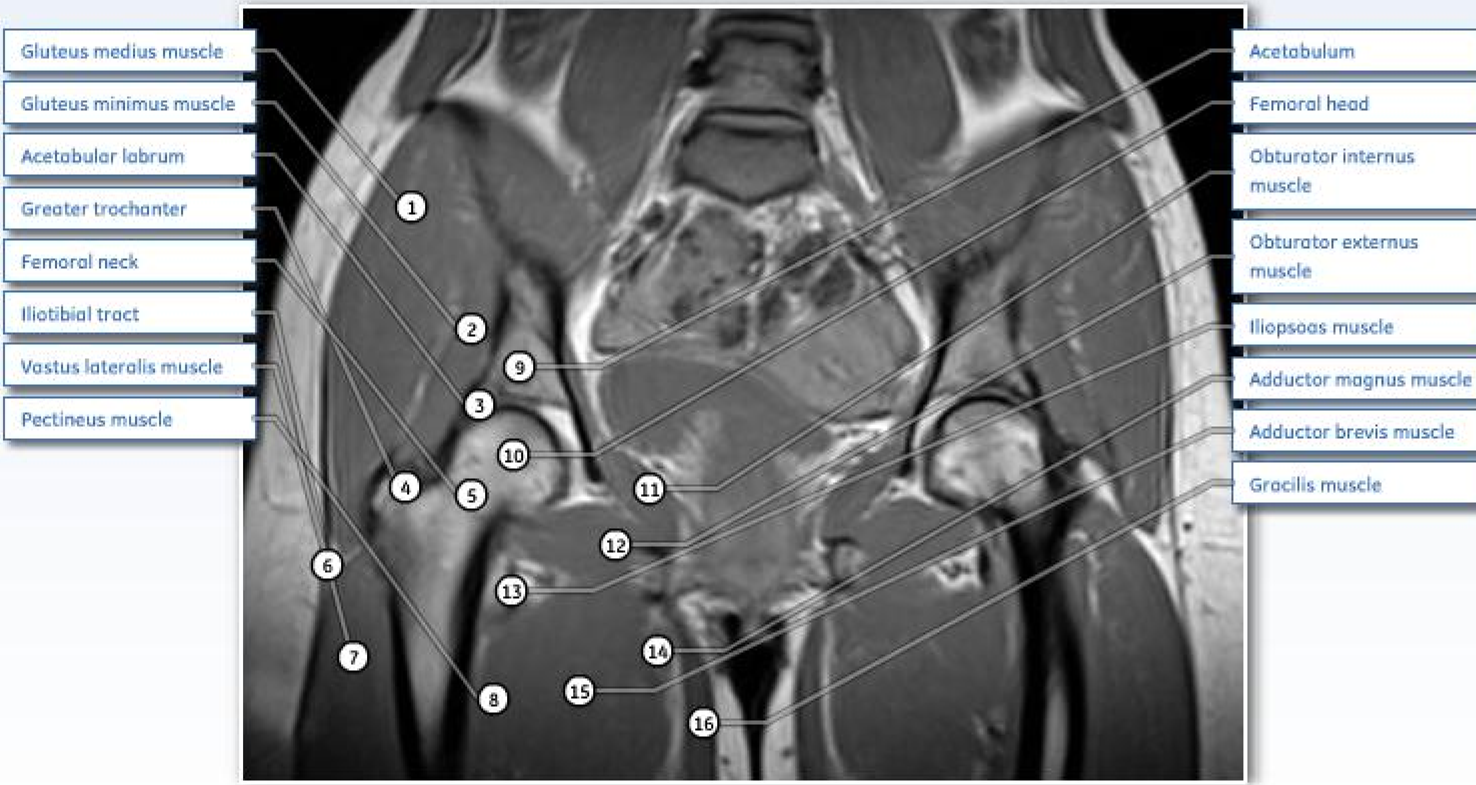
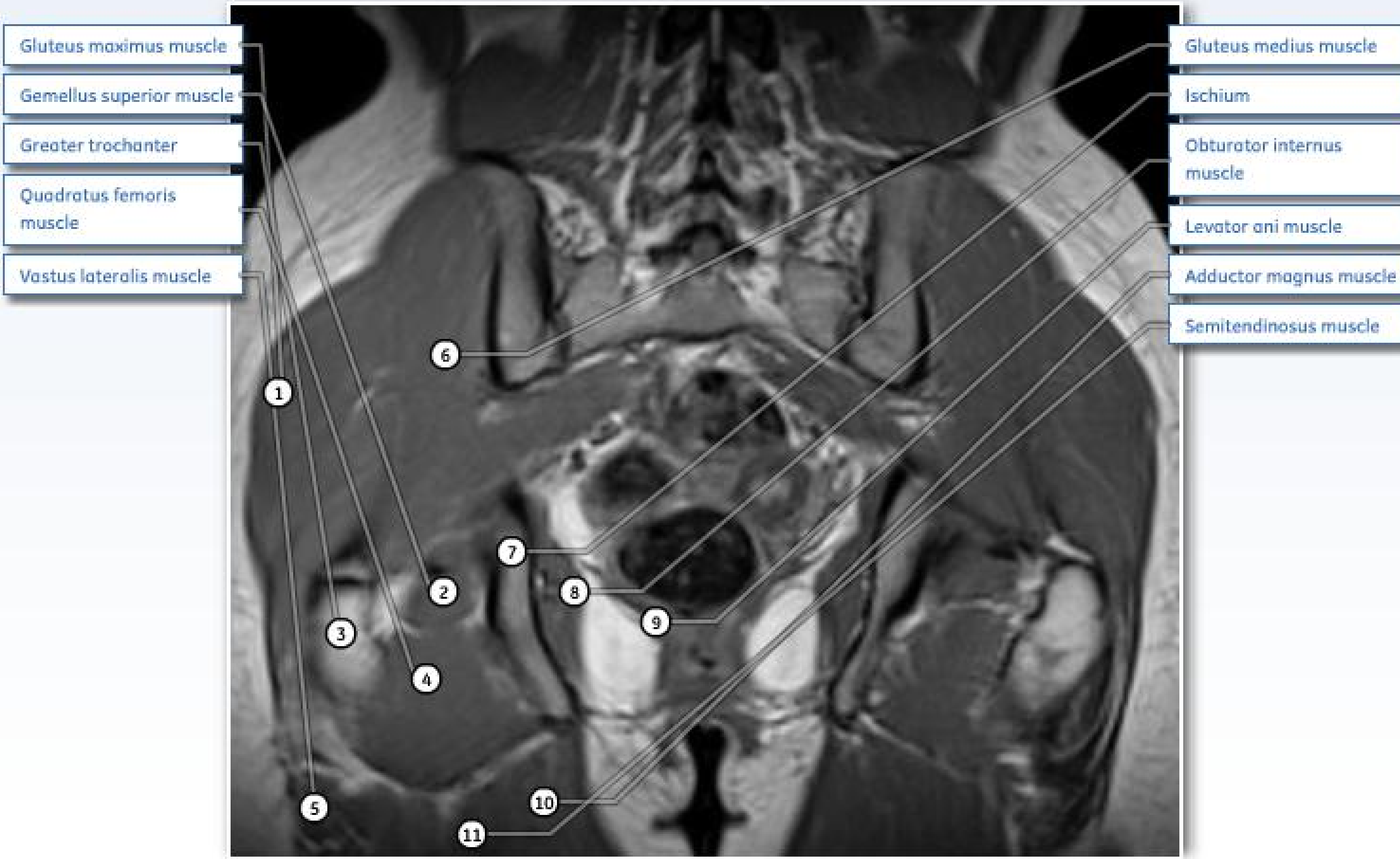


Anterior superior iliac spine
Ilium
Acetabulum
Anterior inferior iliac spine
Greater trochanter
Femoral neck
Lesser trochanter
Femur
Hip joint
Femoral head
Ischial spine
Superior pubic ramus
Ischium
Obturator foramen
Pubis
Inferior pubic ramus
Ischial tuberosity
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

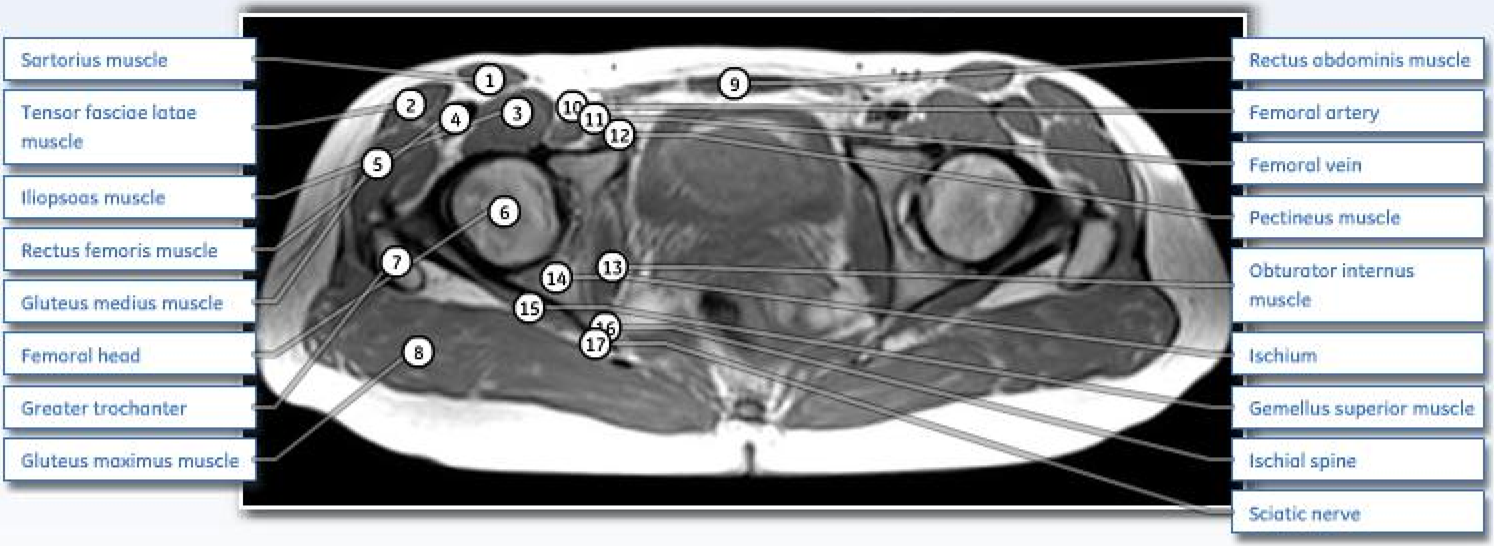

Ilium
Gluteus medius muscle
Gluteus minimus muscle
Iliotibial tract
Femoral head
Iliopsoas muscle
Tensor fasciae latae muscle
Obturator externus muscle
Pubis
Adductor brevis muscle
Pectineus muscle
Femoral artery
Adductor longus muscle
Femoral vein
1
2
3
4
5
6
7
7
8
9
10
11
12
13
14



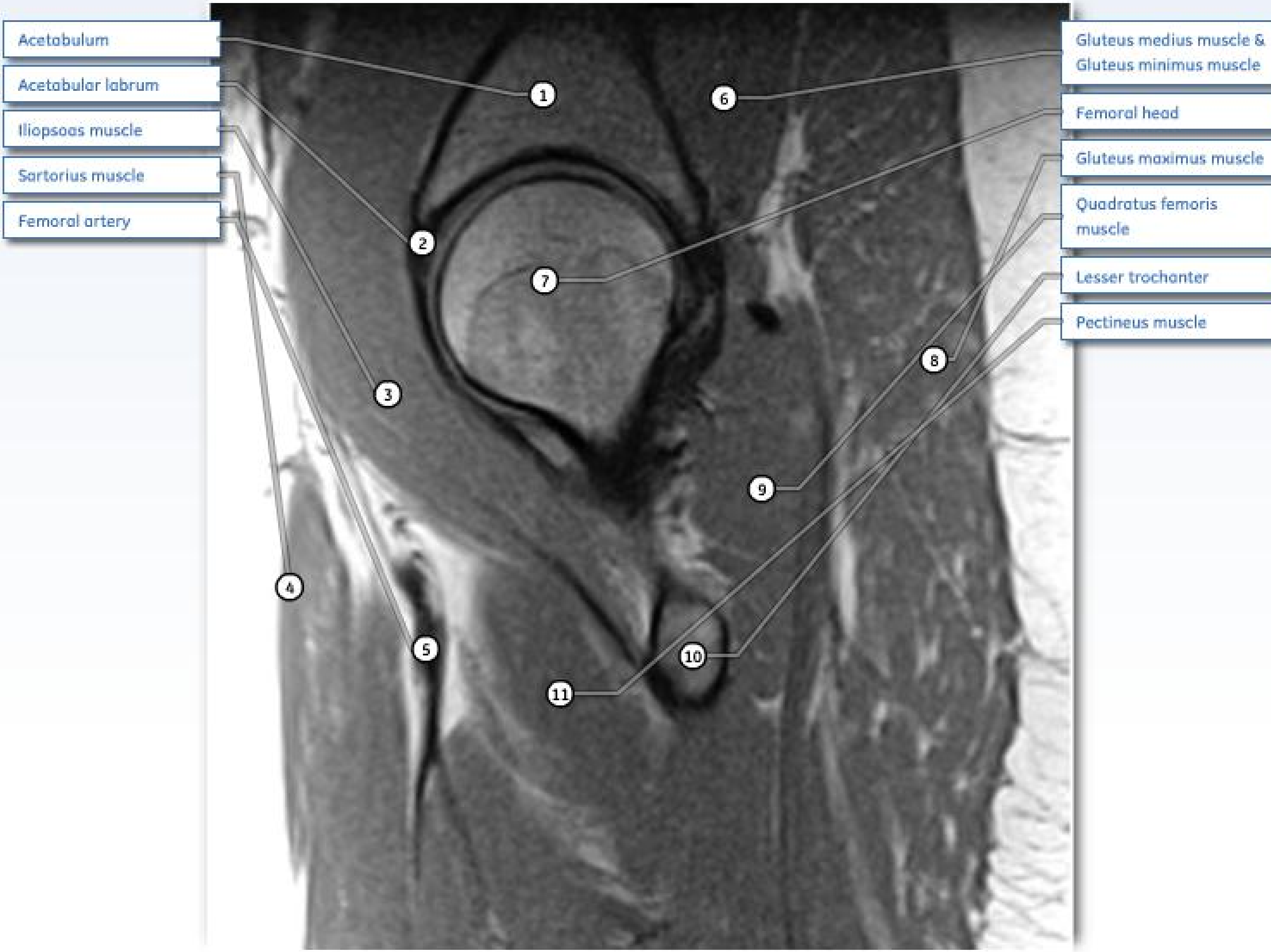
Gluteus medius muscle
Gluteus minimus muscle
Acetabular labrum
Greater trochanter
Femoral neck
Iliotibial tract
Vastus lateralis muscle
Pectineus muscle
Acetabulum
Femoral head
Obturator internus muscle
Obturator externus muscle
Iliopsoas muscle
Adductor magnus muscle
Adductor brevis muscle
Gracilis muscle
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

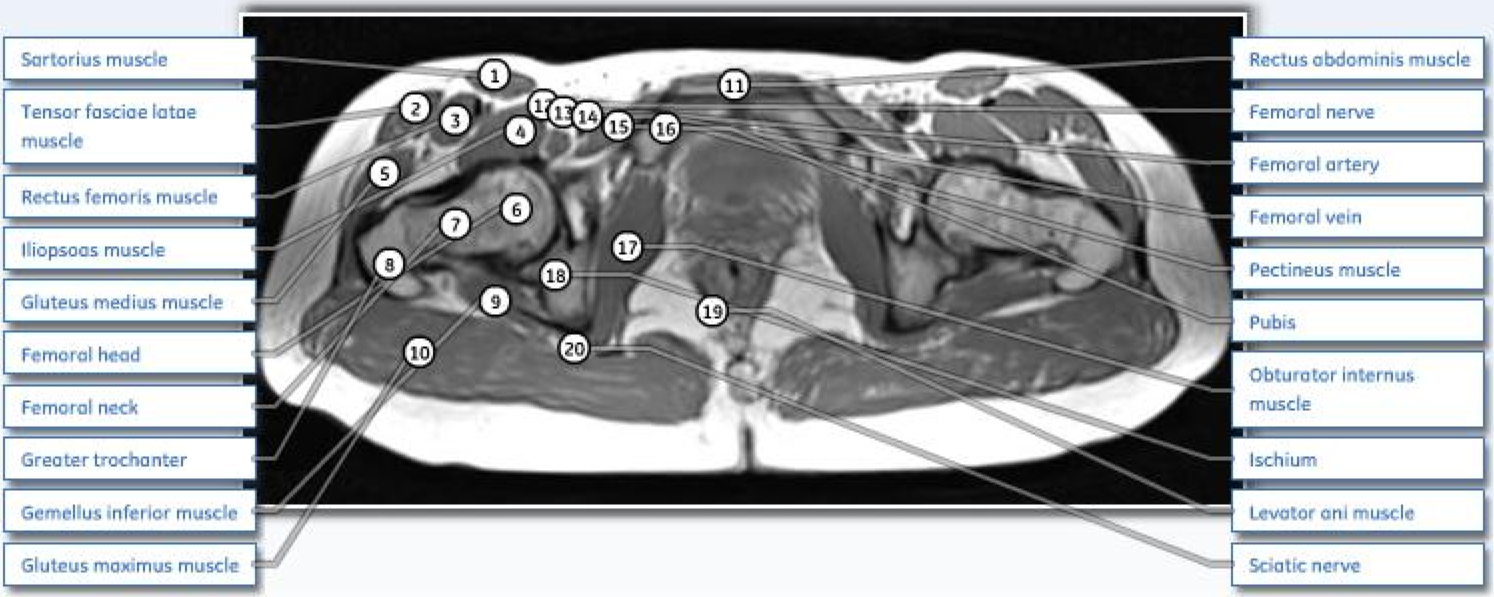


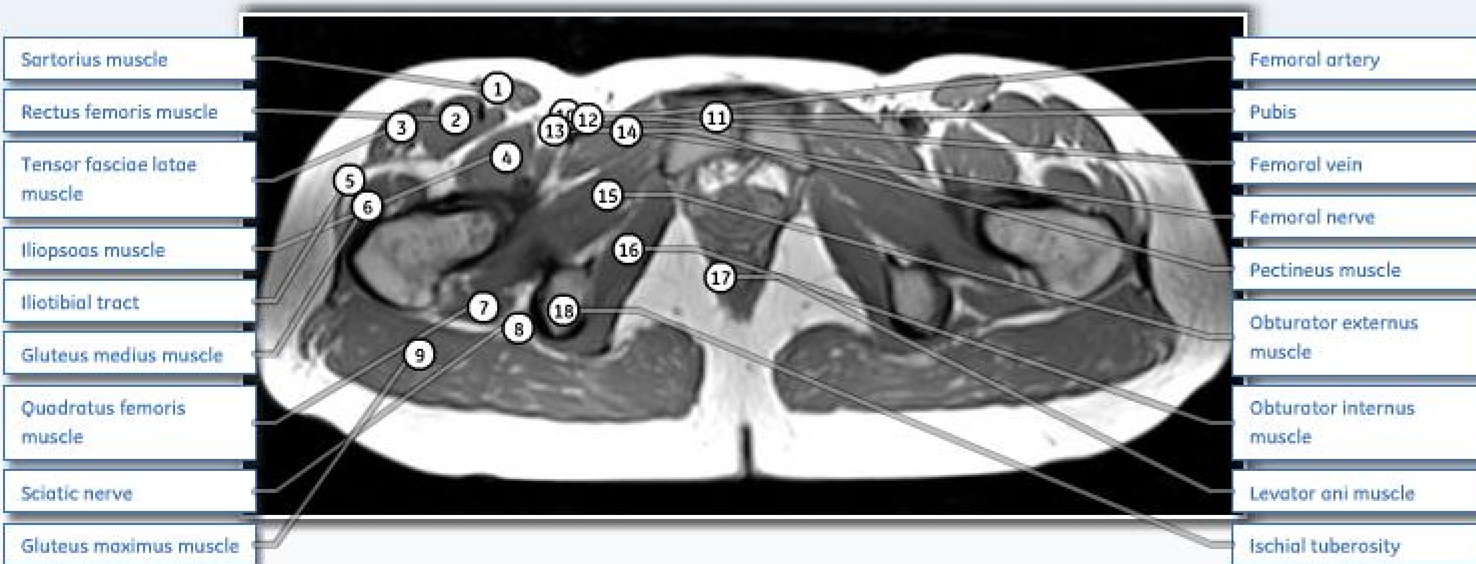
Gluteus maximus muscle
Gemellus superior muscle
Greater trochanter
Quadratus femoris muscle
Vastus lateralis muscle
Gluteus medius muscle
Ischium
Obturator internus muscle
Levator ani muscle
Adductor magnus muscle
Semitendinosus muscle
1
2
3
4
5
6
7
8
9
10
11



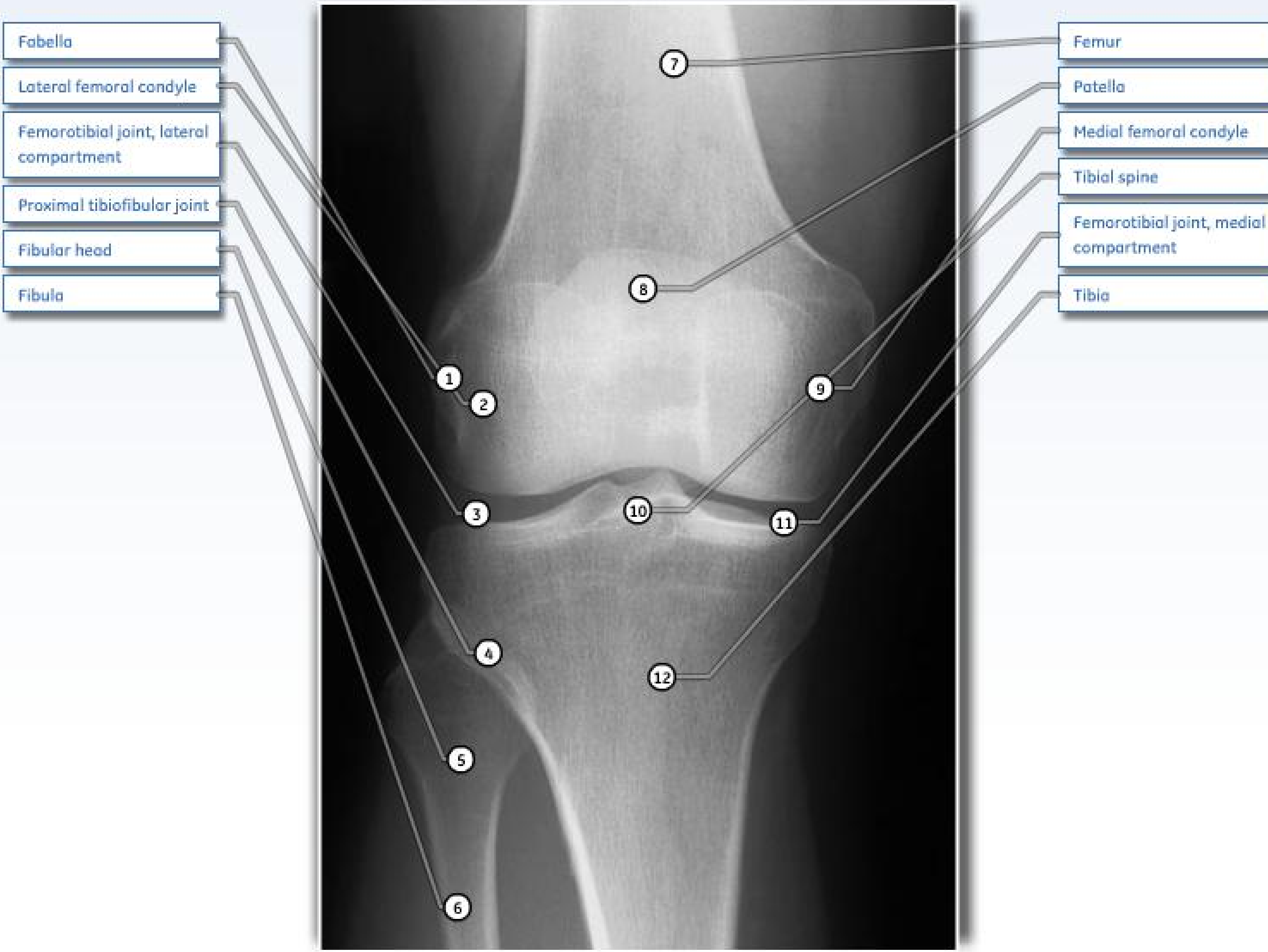
Sartorius muscle
Tensor fasciae latae muscle
Iliopsoas muscle
Rectus femoris muscle
Gluteus medius muscle
Femoral head
Greater trochanter
Gluteus maximus muscle
Rectus abdominis muscle
Femoral artery
Femoral vein
Pectineus muscle
Obturator internus muscle
Ischium
Gemellus superior muscle
Ischial spine
Sciatic nerve
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

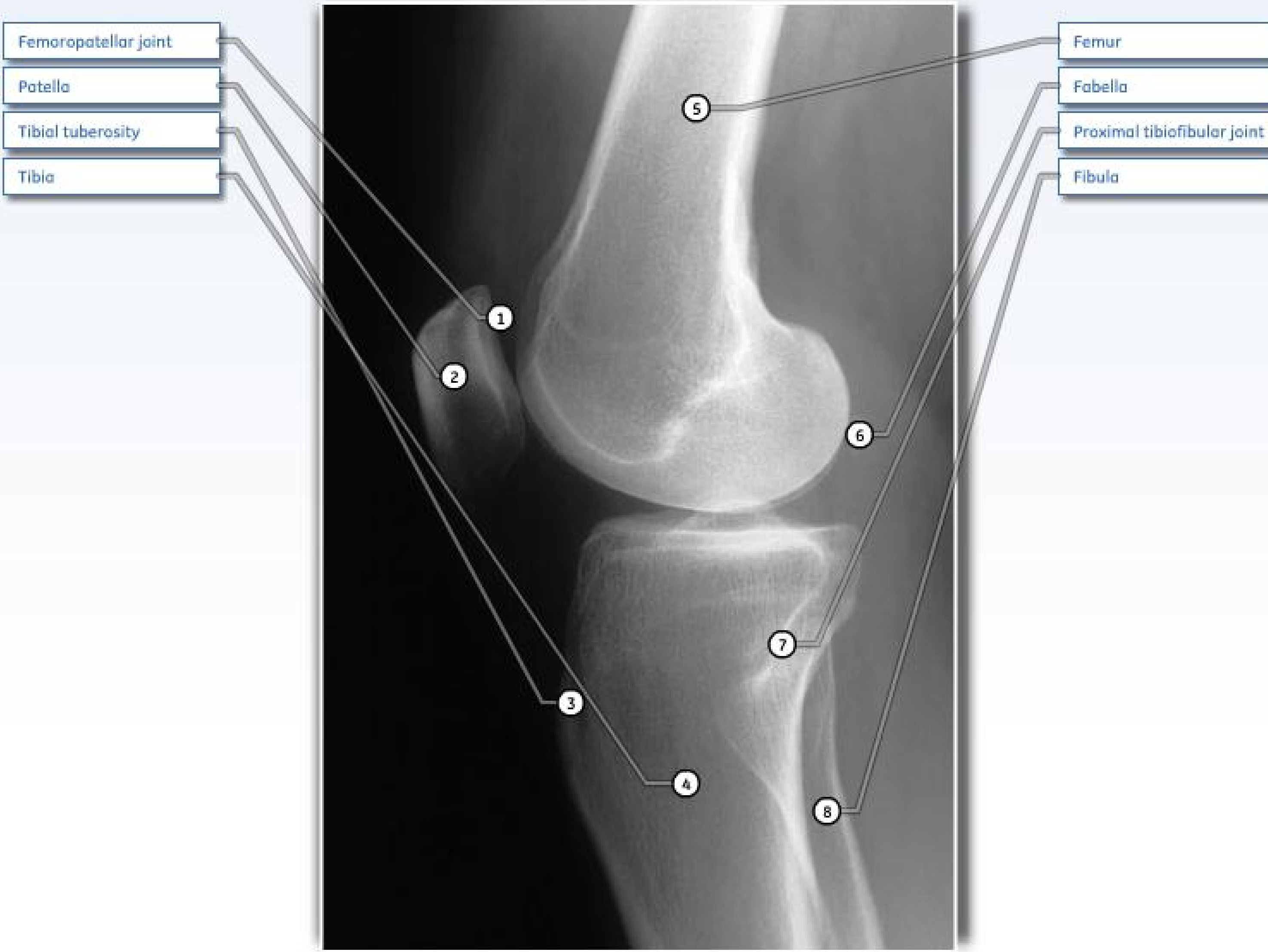

Acetabulum
Acetabular labrum
Iliopsoas muscle
Sartorius muscle
Femoral artery
Gluteus medius muscle & Gluteus minimus muscle
Femoral head
Gluteus maximus muscle
Quadratus femoris muscle
Lesser trochanter
Pectineus muscle
1
2
3
4
5
6
7
8
9
10
11

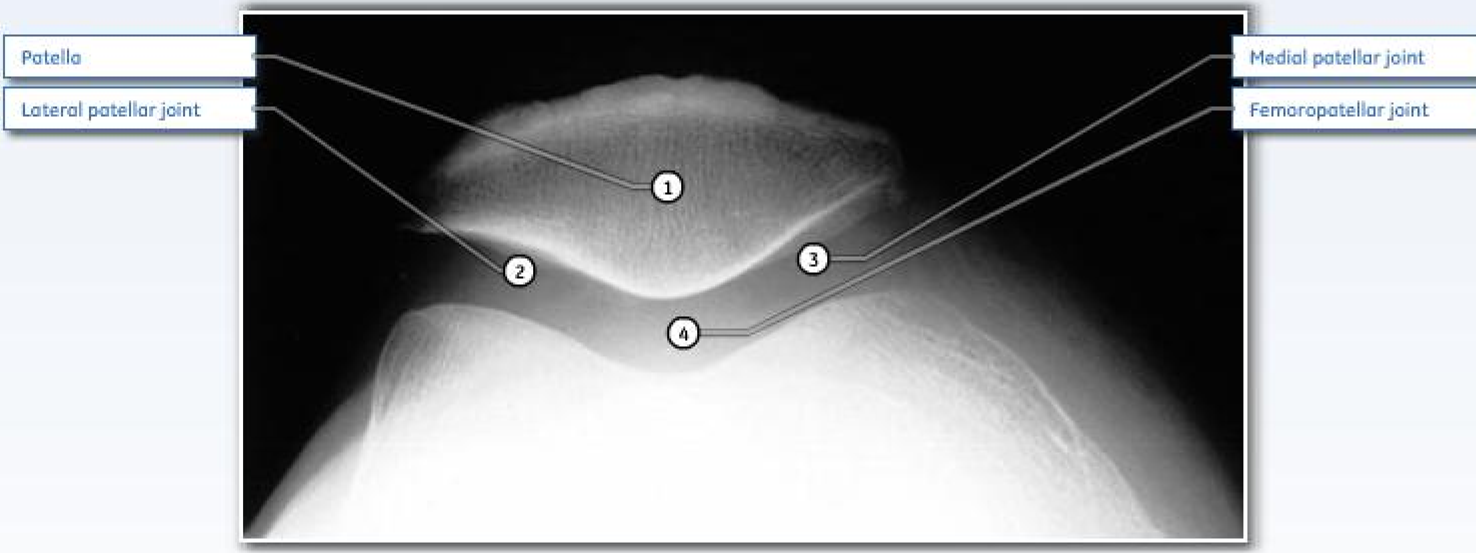

Sartorius muscle
Tensor fasciae latae muscle
Rectus femoris muscle
Iliopsoas muscle
Gluteus medius muscle
Femoral head
Femoral neck
Greater trochanter
Gemellus inferior muscle
Gluteus maximus muscle
Rectus abdominis muscle
Femoral nerve
Femoral artery
Femoral vein
Pectineus muscle
Pubis
Obturator internus muscle
Ischium
Levator ani muscle
Sciatic nerve
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20



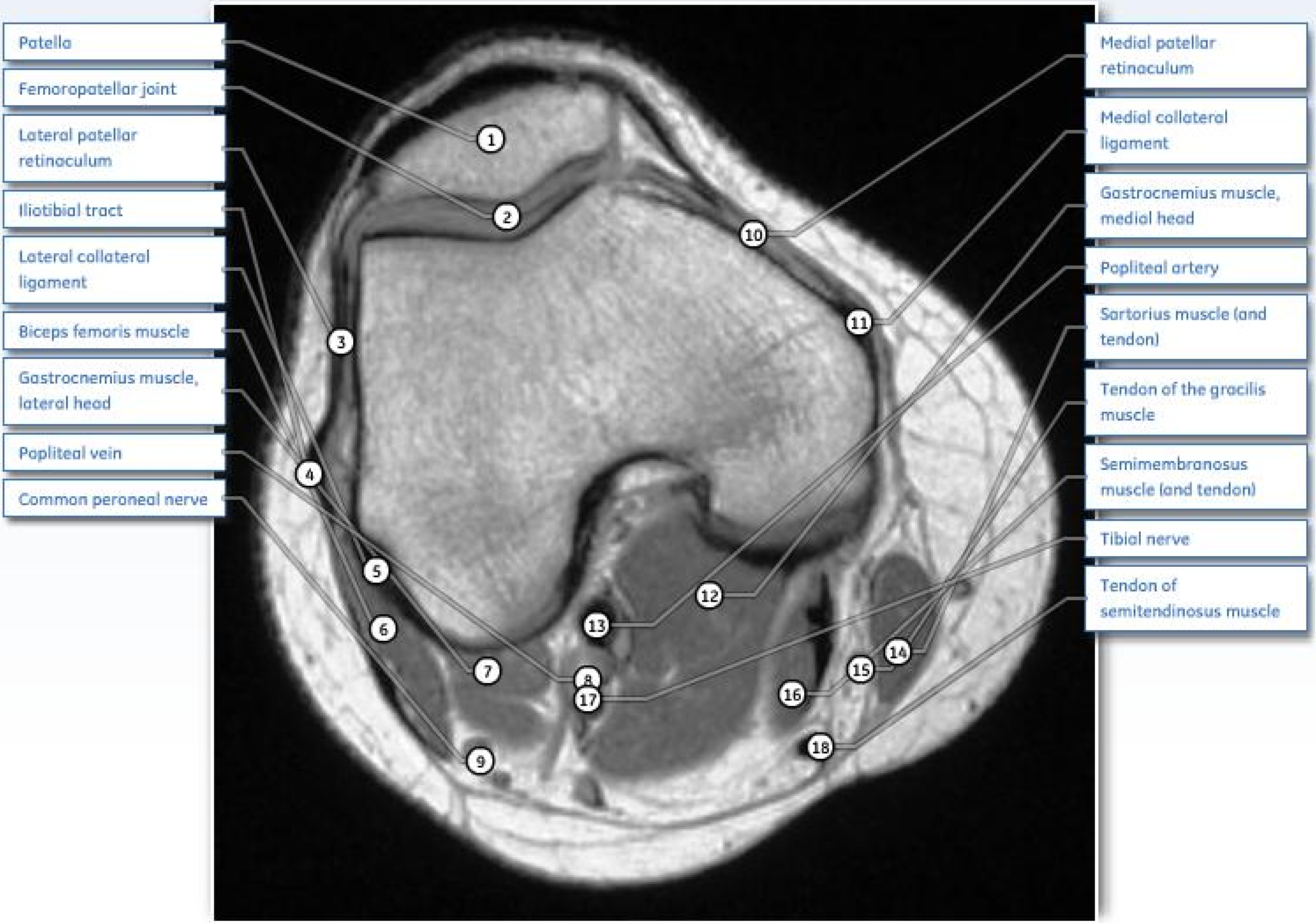
Sartorius muscle
Rectus femoris muscle
Tensor fasciae latae muscle
Iliopsoas muscle
Iliotibial tract
Gluteus medius muscle
Quadratus femoris muscle
Sciatic nerve
Gluteus maximus muscle
Femoral artery
Pubis
Femoral vein
Femoral nerve
Pectineus muscle
Obturator externus muscle
Obturator internus muscle
Levator ani muscle
Ischial tuberosity
1
2
3
4
5
6
7
8
9
11
12
13
14
15
16
17
18


Fabella
Lateral femoral condyle
Femorotibial joint, lateral compartment
Proximal tibiofibular joint
Fibular head
Fibula
Femur
Patella
Medial femoral condyle
Tibial spine
Femorotibial joint, medial compartment
Tibia
1
2
3
4
5
6
7
8
9
10
11
12


Femoropatellar joint
Patella
Tibial tuberosity
Tibia
Femur
Fabella
Proximal tibiofibular joint
Fibula
1
2
3
4
5
6
7
8



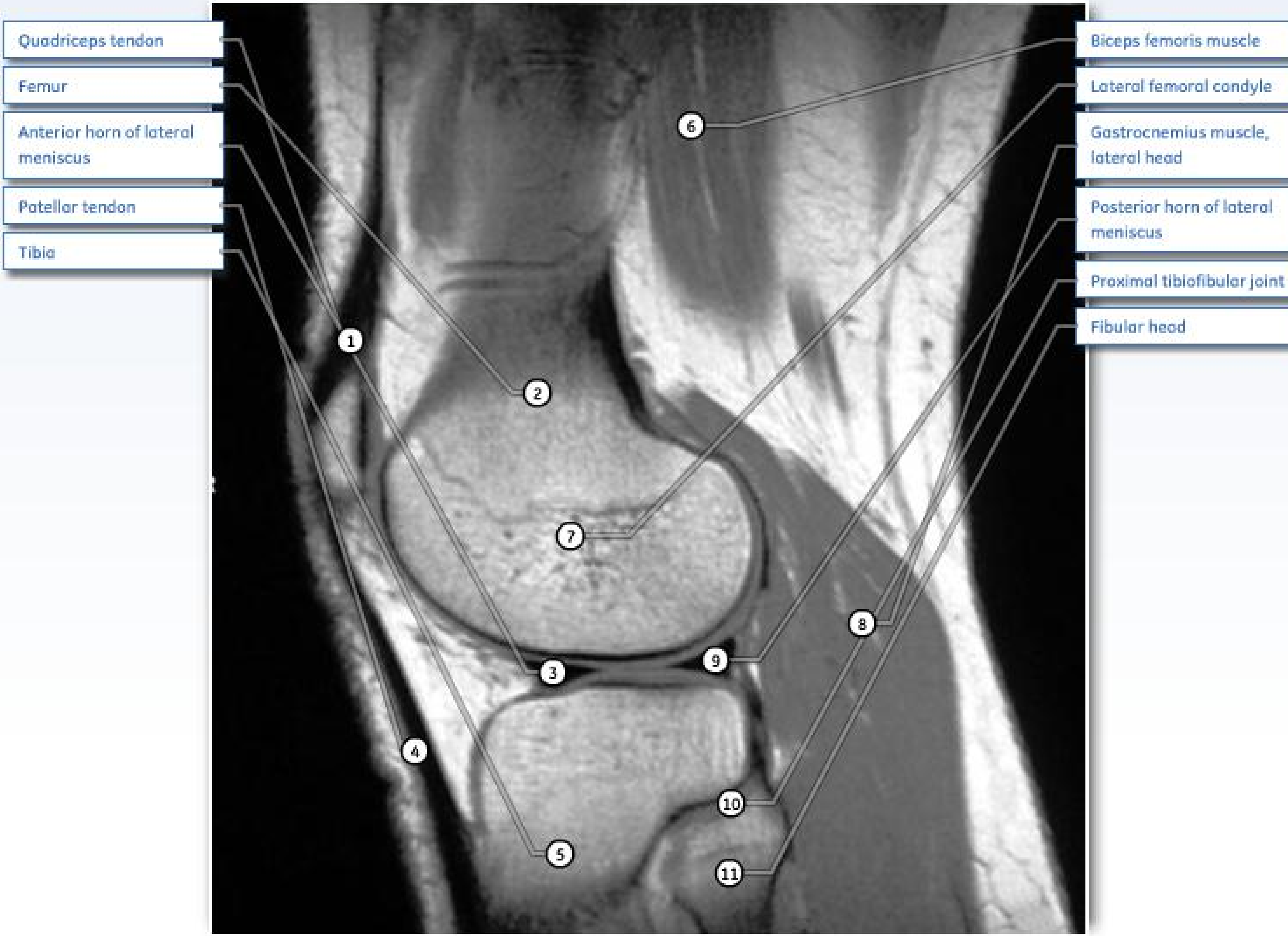
Patella
Lateral patellar joint
Medial patellar joint
Femoropatellar joint
1
2
3
4



Patella
Femoropatellar joint
Lateral patellar retinaculum
Iliotibial tract
Lateral collateral ligament
Biceps femoris muscle
Gastrocnemius muscle, lateral head
Popliteal vein
Common peroneal nerve
Medial patellar retinaculum
Medial collateral ligament
Gastrocnemius muscle, medial head
Popliteal artery
Sartorius muscle (and tendon)
Tendon of the gracilis muscle
Semimembranosus muscle (and tendon)
Tibial nerve
Tendon of semitendinosus muscle
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18


Vastus medialis muscle
Quadriceps tendon
Patella
Infrapatellar fat pad
Patellar tendon
Tibia
Popliteal artery
Semimembranosus muscle (and tendon)
Gastrocnemius muscle, medial head
Gastrocnemius muscle, lateral head
Anterior cruciate ligament
Popliteus muscle
1
2
3
4
5
6
7
8
9
10
11
12

Vastus medialis muscle
Quadriceps tendon
Femur
Patella
Semimembranosus muscle (and tendon)
Posterior cruciate ligament
Gastrocnemius muscle, medial head
Tibia
Popliteus muscle
1
2
3
4
5
6
7
8
9



Quadriceps tendon
Femur
Anterior horn of lateral meniscus
Patellar tendon
Tibia
Biceps femoris muscle
Lateral femoral condyle
Gastrocnemius muscle, lateral head
Posterior horn of lateral meniscus
Proximal tibiofibular joint
Fibular head
1
2
3
4
5
6
7
8
9
10
11

Anterolateraler Zugang zum Hüftgelenk

Hauptindikationen

- Totalendoprothesen, Schenkelhalsfrakturen,
- juvenile Kopfkappenlösung,
- Synovektomie,
- Schenkelhalsosteotomien.

Lagerung und Schnittführung

Der Patient wird auf dem Rücken gelagert, mit einem Kissen unter dem Gesäß. Die Hautinzision ist leicht gebogen und etwa 15 cm lang mit Zentrum über dem Trochanter major. Der Schnitt beginnt eine Handbreite hinter der Spina iliaca anterior superior und zieht seitlich über den Trochanter major nach distal (Abb. **178**). Nach Spaltung der Subkutis wird die Fascia lata parallel zum Hautschnitt von distal nach proximal eingeschnitten (Abb. **179**). Die Inzision der Faszie sollte zwischen den Muskelanteilen des M. tensor fasciae latae und des M. gluteus maximus liegen. Der dorsale Faszienanteil wird mit einem Hohmann-Hebel zurückgedrängt, während der ventrale Anteil mit Wundhaken zurückgehalten wird. Die Schicht zwischen dem M. tensor fasciae latae und dem M. gluteus medius wird nun aufgesucht. Einige oberflächlich liegende Gefäße werden koaguliert bzw. ligiert und durchtrennt (Abb. **180**).

Die Mm. tensor fasciae latae einerseits und der M. gluteus maximus andererseits werden zur Darstellung der Hüftgelenkkapsel nach ventral und dorsal weggehalten.

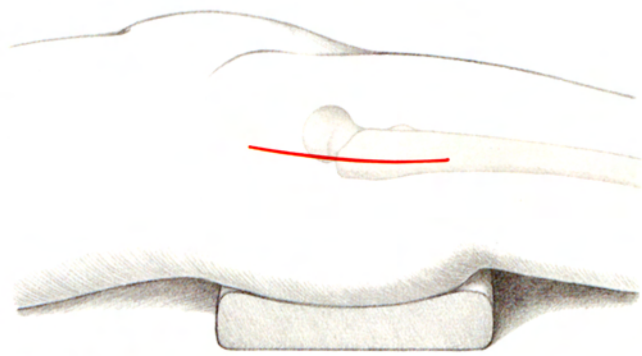


Abb. **178** Der anterolaterale Zugang zum Hüftgelenk. Lagerung und Schnittführung.

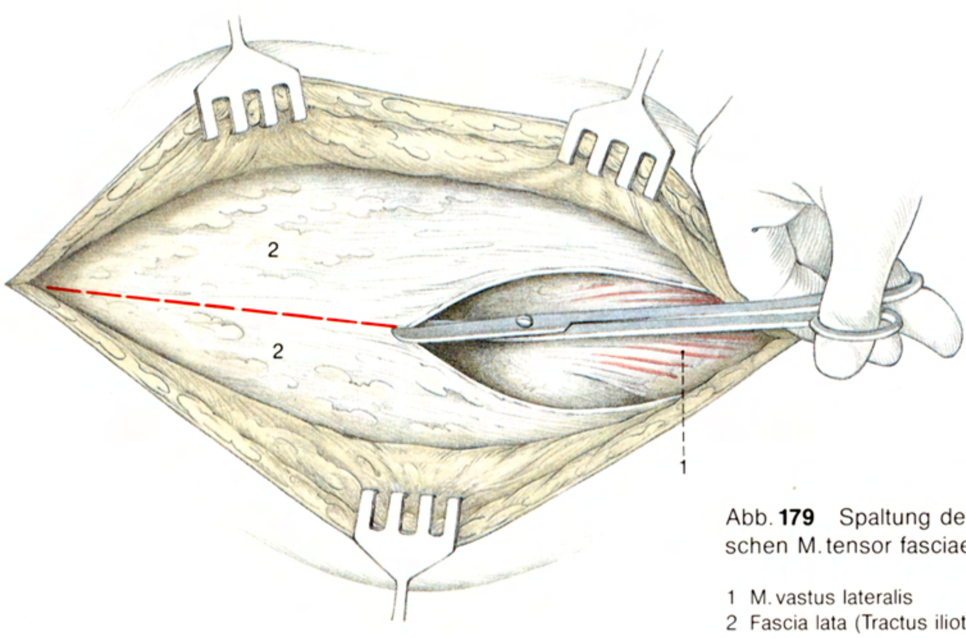
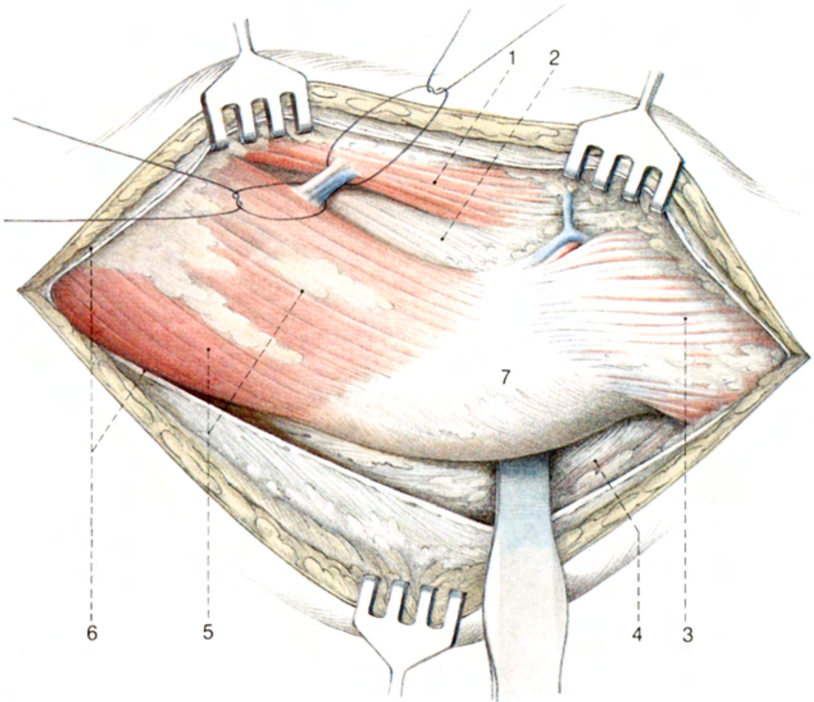


Abb. **179** Spaltung der Fascia lata parallel zum Hautschnitt zwischen M. tensor fasciae latae und M. gluteus maximus.

1 M. vastus lateralis
2 Fascia lata (Tractus iliotibialis)

Abb. **180** Retraktion der Fascia lata und Präparation zwischen M. tensor fasciae latae und M. gluteus medius. Ligatur bzw. Elektrokoagulation von oberflächlich liegenden Gefäßen.

1 M. tensor fasciae latae
2 M. glutaeus minimus
3 M. vastus lateralis
4 M. gluteus maximus
5 M. gluteus medius
6 Fascia lata
7 Trochanter major



Darstellung der Hüftgelenkkapsel

Mit einem Cobbschen Raspatorium wird der vordere Anteil der Hüftgelenkkapsel von Faszie und Muskulatur freipräpariert. Mit dem Raspatorium stellt man zuerst die Schicht zwischen geradem Rektuskopf und vorderer Azetabulumwand dar und setzt hier einen gebogenen Hohmann-Hebel ein (Abb. **181**). Anschließend wird mit dem gleichen Instrument die Schicht zwischen Gelenkkapsel und M. iliopsoas präpariert und hier ein weiterer Hohmann-Hebel eingesetzt. Den sehnigen Ansatz der Mm. gluteus medius und minimus am Trochanter major inzidiert man etwas mit dem Messer, bis die darunterliegende Bursa sichtbar wird. Nun läßt sich, nach Präparation der proximalen Kapselanteile, auch an dieser Stelle ein Hohmann-Hebel einsetzen. Die Hüftgelenkkapsel kann T-förmig eröffnet werden (s. Abb. **187** und **188**). Ist eine Luxation des Hüftkopfes erwünscht, so muß diese in Beugung, Adduktion und Außenrotation durchgeführt werden.

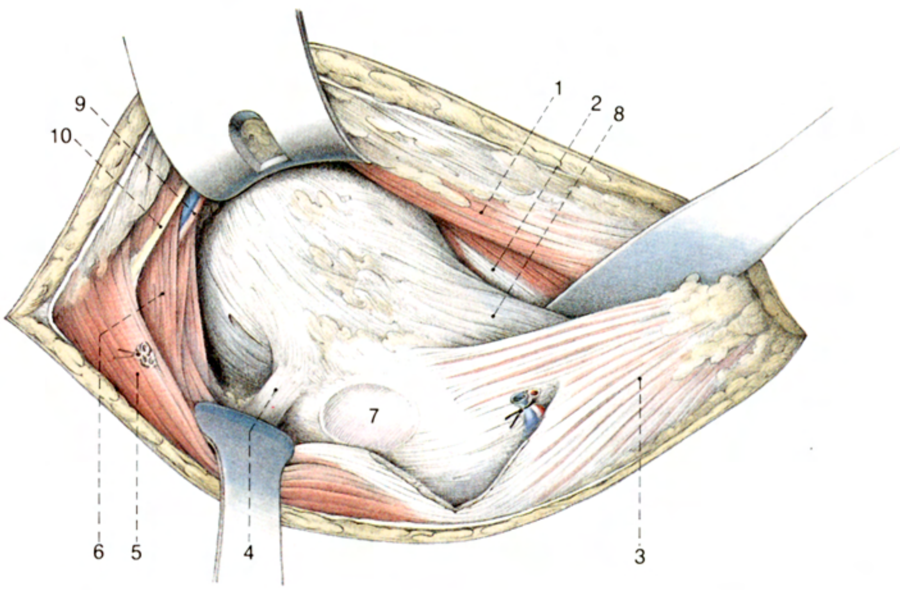


Abb. **181** Darstellung der vorderen Hüftgelenkkapsel und Einsetzen von Hohmann-Hebeln. *Beachte:* Limitierung des oberen Zugangsbereiches durch N. gluteus superior.

1 M. rectus femoris
2 M. iliopsoas
3 M. vastus lateralis
4 M. piriformis
5 M. gluteus medius
6 M. gluteus minimus
7 Bursa trochanterica
8 Lig. iliofemorale
9 Vasa glutea superiora
10 N. gluteus superior

Anatomischer Situs
(Abb. **182–184**)

Ein Nachteil des anterolateralen Zuganges ist die mögliche Schädigung des den M. tensor fasciae latae versorgenden Anteiles des N. gluteus superior. In Abb. **182** wurde der M. gluteus medius am Beckenkamm und am Trochanter major abgelöst und nach dorsal weggeschlagen, so daß der N. gluteus superior in seinem Verlauf zur Darstellung kommt. Der rote Pfeil bezeichnet jene Stelle, an welcher der Nerv während der Operation durch Zug geschädigt oder durchtrennt werden kann.

Wundverschluß

Beim Wundverschluß ist die Reinsertion der abgelösten Anteile des M. gluteus medius und minimus wichtig.

Gefahren

Die Lage des dorsalen Hohmann-Hebels und seine Beziehung zum N. ischiadicus ist in den Abb. **183** und **184** schematisch dargestellt. Der N. ischiadicus kann bei distalem Hebelsitz und gleichzeitig maximaler Außenrotation des Beines beschädigt werden.

In Abb. **185** ist die Lage der Hohmann-Hebel schematisch eingezeichnet. Bei übermäßigem Zug am mittleren ventralseitig gelegenen Hebel kann es zu einem Dehnungsschaden des N. femoralis kommen, speziell wenn dieser Hebel nicht unter den Muskeln, sondern mit seiner Spitze in der Muskulatur liegt. Eine falsche Lage dieses Hebels kann auch zu einer Schädigung der A. femoralis oder der A. profunda femoris führen. Ein zu tiefes Einsetzen des distal gelegenen Hohmann-Hebels birgt die Gefahr einer Verletzung der A. circumflexa femoris medialis in sich.

Anmerkung

Die teilweise Ablösung der Mm. gluteus medius und minimus vom Trochanter major wurde von M. E. Müller empfohlen, um eine Schädigung der Glutealmuskulatur durch Hakenzug möglichst zu vermeiden.

Ist eine adäquate Darstellung der Hüftgelenkkapsel durch diesen Zugang nicht möglich, so kann zusätzlich eine Osteotomie des Trochanter major erfolgen.

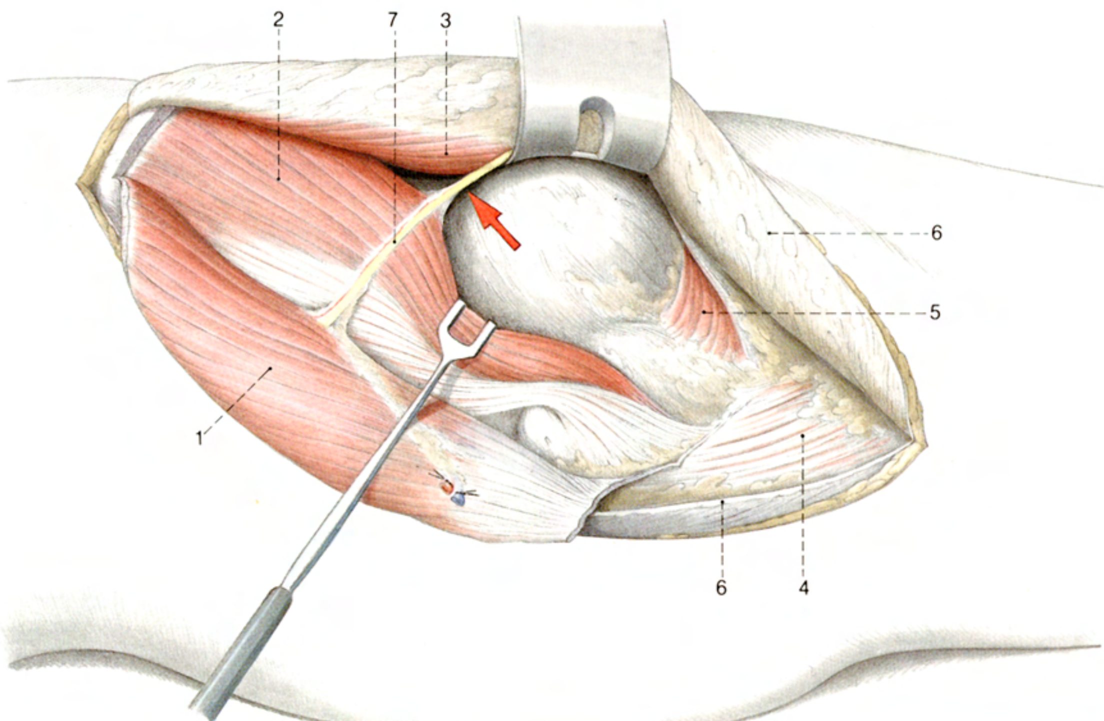


Abb. **182** Anatomischer Situs. Der M. gluteus medius wurde am Beckenkamm und am Trochanter major abgetrennt und zurückgeschlagen, um den Verlauf des N. gluteus superior zu zeigen. Der rote Pfeil markiert jene Stelle, an welcher der Nerv während der Operation verletzt werden kann.

1 M. gluteus medius
2 M. gluteus minimus
3 M. tensor fasciae latae
4 M. vastus lateralis
5 M. vastus intermedius
6 Fascia lata
7 N. gluteus superior

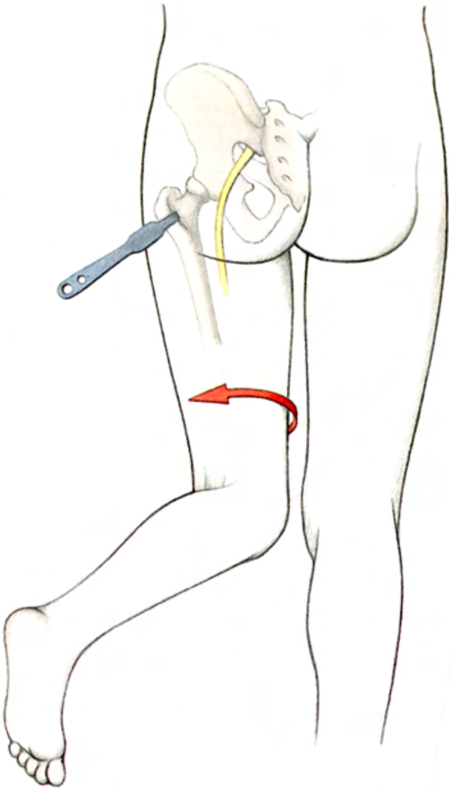


Abb. **183** Schematische Darstellung der Beziehung des dorsalen Hohmann-Hebels zum N. ischiadicus in Innenrotation (relativ großer Abstand).

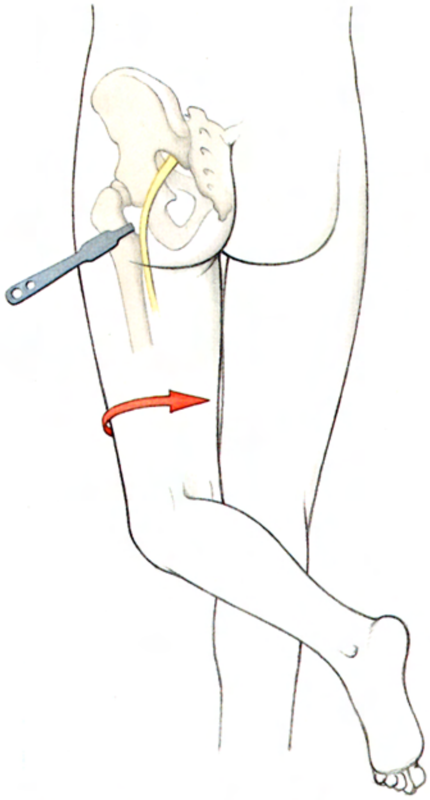


Abb. **184** Schematische Darstellung der Beziehung des dorsalen Hohmann-Hebels zum N. ischiadicus in Außenrotation: Deutliche Annäherung, Gefährdung des Nervs.

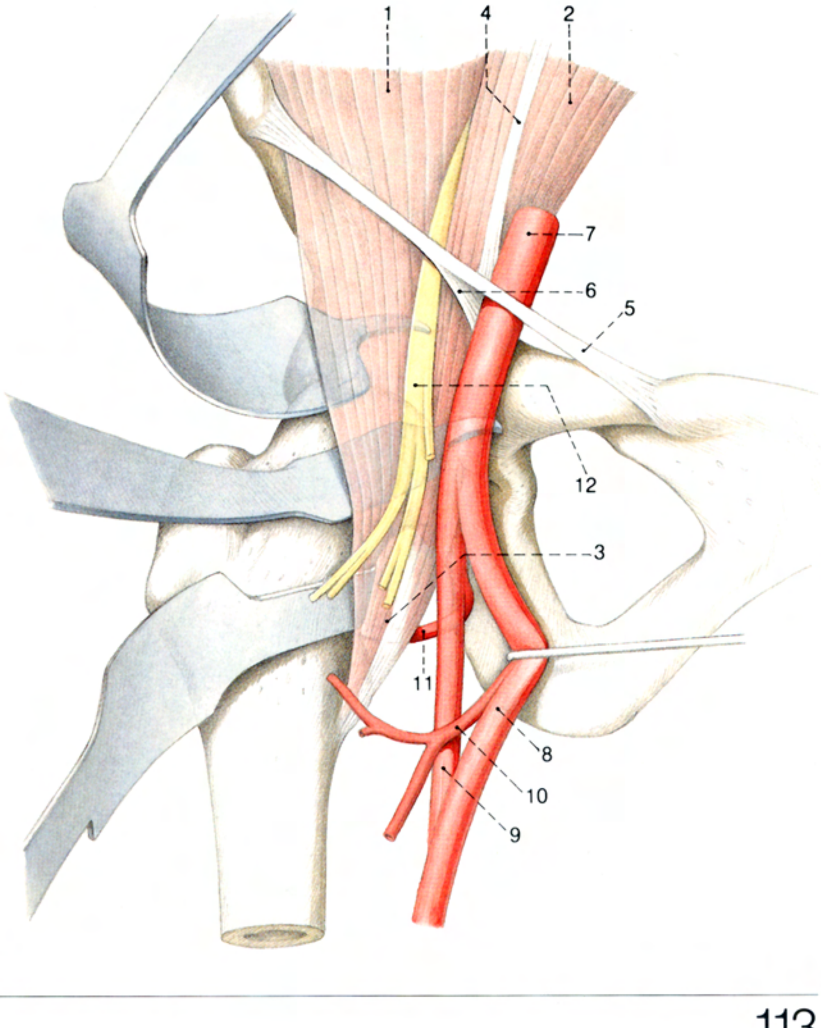


Abb. **185** Lage der zwei ventralen und des distalen Hohmann-Hebels bei der Darstellung der Hüftgelenkkapsel von anterolateral.
Beachte die Verletzungsmöglichkeit des N. femoralis durch Überdehnung sowie der A. femoralis und A. profunda femoris, welche unmittelbar über der Spitze des mittleren Hohmann-Hebels liegen.
Bei zu tiefem Sitz des distalen Hohmann-Hebels kann die A. circumflexa femoris medialis geschädigt werden.

1 M. iliacus
2 M. psoas major
3 M. iliopsoas
4 M. psoas minor
5 Lig. inguinale
6 Arcus iliopectineus
7 A. iliaca externa
8 A. femoralis
9 A. profunda femoris
10 A. circumflexa femoris lateralis
11 A. circumflexa femoris medialis
12 N. femoralis

Transglutealer Zugang nach Bauer

Hauptindikationen

- Totalendoprothesen,
- Schenkelhalsfrakturen,
- Schenkelhalsosteotomien,
- juvenile Hüftkopfkappenlösung,
- Hüftgelenkssynovektomie.

Lagerung und Schnittführung

Der Patient liegt auf dem Rücken mit einem Kissen unter dem Gesäß. Die Schnittführung entspricht jener in der Abb. **178** gezeigten leicht bogenförmigen Inzision. Nach Spaltung der Subkutis und der Fascia lata parallel zum Hautschnitt werden die Mm. gluteus medius und minimus sowie der M. vastus lateralis in ihrem vorderen Drittel entsprechend ihrem Faserverlauf gespalten (Abb. **186**). Dabei ist zu beachten, daß das tendoperiostale Gewebe zwischen dem M. gluteus medius und dem M. vastus lateralis an der Vorderseite des Trochanter major in einer Schicht sorgfältig vom Knochen abgelöst wird. Diese Ablösung gelingt am besten mittels Diathermie.

Darstellung der Hüftgelenkkapsel

Mit einem Cobbschen Raspatorium werden die ventralen Anteile der Gelenkkapsel freipräpariert. Es wird ein gebogener Hohmann-Hebel zwischen dem geraden Rektusursprung und der ventralen Azetabulumwand eingesetzt. Ein kranial gelegener Hohmann-Hebel sitzt zwischen Gelenkkapsel und M. gluteus minimus und ein weiterer liegt distal zwischen M. iliopsoas und der Gelenkkapsel. Bei Bedarf kann noch ein zweiter ventraler Hohmann-Hebel etwas distal des großen gebogenen Hebels eingesetzt werden. Die Öffnung der Hüftgelenkkapsel erfolgt T-förmig (Abb. **187**). Nach dem breiten, pfannennahen Eröffnen der Gelenkkapsel können zwei Hohmann-Hebel zwischen diese und dem Schenkelhals eingesetzt werden. Eine Schädigung der Hüftkopfdurchblutung ist bei diesem Vorgehen nicht zu erwarten (Abb. **188**).

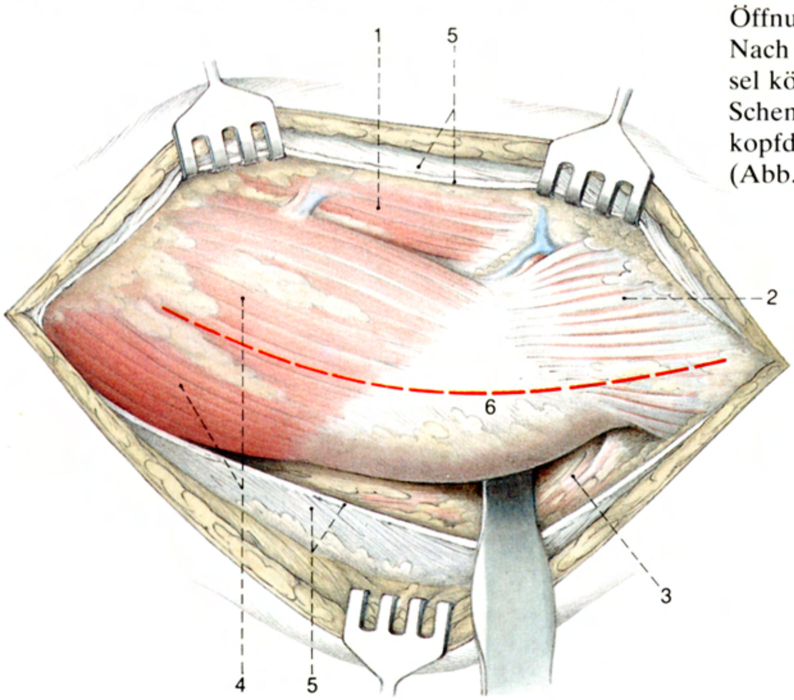


Abb. **186** Der transgluteale Zugang zum Hüftgelenk. Inzision der Mm. glutaeus medius und vastus lateralis an der Grenze zwischen mittlerem und vorderem Muskeldrittel (rechtes Bein).

1 M. tensor fasciae latae
2 M. vastus lateralis
3 M. gluteus maximus
4 M. gluteus medius
5 Fascia lata
6 Trochanter major

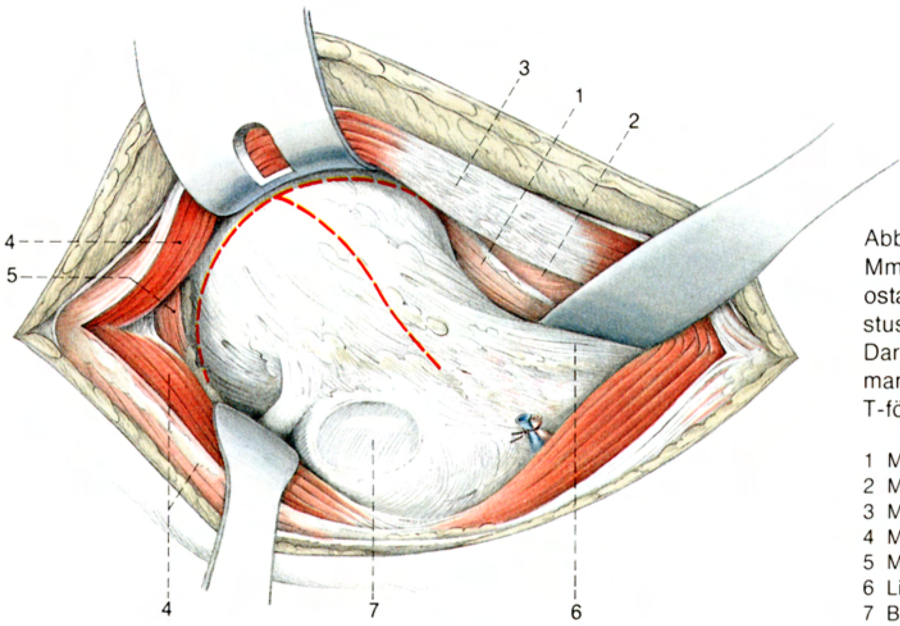
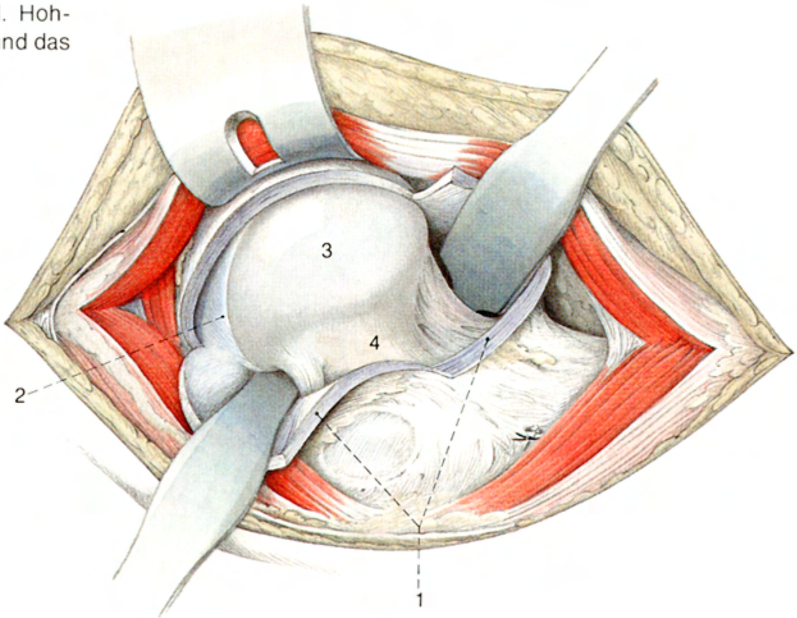


Abb. **187** Die Muskelschicht, bestehend aus den Mm. gluteus medius und minimus, dem tendoperiostalen Gewebe am Trochanter major und dem M. vastus lateralis wird nach ventral weggehalten. Nach Darstellung der Hüftgelenkkapsel werden Hohmann-Hebel eingesetzt. Die Hüftgelenkkapsel wird T-förmig eröffnet.

1 M. iliopsoas
2 M. vastus intermedius
3 M. vastus lateralis
4 M. gluteus medius
5 M. gluteus minimus
6 Lig. iliofemorale
7 Bursa trochanterica m. glutei minimi

Abb. **188** Zustand nach Eröffnung der Hüftgelenkkapsel. Hohmann-Hebel wurden hinter dem Schenkelhals eingesetzt und das Bein maximal nach außen rotiert und adduziert.

1 Capsula articularis
2 Labrum acetabulare
3 Caput femoris
4 Collum femoris



Anatomischer Situs

Wie in Abb. **189** dargestellt, liegt der Vorteil des transglutealen Zuganges u.a. darin, daß der N. gluteus superior durch die breite Muskelschicht des M. gluteus minimus vor zu starkem Hakendruck geschützt wird (vgl. mit Abb. **182**). Der Verlauf des N. gluteus superior wurde durch Ablösung des M. gluteus medius vom Beckenkamm und vom Trochanter major besser dargestellt. Weitere Vorteile dieses Zuganges sind die übersichtlichere Darstellung des Schenkelhalses, der oberen Hüftkapselanteile und der Schenkelhalsresektionsebene bei Prothesenimplantationen.

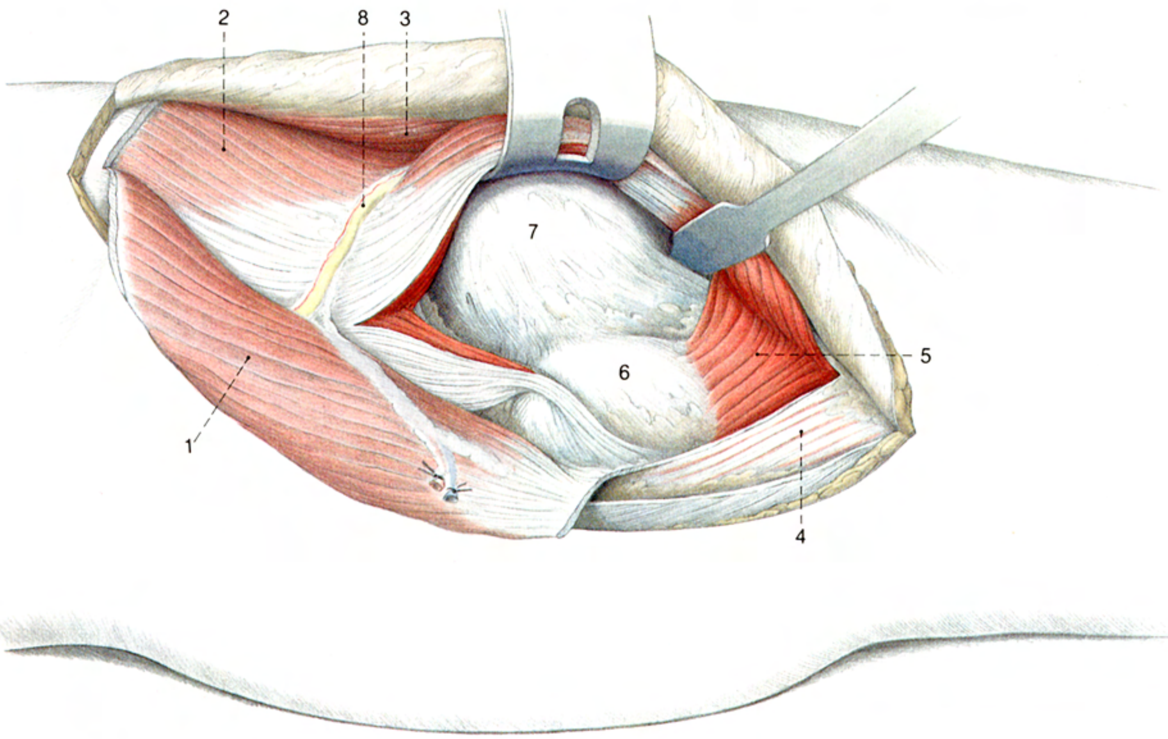


Abb. **189** Anatomischer Situs. Verlauf des N. gluteus superior beim transglutealen Zugang. Der M. gluteus medius wurde am Beckenkamm und am Trochanter major teilweise abgetrennt und nach dorsal zurückgeschlagen.

1 M. gluteus medius
2 M. gluteus minimus
3 M. tensor fasciae latae
4 M. vastus lateralis
5 M. vastus intermedius
6 Trochanter major
7 Caput femoris
8 N. gluteus superior

Wundverschluß
(Abb. **190**)

Der Wundverschluß durch Adaptierung der in Faserrichtung gespaltenen Muskulatur (M. gluteus medius und minimus sowie M. vastus lateralis). Die Faszienperiostplatte wird im Bereich des Trochanter major solide vernäht.

Anmerkung
Der transgluteale Zugang wird von den Autoren routinemäßig bei Implantation von Hüfttotalendoprothesen angewendet. Bei diesem Zugang ist eine Osteotomie des Trochanter major nur selten notwendig.

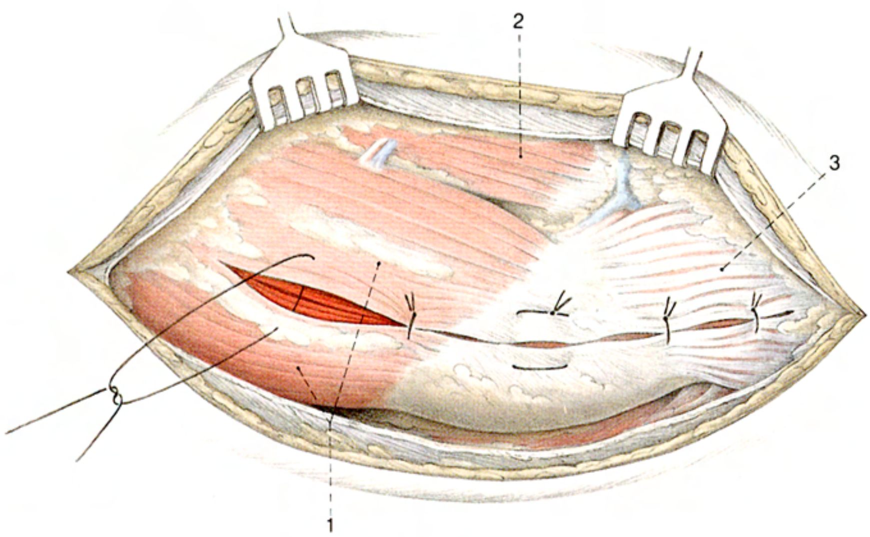


Abb. **190** Verschluß der Muskulatur durch Einzelknopfnähte.

1 M. gluteus medius
2 M. tensor fasciae latae
3 M. vastus lateralis

Vorderer Zugang zum Hüftgelenk

Hauptindikationen

- Offene Reposition bei angeborener Hüftgelenksluxation,
- Beckenosteotomien,
- Totalprothesen,
- Darmbeinfrakturen,
- Tumoren,
- Osteomyelitis,
- Arthrodese.

Lagerung und Schnittführung

Der Patient wird auf dem Rücken gelagert, das Bein beweglich abgedeckt. Der Hautschnitt beginnt am höchsten Punkt des Darmbeinkammes (Tuberculum iliacum) und verläuft lateral desselben bis zur Spina iliaca anterior superior und von hier noch 15 cm gerade nach distal (Abb. **191**). Es ist zu beachten, daß der Hautschnitt lateral des Darmbeinkammes verlaufen soll, um störende postoperative Verwachsungen zwischen Haut und Beckenkamm zu vermeiden. Nach Spaltung von Haut und Subkutis wird die Faszie gerade über dem M. tensor fasciae latae indiziert (Abb. **192**). Dieses Vorgehen erlaubt eine Schonung des N. cutaneus femoris lateralis, welcher zwischen den Mm. sartorius und tensor fasciae latae die Faszie durchstößt (Abb. **193**). Die Schicht zwischen dem M. tensor fasciae latae einerseits und dem M. sartorius andererseits wird nun präpariert, beide Muskeln werden zur Seite gehalten. Anschließend werden die Mm. tensor fasciae latae, gluteus minimus und medius in einer Schicht vom Darmbein abgelöst.

Darstellung der Hüftgelenkkapsel

Die Ablösung des M. tensor fasciae latae und der Glutealmuskulatur vom Darmbeinkamm sollte möglichst subperiostal erfolgen. Bei Kindern wird zu diesem Zweck vorher der knorpelig angelegte Darmbeinkamm gespalten. Das daran anheftende Periost kann mit einem Raspatorium leicht vom Darmbeinkamm gelöst werden. Beim Erwachsenen ist diese Präparation schwieriger und erfordert eine exakte Blutstillung. Die Facies glutea wird ggf. bis zum Foramen ischiadicum majus freigelegt. Anschließend wird ein Hohmann-Hebel eingesetzt, mit welchem die Glutealmuskulatur retrahiert werden kann. Ein großer gebogener Hohmann-Hebel kann zwischen die ventralen Kapselanteile und den Rektusursprung eingesetzt werden (Abb. **194**). Die Eröffnung

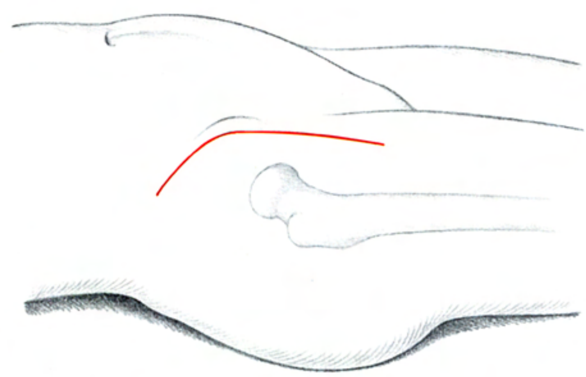


Abb. **191** Der vordere Zugang zum Hüftgelenk. Lagerung und Schnittführung (rechtes Bein).

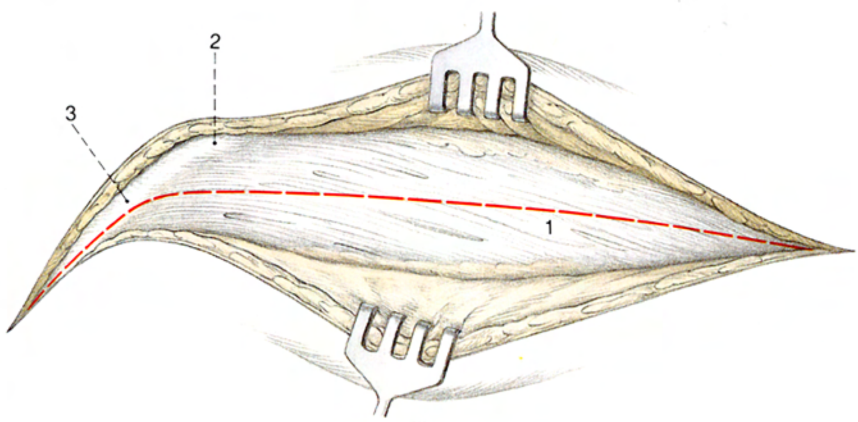


Abb. **192** Spaltung der Faszie parallel zum Hautschnitt über dem M. tensor fasciae latae.

1 Fascia lata
2 Spina iliaca anterior superior
3 Crista iliaca

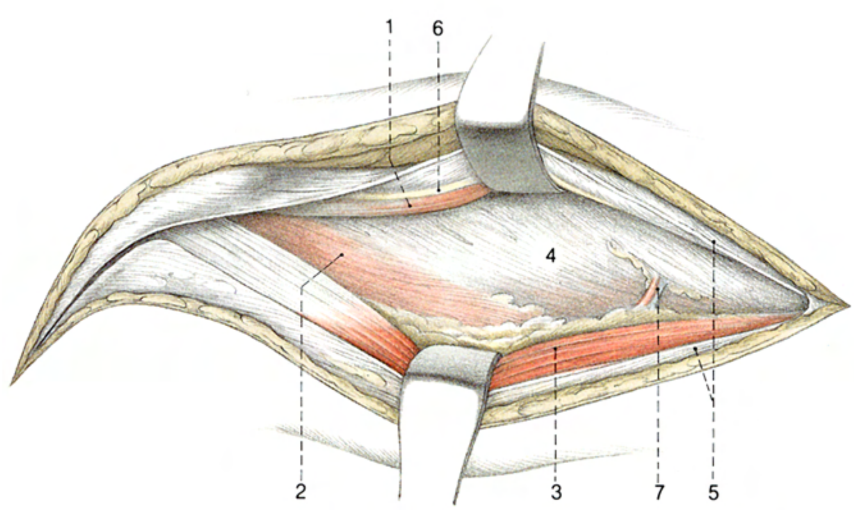


Abb. **193** Stumpfe Präparation zwischen M. sartorius und M. tensor fasciae latae bis zur Faszie, welche den M. rectus femoris bedeckt. Darstellung von Ästen der A. circumflexa femoris lateralis.

1 M. sartorius
2 M. gluteus minimus
3 M. tensor fasciae latae
4 M. rectus femoris
5 Fascia lata
6 N. cutaneus femoris lateralis
7 A. circumflexa femoris lateralis, R. ascendens

der Hüftgelenkkapsel erfolgt T-förmig. Für eine breite Darstellung der Hüftgelenkkapsel, vor allem nach distal, ist die Ligatur und Durchtrennung des aufsteigenden Astes der A. circumflexa femoris lateralis notwendig. Nach dem Eröffnen der Hüftgelenkkapsel können breite Hohmann-Hebel hinter dem Schenkelhals eingesetzt werden (Abb. **195**). Die Luxation des Hüftkopfes ist durch Beugung, Adduktion und Außenrotation des Beines möglich.

Wundverschluß

Nach Naht der Hüftgelenkkapsel werden die Glutealmuskulatur und der M. tensor fasciae latae mit Einzelknopfnähten wieder am Darmbeinkamm befestigt. Anschließend muß die Faszie über dem M. tensor fasciae latae verschlossen werden.

Anmerkung

Der vordere Zugang wurde von Smith-Petersen, Hueter, Callahan, Fahey und anderen beschrieben. Bei bestimmten Operationen, wie z. B. der Beckenosteotomie nach Chiari, muß dieser Zugang durch eine Ablösung des M. sartorius und M. iliacus von der Spina iliaca anterior superior bzw. von der Fossa iliaca ergänzt werden. Dies geschieht am besten durch Ablösen der genannten Muskelgruppen mit einer Darmbeinkammschuppe.

Salter verwendet für seine Osteotomie einen Hautschnitt, welcher fast gerade vom Beckenkamm bis zur Leiste zieht.

Tönnis empfiehlt als Zugangsweg zur operativen Behandlung der angeborenen Hüftgelenksluxation einen Leistenschnitt.

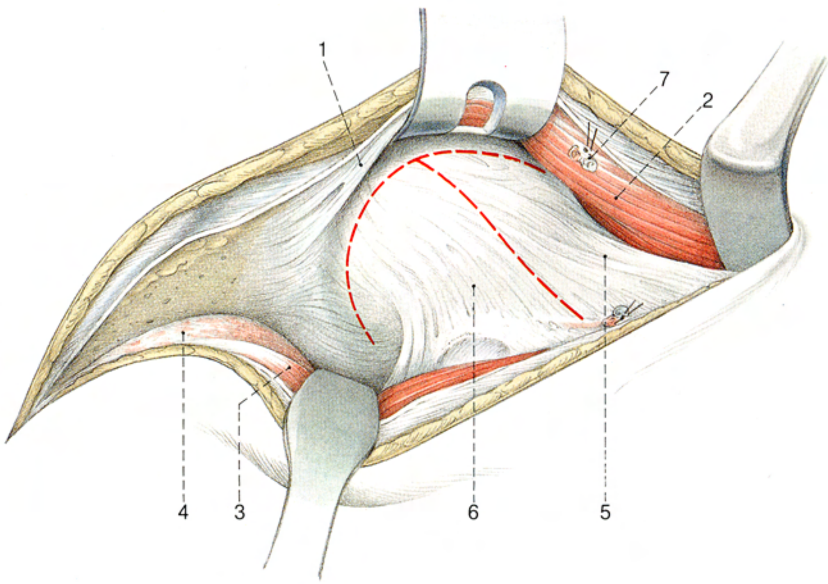


Abb. **194** Ablösung des M. tensor fasciae latae und der Glutealmuskulatur vom Beckenkamm und subperiostale Präparation ggf. bis zum Foramen ischiadicum. Darstellung der Hüftgelenkkapsel und Einsetzen von Hohmann-Hebeln. Die Hüftgelenkkapsel wird T-förmig eröffnet, Ligatur und Durchtrennung des aufsteigenden Astes der A. circumflexa femoris lateralis.

1 M. rectus femoris, Caput reflexum
2 M. rectus femoris
3 M. tensor fasciae latae
4 M. gluteus minimus
5 Lig. iliofemorale, Pars medialis
6 Lig. iliofemorale, Pars lateralis
7 A. circumflexa femoris lateralis, R. ascendens

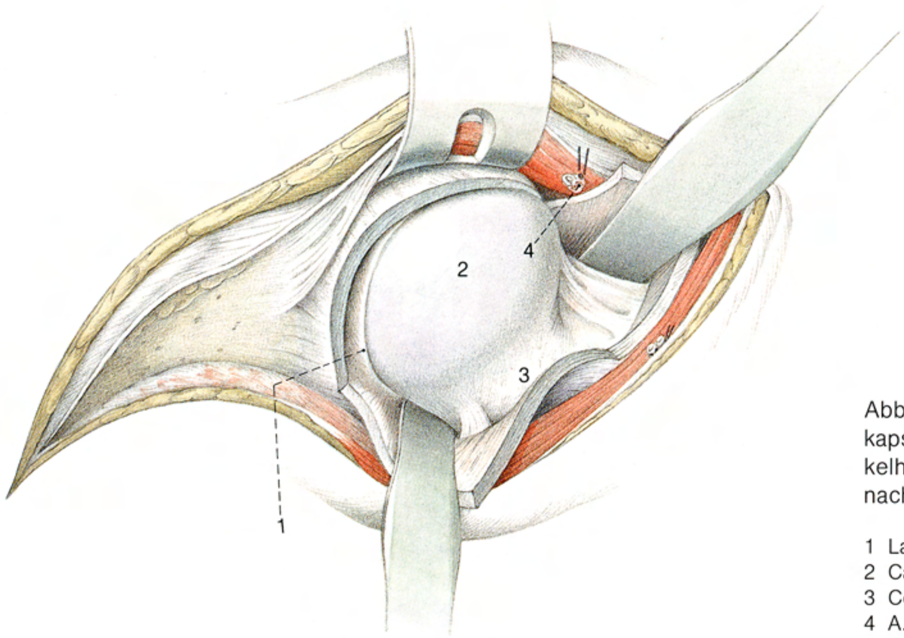


Abb. **195** Zustand nach Eröffnung der Hüftgelenkkapsel. Hohmann-Hebel wurden hinter dem Schenkelhals eingesetzt, das Bein wurde adduziert und nach außen gedreht.

1 Labrum acetabulare
2 Caput femoris
3 Collum femoris
4 A. circumflexa femoris lateralis, R. ascendens

The Effect of the Orientation of the Acetabular and Femoral Components on the Range of Motion of the Hip at Different Head-Neck Ratios

DARRYL D. D'LIMA, ANDREW G. URQUHART, KNUTE O. BUEHLER, RICHARD H. WALKER and CLIFFORD W. COLWELL
J Bone Joint Surg Am. 2000;82:315-21.

The Effect of the Orientation of the Acetabular and Femoral Components on the Range of Motion of the Hip at Different Head-Neck Ratios*

BY DARRYL D. D'LIMA, M.D.†, ANDREW G. URQUHART, M.D.‡, KNUTE O. BUEHLER, M.D.§, RICHARD H. WALKER, M.D.†, AND CLIFFORD W. COLWELL, JR.†, M.D., LA JOLLA, CALIFORNIA

Investigation performed at the Division of Orthopaedic Surgery, Scripps Clinic, La Jolla

Abstract

Background: **Prosthetic impingement due to poor positioning can limit the range of motion of the hip after total hip arthroplasty. In this study, a computer model was used to determine the effects of the positions of the acetabular and femoral components and of varying head-neck ratios on impingement and range of motion.**

Methods: **A three-dimensional generic hip prosthesis with a hemispherical cup, a neck diameter of 12.25 millimeters, and a head size ranging from twenty-two to thirty-two millimeters was simulated on a computer. The maximum range of motion of the hip was measured, before the neck impinged on the liner of the cup, for acetabular abduction angles ranging from 35 to 55 degrees and acetabular and femoral anteversion ranging from 0 to 30 degrees. Stability of the hip was estimated as the maximum possible flexion coupled with 10 degrees of adduction and 10 degrees of internal rotation and also as the maximum possible extension coupled with 10 degrees of external rotation. The effects of prosthetic orientation on activities of daily living were analyzed as well.**

Results: **Acetabular abduction angles of less than 45 degrees decreased flexion and abduction of the hip, whereas higher angles decreased adduction and rotation. Femoral and acetabular anteversion increased flexion but decreased extension. Acetabular abduction angles of between 45 and 55 degrees permitted a better overall range of motion and stability when combined with appropriate acetabular and femoral anteversion. Lower head-neck ratios decreased the range of motion that was possible without prosthetic impingement. The addition of a modular sleeve that increased the diameter of the femoral neck by two millimeters decreased the range of motion by 1.5 to 8.5 degrees, depending on the direction of motion that was studied.**

Conclusions: **There is a complex interplay between the angles of orientation of the femoral and acetabular components. Acetabular abduction angles between 45 and 55 degrees, when combined with appropriate acetabular and femoral anteversion, resulted in a maximum overall range of motion and stability with respect to prosthetic impingement.**

Clinical Relevance: **During total hip arthroplasty, acetabular abduction is often constrained by available bone coverage, while femoral anteversion may be dictated by the geometry of the femoral shaft. For each combination of acetabular abduction and femoral anteversion, there is an optimum range of acetabular anteversion that allows the potential for a maximum range of motion without prosthetic impingement after total hip arthroplasty. These data can be used intraoperatively to determine optimum position.**

The orientation of the prosthetic components in terms of acetabular abduction and anteversion and femoral anteversion is one of the major implant-related factors limiting the range of motion after total hip arthroplasty. Implant-design variables, such as the head-neck ratio[1] and the presence of a modular head with an extended sleeve, also have been implicated[8,14]. In the current study, a three-dimensional computer simulation was used to analyze the interactions between head-neck ratios and prosthetic orientations in determining the range of motion of the hip.

Materials and Methods

A three-dimensional model of a generic hip-replacement prosthesis (Fig. 1) was initially generated with use of Pro/ENGINEER (Parametric Technology, Waltham, Massachusetts), a parametric computer-assisted-design software program. The femoral head diameter ranged from twenty-two to thirty-two millimeters. A diameter of 12.25 millimeters was arbitrarily chosen for the femoral neck. The femoral component was modeled with a 135-degree neck angle and a forty-four-millimeter head offset; offset was measured as the horizontal distance between the center of the head and a vertical line through the center of the distal portion of the stem. The acetabular component was modeled as a pure hemisphere, with an outer diameter of sixty millimeters and an inner diameter set to match each respective head size. The depth of the socket was therefore the same as the radius of the head for each condition.

The axes around which motion was described were determined according to recommendations made by the International Society of Biomechanics[15]. The origin of the hip axis is located at the center of the head. With the hip in the neutral position, the x axis points anteri-

*No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article. No funds were received in support of this study.

†Division of Orthopaedic Surgery, Scripps Clinic, 10666 North Torrey Pines Road, MS126, La Jolla, California 92037. E-mail address for D. D. D'Lima: ddlima@scripps.edu. E-mail address for C. W. Colwell, Jr.: colwell@scripps.edu. Please address requests for reprints to C. W. Colwell, Jr.

‡1050 Isaac Streets Drive, 122, Oregon, Ohio 43616.

§2600 N.E. Ness Road, Suite 1, Bend, Oregon 97701.

TABLE I

COMBINATIONS OF PROSTHETIC ORIENTATIONS THAT PERMIT TYING A SHOE AND STOOPING[6]

Acetabular Abduction *(degrees)*	Femoral Anteversion *(degrees)*	Acetabular Anteversion *(degrees)*
35	0	No position
35	10	≥10
35	20	All positions
35	30	≥10
45	All positions	All positions
55	All positions	All positions

orly, the y axis points superiorly, and the z axis points to the patient's right side. Flexion of the hip is described around the pelvic z axis, which is fixed to the pelvis; axial rotation of the hip, around the femoral y axis, which is fixed to the femur; and adduction and abduction of the hip, around a floating axis, which is mutually perpendicular to the hip flexion axis and the hip rotation axis. Abduction of the acetabular component is measured from the horizontal around the pelvic x axis, and anteversion (true anteversion) of the acetabular component is measured around the pelvic y axis (Fig. 1). The femoral component was assumed to have been inserted in direct alignment with the mechanical axis that corresponds to the femoral y axis (0 degrees of mechanical femoral varus or valgus), and anteversion of the femoral component was measured around the femoral y axis (Fig. 1).

The range of motion was measured by moving the femur in the desired direction until the neck visually impinged on the liner of the cup. Acetabular abduction angles of between 35 and 55 degrees were studied in combination with acetabular and femoral anteversion angles of between 0 and 30 degrees. Flexion, extension, abduction, adduction, and axial rotation were measured for various combinations of acetabular abduction, acetabular anteversion, and femoral anteversion. This was done for head-neck ratios corresponding to a 12.25-millimeter neck diameter associated with head diameters of twenty-two, twenty-six, twenty-eight, and thirty-two millimeters (range of head-neck ratios, 1.8 to 2.6). The range of motion associated with a component that had a modular head with a sleeve extension that increased the diameter of the neck by two millimeters (but did not change the offset of forty-four millimeters) also was measured.

To determine the effect of different combinations of prosthetic positions on implant impingement, contour maps were generated for a prosthesis with a twenty-eight-millimeter-diameter head and a 12.25-millimeter-diameter neck for three representative acetabular abduction angles (35, 45, and 55 degrees). The range of motion of the hip was mapped against femoral anteversion and acetabular anteversion on the x and y axes, respectively. Range-of-motion measurements included flexion, extension, adduction, abduction, and internal and external rotation, which were uncoupled from each other. Each range of motion was classified according to three zones: excellent, poor, and borderline (white, black, and gray, respectively, in Fig. 2). The contour maps then were blended so that each displayed a zonal classification (excellent, borderline, and poor) for the combined range of motion in all directions (flexion-extension, adduction-abduction, and rotation). All motions were recorded as the maximum range before impingement.

To determine the effect of each combination on the stability of the hip, two coupled ranges of motion were measured: the maximum flexion possible with the hip in 10 degrees of adduction and 10 degrees of internal rotation, and the maximum extension possible with the hip in 10 degrees of external rotation. These ranges of motion were chosen to simulate one of the intraoperative stability tests performed during total hip arthroplasty. Contour maps again were generated, as described, to determine which combinations resulted in optimum stability (that is, the maximum range of motion before impingement) (Fig. 3).

In addition, prosthetic orientations that permitted certain activities of daily living, such as tying a shoe with the foot on the ground and stooping, were recorded. According to the positions described by Johnston and Smidt[6], a position of 129 degrees of flexion, 18 degrees of abduction, and 13 degrees of external rotation was chosen for tying a shoe and a position of 125 degrees of flexion, 25 degrees of abduction, and 15 degrees of external rotation was selected for stooping.

Results

Overall, increasing acetabular abduction angles increased hip flexion, extension, and abduction and decreased adduction and axial rotation (Figs. 4 through 8). Increasing acetabular or femoral anteversion increased hip flexion (Fig. 4) and decreased hip extension (Fig. 5), but to varying degrees at different angles of acetabular abduction. At 45 degrees of acetabular abduction, both femoral and acetabular anteversion increased flexion to the same degree. At acetabular abduction angles of more than 45 degrees, acetabular anteversion increased flexion more than femoral anteversion did; this effect was reversed at acetabular abduction angles of less than 45 degrees. Combined femoral and acetabular anteversion had an additive effect on hip flexion. Acetabular anteversion decreased hip abduction, whereas femoral anteversion alone did not have much effect (Fig. 6). On

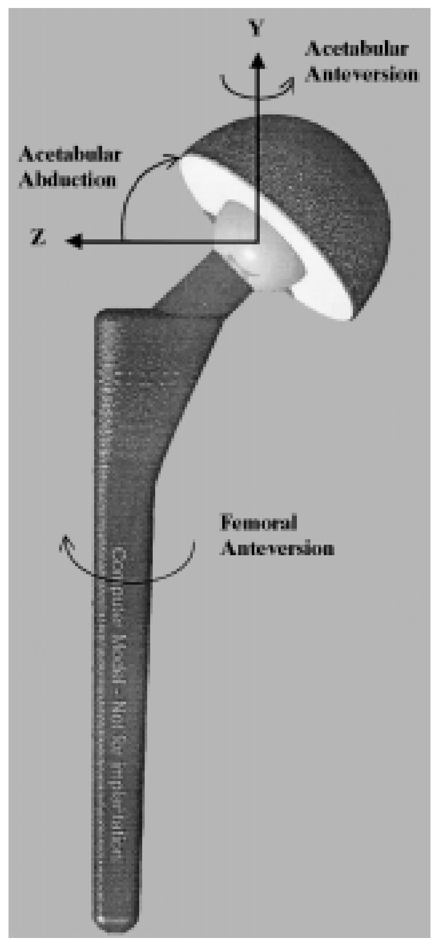


FIG. 1

Rendered image of computer simulation demonstrating the axes around which the prosthetic orientation is described. The curved arrows indicate the positive direction of rotation.

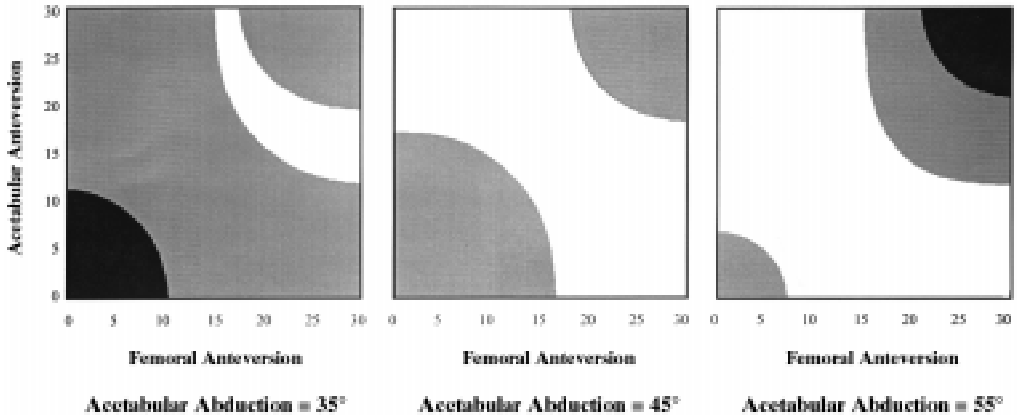


FIG. 2

Combined contour maps for range of motion (for a prosthesis with a head diameter of twenty-eight millimeters). White zones correspond to prosthetic orientations that allow an excellent range of motion (greater than 110 degrees of flexion, 30 degrees of extension, 45 degrees of adduction-abduction, and 45 degrees of external rotation) in all directions; black zones correspond to those that result in a poor range of motion (less than 90 degrees of flexion, 15 degrees of extension, 30 degrees of adduction-abduction, and 30 degrees of external rotation) due to prosthetic impingement in at least one direction; and gray zones correspond to those that allow at least a borderline range of motion (between excellent and poor) in all directions.

the other hand, femoral anteversion decreased hip adduction, whereas acetabular anteversion alone did not have much effect (Fig. 7). Acetabular and femoral anteversion were inversely related to external rotation of the hip, with the decrease in external rotation equaling the amount of acetabular or femoral anteversion (Fig. 8). Maximum internal rotation of the hip was always greater than 45 degrees for all combinations and hence was not included in the analysis, as prosthetic impingement does not seem to be a limiting factor for this parameter.

Femoral Head Size

The size of the head was related to the range of motion of the hip, as expected, but this relationship was not linear. An increase in head size of four millimeters, from twenty-two to twenty-six millimeters, resulted in a larger improvement in the range of motion than did a similar increase from twenty-eight to thirty-two millimeters (Figs. 4 through 8). Also, the position of the component was related to the extent to which head size affected the total range of motion. Higher acetabular abduction angles magnified the changes in hip flexion, extension, and external rotation due to changes in the head-neck ratios. Femoral anteversion reduced the changes in flexion and extension and increased the changes in adduction and abduction due to changes in head size, but it had no such effect on rotation.

Range of Motion

With the cup in 35 degrees of abduction, a very narrow band of prosthetic orientations resulted in the potential for an excellent range of motion (Fig. 2). The femoral or the acetabular component, or both, had to be anteverted more than 10 degrees to result in at least a borderline range of motion. With the cup in 45 de-

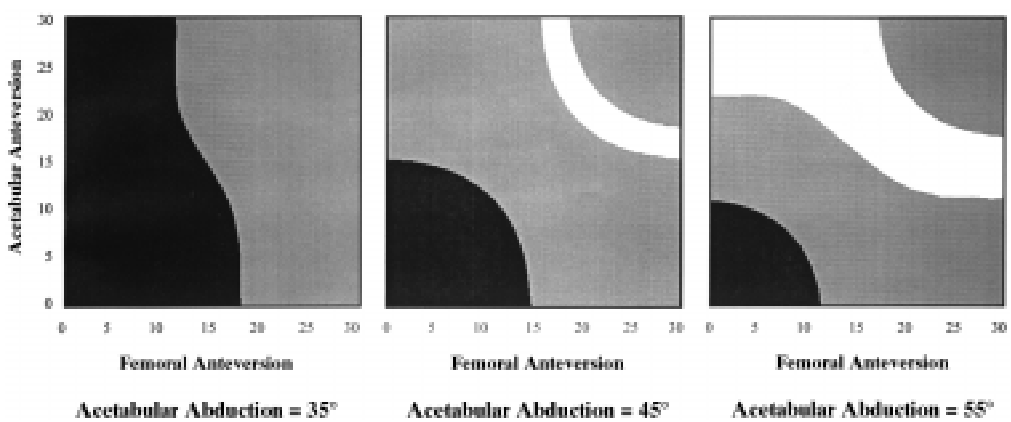


FIG. 3

Combined contour maps for intraoperative stability (for a prosthesis with a head diameter of twenty-eight millimeters). White zones correspond to prosthetic orientations that allow an excellent range of motion in all directions; black zones, to those that result in a poor range of motion due to prosthetic impingement in at least one direction; and gray zones, to those that allow at least a borderline range of motion in all directions.

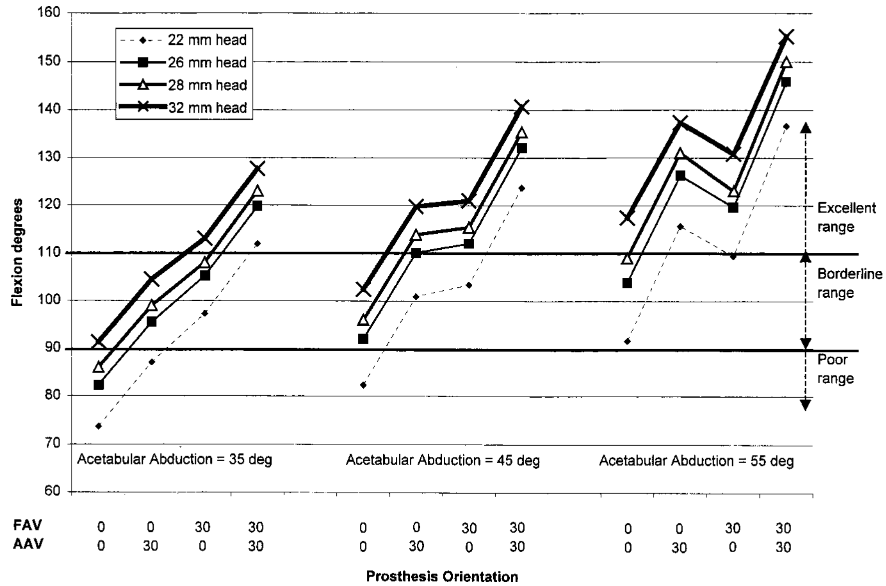


FIG. 4

Graph showing the maximum hip flexion possible with different combinations of prosthetic orientation and different head sizes. FAV = femoral anteversion, and AAV = acetabular anteversion.

grees of abduction, there was a wider margin for error. Judicious combination of femoral and acetabular anteversion could result in an excellent range of motion. For example, if the femoral component was anteverted less than 15 degrees, the acetabular component had to be anteverted more than 15 degrees to make up for the loss in the range of motion; on the other hand, if the femoral component was anteverted more than 25 degrees, the acetabular component had to be anteverted less than 20 degrees to stay in the excellent zone. With the cup in 55 degrees of abduction, the pattern was different; femoral anteversion of less than 15 degrees resulted in an excellent range of motion, whereas a combination of high anteversion of both the acetabular and the femoral component (greater than 15 degrees for each) resulted in a borderline or poor range of motion.

Stability

The combined contour maps for intraoperative stability (Fig. 3) demonstrated somewhat different results. At 35 degrees of acetabular abduction, there were no zones of excellent stability and femoral anteversion of less than 10 degrees resulted in zones of poor stability. At 45 degrees of acetabular abduction, there was a narrow zone of excellent stability. Less than 15 degrees of anteversion of one component had to be compensated

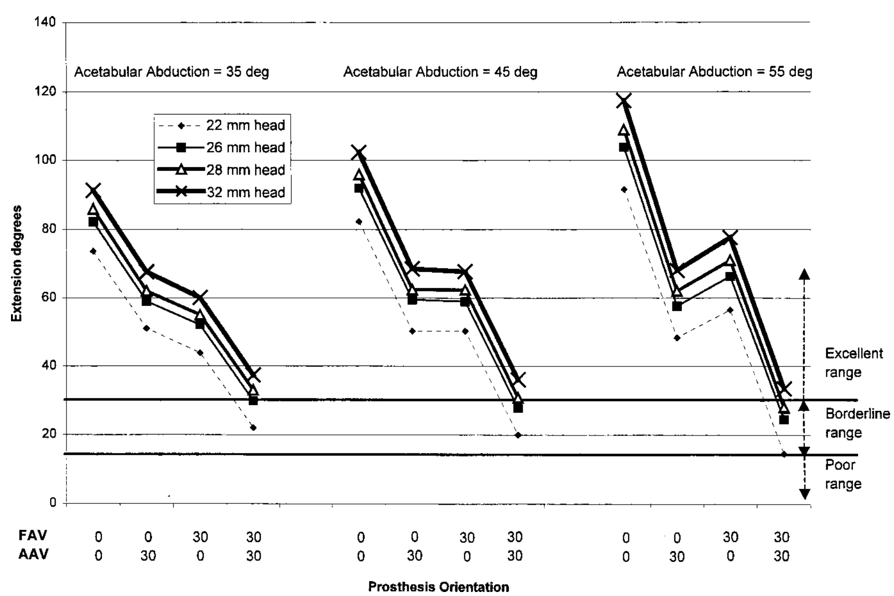


FIG. 5

Graph showing the maximum hip extension possible with different combinations of prosthetic orientation and different head sizes. FAV = femoral anteversion, and AAV = acetabular anteversion.

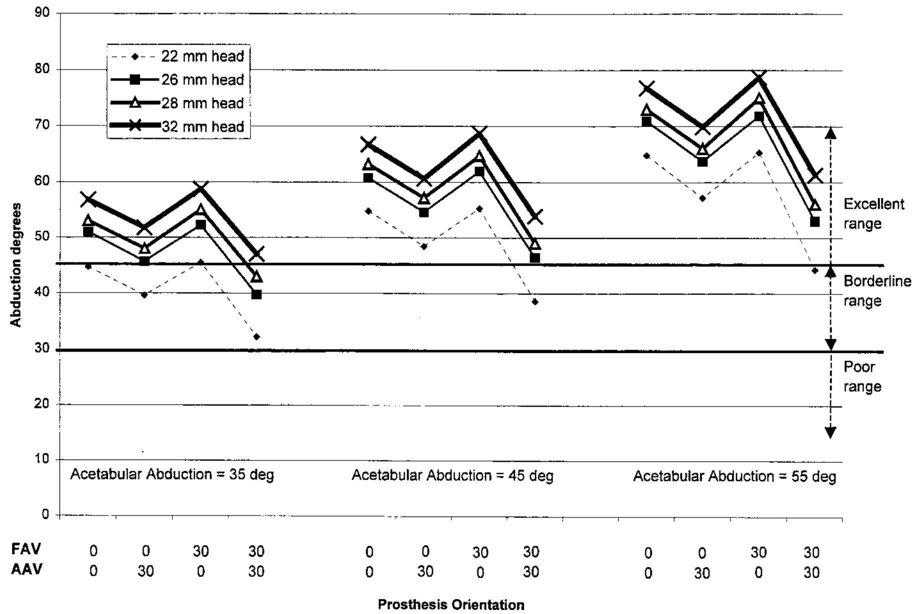


FIG. 6

Graph showing the maximum hip abduction possible with different combinations of prosthetic orientation and different head sizes. FAV = femoral anteversion, and AAV = acetabular anteversion.

for by anteversion of the other component to remain outside a zone of poor stability. At 55 degrees of acetabular abduction, the zone of excellent stability was wider. Zones of poor and borderline stability were restricted to either too little or too much anteversion of both components.

Modular Sleeve Extension

The use of a modular head component with an extended sleeve that effectively increased the diameter of the neck by two millimeters resulted in a 1.5 to 8.5-degree decrease in the range of motion, depending on the direction of motion that was tested.

Activities of Daily Living

Combinations resulting in a range of motion that was sufficient to permit tying a shoe with the foot on the ground and stooping were analyzed (Table I). For example, at 35 degrees of acetabular abduction and 10 degrees of femoral anteversion, at least 10 degrees of

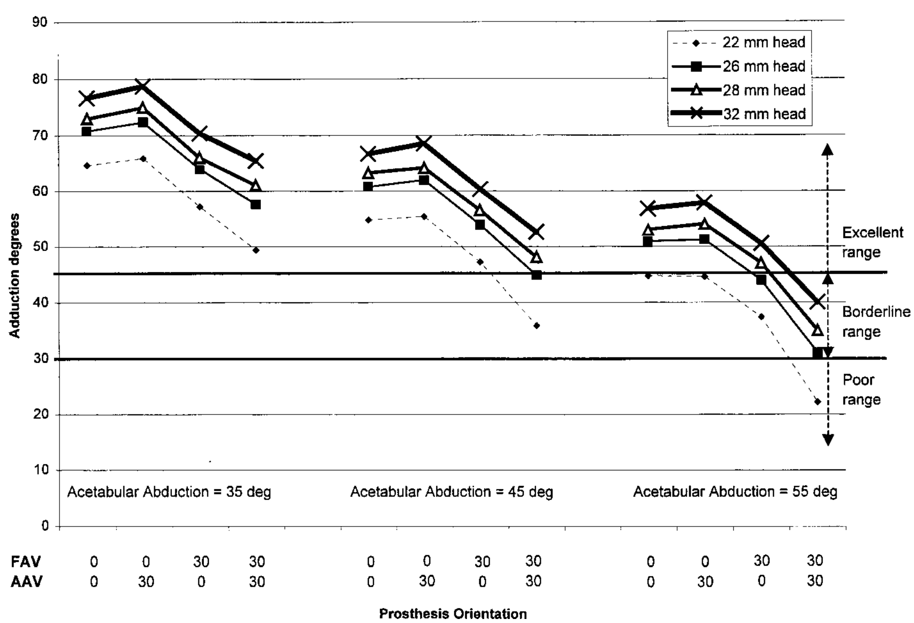


FIG. 7

Graph showing the maximum hip adduction possible with different combinations of prosthetic orientation and different head sizes. FAV = femoral anteversion, and AAV = acetabular anteversion.

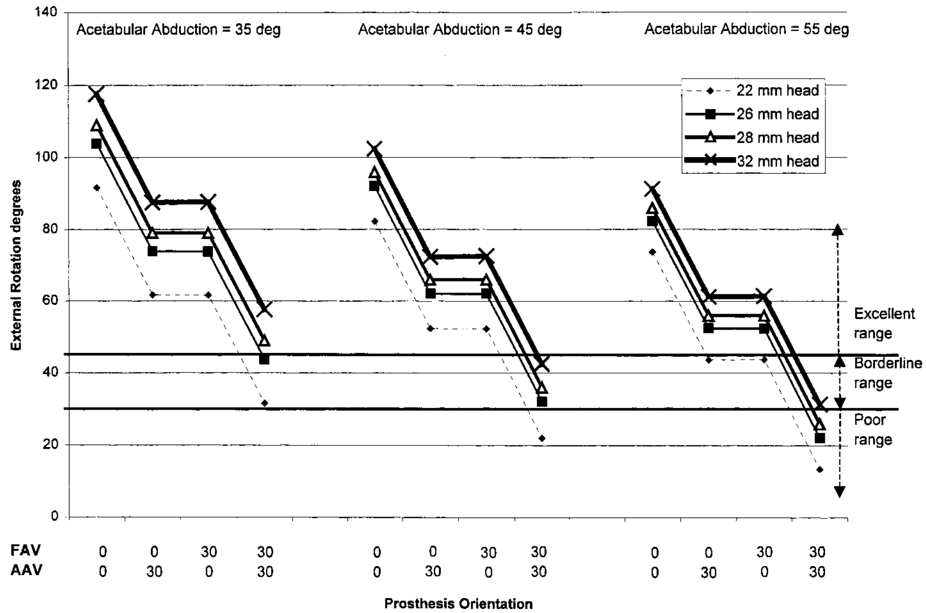


FIG. 8

Graph showing the maximum external rotation of the hip possible with different combinations of prosthetic orientation and different head sizes. FAV = femoral anteversion, and AAV = acetabular anteversion.

acetabular anteversion was necessary to permit tying a shoe or stooping.

Discussion

Prosthetic impingement determines the functional end point of the stable range of motion after a hip arthroplasty. Additional factors, such as osseous impingement and soft-tissue tension, can only decrease this range of motion. Therefore, optimum positioning of the components is necessary to avoid a decrease in the stable range of motion due to prosthetic impingement.

The optimum orientation of hip components remains controversial, with recommendations varying widely. Coventry[3] suggested that more than 40 degrees of abduction and more than 15 degrees of anteversion of the cup prevents posterior dislocation due to impingement, Charnley[2] recommended no anteversion, Harris[5] recommended acetabular abduction of 30 degrees and acetabular anteversion of 20 degrees, and Lewinnek et al.[9] recommended acetabular abduction of between 30 and 50 degrees and acetabular anteversion of between 5 and 20 degrees. Seki et al.[13], in a computer-simulation study, recommended acetabular abduction of between 30 and 50 degrees, acetabular anteversion of between 10 and 30 degrees, and femoral anteversion of 10 degrees; however, only one specific manufacturer's design with a single head size (twenty-six millimeters) was modeled, and only the range of hip flexion and extension was studied. Robinson et al.[12] reported the results of another computer-simulation study in which the range of motion and the contact area were measured. They suggested that, although flexion of the hip increased with acetabular abduction, acetabular anteversion, and femoral anteversion (similar to the findings in the present study), the contact area between the head and the liner decreased. Again, their range-of-motion analysis was limited to one head size and one specific manufacturer's design. Therefore, in the current study, an objective computer simulation of different combinations of component positions was performed, without use of any specific manufacturer's design but with use of a generic model with different head sizes (range of head-neck ratios, 1.8 to 2.6).

There is a complex interaction among abduction of the acetabular component, anteversion of the acetabular component, and anteversion of the femoral component in determining the maximum prosthetic range of motion. The results of the present study suggest that, for a twenty-eight-millimeter-diameter head with a 12.25-millimeter-diameter neck, acetabular abduction angles of between 45 and 55 degrees offer the widest excellent zones in terms of maximizing the range of motion; they also offer wider excellent zones in terms of stability according to the criteria used in this study. However, a previous computer-simulation study demonstrated a decrease in the contact area with increasing abduction of the cup, which may increase the potential for wear[12]. The abduction angle of the cup may be constrained intraoperatively by osseous coverage. Femoral anteversion may be similarly dictated by the anatomy of the femoral canal, especially when the implant is inserted without cement. In the event that the chosen acetabular abduction angle is not optimum, the potential for prosthetic impingement can be minimized by selecting the appropriate degree of anteversion. Too little anteversion of either the femoral or the acetabular component decreases flexion, while too much anteversion reduces extension and adduction. Acetabular abduction angles of less than 45 degrees tend to decrease flexion and abduction; this can be countered by increasing acetabular or femoral anteversion, or both. Higher acetabular abduction angles increase flexion and abduction but may reduce extension, adduction, and external rotation, especially if combined with too much femoral or acetabular anteversion, or both. Therefore, for each combination of acetabular abduction and femoral anteversion, there is an optimum range of acetabular anteversion that may minimize impingement and thus give the patient the potential for a maximum range of motion.

Head size is known to influence range of motion, wear, and dislocation[1,4,7,8]. An increase in head size increases the range of motion and stability but also increases volumetric wear[10,11]. Neck extensions in modular components sometimes necessitate the addition of a sleeve or flange to the head, effectively decreasing the head-neck ratio as well as the range of motion. This phenomenon was recently found to be associated with increased radiographic wear[14].

Surgeons face a complex decision in selecting the appropriate design features. Knowledge of the effect of these features, singly and in combination with other factors, can lead to better selection of the implant, with positive effects with regard to the postoperative range of motion and decreased impingement, dislocation, and wear.

The computer model of the hip that is presented in this study is relatively easy to reproduce. Any combination of positions of the acetabular and femoral components and head-neck ratios can be studied. Although our model uses generic design features, specific design parameters also can be implemented either with use of data provided by the manufacturer or by digitizing the surface of an actual prosthesis with a high-resolution digitizing stylus. The effect of design features such as polyethylene liner lips and offset thus can be investigated, and the findings can be used to assist the surgeon in choosing the appropriate implant.

References

1. **Chandler, D. R.; Glousman, R.; Hull, D.; McGuire, P. J.; Kim, I. S.; Clarke, I. C.;** and **Sarmiento, A.:** Prosthetic hip range of motion and impingement. The effects of head and neck geometry. *Clin. Orthop.,* 166: 284-291, 1982.
2. **Charnley, J.:** Total hip replacement by low-friction arthroplasty. *Clin. Orthop.,* 72: 7-21, 1970.
3. **Coventry, M. B.:** Late dislocations in patients with Charnley total hip arthroplasty. *J. Bone and Joint Surg.,* 67-A: 832-841, July 1985.
4. **Elfick, A. P.; Hall, R. M.; Pinder, I. M.;** and **Unsworth, A.:** Wear in retrieved acetabular components: effect of femoral head radius and patient parameters. *J. Arthroplasty,* 13: 291-295, 1998.
5. **Harris, W. H.:** Advances in surgical technique for total hip replacement: without and with osteotomy of the greater trochanter. *Clin. Orthop.,* 146: 188-204, 1980.
6. **Johnston, R. C.,** and **Smidt, G. L.:** Hip motion measurements for selected activities of daily living. *Clin. Orthop.,* 72: 205-215, 1970.
7. **Kelley, S. S.; Lachiewicz, P. F.; Hickman, J. M.;** and **Paterno, S. M.:** Relationship of femoral head and acetabular size to the prevalence of dislocation. *Clin. Orthop.,* 355: 163-170, 1998.
8. **Krushell, R. J.; Burke, D. W.;** and **Harris, W. H.:** Range of motion in contemporary total hip arthroplasty. The impact of modular head-neck components. *J. Arthroplasty*, 6: 97-101, 1991.
9. **Lewinnek, G. E.; Lewis, J. L.; Tarr, R.; Compere, C. L.;** and **Zimmerman, J. R.:** Dislocations after total hip-replacement arthroplasties. *J. Bone and Joint Surg.,* 60-A: 217-220, March 1978.
10. **Livermore, J.; Ilstrup, D.;** and **Morrey, B.:** Effect of femoral head size on wear of the polyethylene acetabular component. *J. Bone and Joint Surg.,* 72-A: 518-528, April 1990.
11. **Maxian, T. A.; Brown, T. D.; Pedersen, D. R.;** and **Callaghan, J. J.:** Adaptive finite element modeling of long-term polyethylene wear in total hip arthroplasty. *J. Orthop. Res.,* 14: 668-675, 1996.
12. **Robinson, R. P.; Simonian, P. T.; Gradisar, I. M.;** and **Ching, R. P.:** Joint motion and surface contact area related to component position in total hip arthroplasty. *J. Bone and Joint Surg.,* 79-B(1): 140-146, 1997.
13. **Seki, M.; Yuasa, N.;** and **Ohkuni, K.:** Analysis of optimal range of socket orientations in total hip arthroplasty with use of computer-aided design simulation. *J. Orthop. Res.,* 16: 513-517, 1998.
14. **Urquhart, A. G.; D'Lima, D. D.; Venn-Watson, E.; Colwell, C. W., Jr.;** and **Walker, R. H.:** Polyethylene wear after total hip arthroplasty: the effect of a modular femoral head with an extended flange-reinforced neck. *J. Bone and Joint Surg.,* 80-A: 1641-1647, Nov. 1998.
15. **Wu, G.,** and **Cavanagh, P. R.:** ISB recommendations for standardization in the reporting of kinematic data. *J. Biomech.,* 28: 1257-1261, 1995.

Kniegelenk

Medialer parapatellarer Zugang

Hauptindikationen

- Arthroplastik,
- Synovektomie,
- Arthrodese,
- Bandplastiken.

Lagerung und Schnittführung

Der Patient liegt auf dem Rücken mit gestrecktem, frei abgedeckten Bein. Der Hautschnitt beginnt 5 cm proximal des oberen Patellarandes etwa in der Mitte und zieht bogenförmig 1 cm medial des inneren Patellarandes nach distal, um anschließend wieder medial des Lig. patellae zur Tuberositas tibiae zu verlaufen.

Ist eine Darstellung des Pes anserinus oder des medialen Seitenbandapparates notwendig, so kann der Hautschnitt noch 5 cm weiter nach distal verlängert werden (Abb. **228**). Die Subkutis wird nun nach vorne und hinten abpräpariert, und anschließend wird der R. infrapatellaris des N. saphenus aufgesucht (Abb. **229**).

Abb. **228** Der mediale parapatellare Zugang. Hautinzision und mögliche Verlängerung für die Darstellung des Pes anserinus und des medialen Kapselbandapparates.

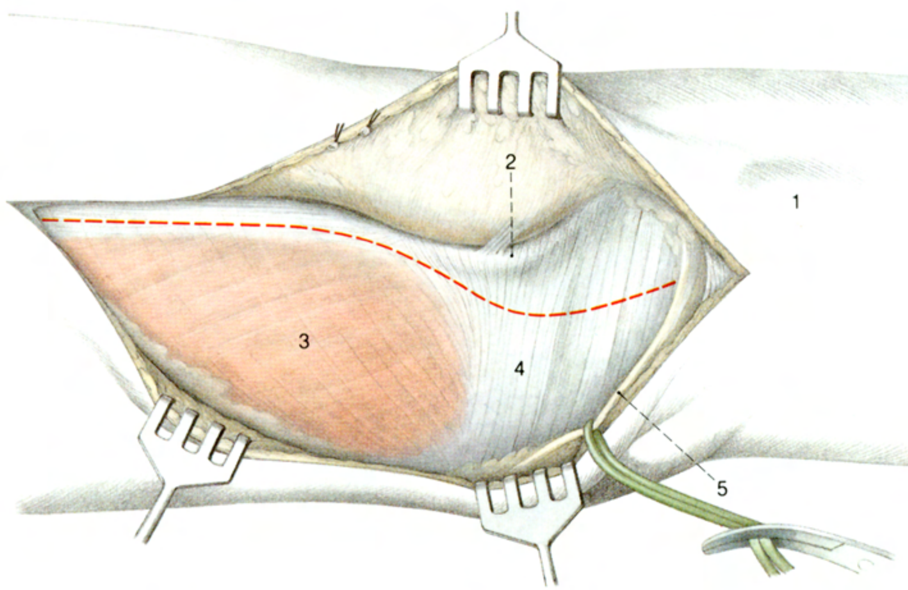


Abb. **229** Anschlingung des R. infrapatellaris des N. saphenus. Inzision des medialen Patellaretinakulums und der Quadrizepssehne.

1 Tuberositas tibiae
2 Patella
3 M. vastus medialis
4 Retinaculum patellae transversum mediale
5 R. infrapatellaris n. sapheni

Darstellung des Kniegelenkes

Das Retinaculum patellae mediale wird 2 cm medial des Patellarandes inzidiert. Anschließend präpariert man die Gelenkkapsel mit der Schere stumpf vom Retinakulum und von der Quadrizepssehne ab (Abb. **230**). Der Kniegelenkstreckapparat wird in Höhe des proximalen Patellarandes mit je einem Haltefaden armiert, um einen korrekten Verschluß der Retinacula zu ermöglichen. Alsdann spaltet man die Quadrizepssehne einige Millimeter lateral der Einstrahlung des M. vastus medialis. Etwa 2 cm proximal des medialen Gelenkspaltes wird die Gelenkkapsel eröffnet. Bei der Spaltung der synovialen Gelenkkapsel nach distal muß auf die Insertion des Meniskusvorderhornes Rücksicht genommen werden (Abb. **231**). Die Kniescheibe kann nun nach lateral weggehalten und um 180 Grad gedreht werden. Ist eine Luxation der Kniescheibe und Drehung derselben nach lateral nicht möglich, so ist die Inzision der Quadrizepssehne sowie der Gelenkkapsel nach proximal weiter auszudehnen. Bei Rezidiveingriffen müssen gelegentlich Vernarbungen im Bereich des Hoffaschen Fettkörpers (Corpus adiposum infrapatellare) und der lateralen Gelenkkapsel gelöst werden, um eine vollständige Luxation und Rotation der Patella zu ermöglichen. Anschließend wird das Kniegelenk rechtwinkelig gebeugt, womit eine übersichtliche Darstellung des medialen und lateralen Femurkondylus, der Fossa intercondylaris mit beiden Kreuzbändern, des medialen und des lateralen Meniskus sowie des Tibiaplateaus möglich ist (Abb. **232**).

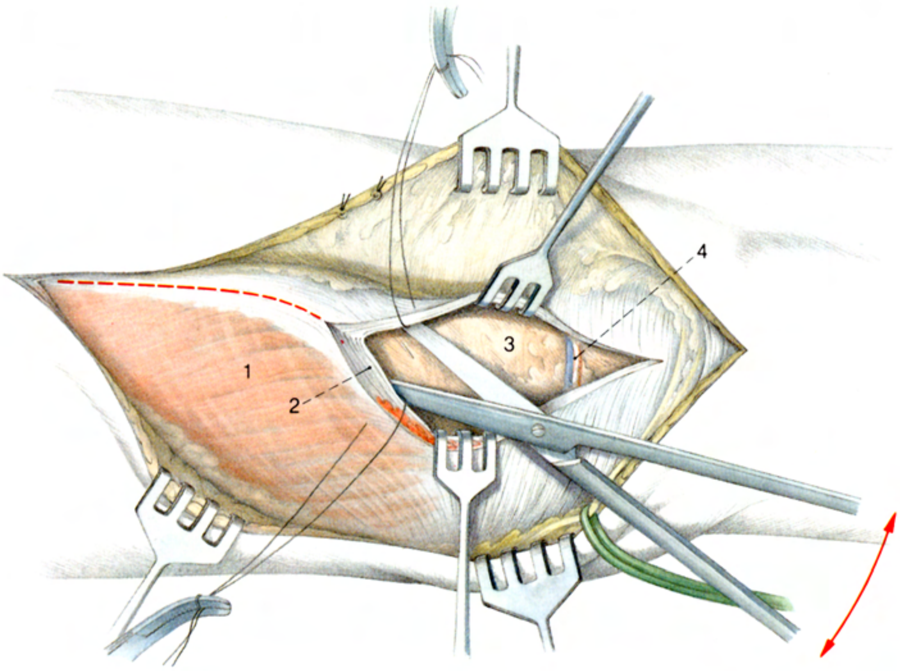


Abb. **230** Präparation der Kniegelenkkapsel unter dem M. vastus medialis und der Quadrizepssehne. Markierung der Insertion des M. vastus medialis mittels Haltefäden. Spaltung der Quadrizepssehne nach proximal.

1 M. vastus medialis
2 Tendo m. quadricipitis
3 Capsula articularis, Membrana synovialis
4 A. et V. genus superior medialis

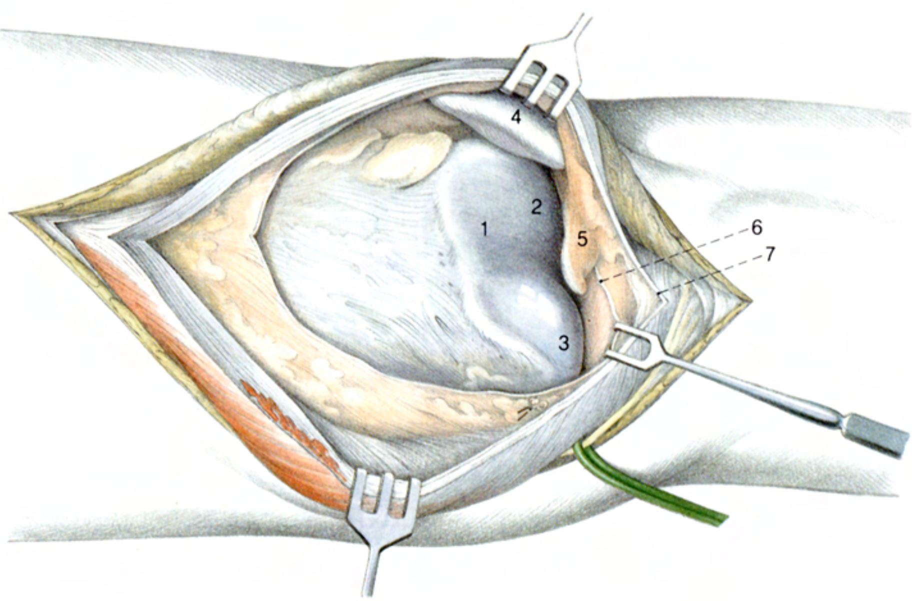


Abb. **231** Zustand nach Eröffnen der Kniegelenkkapsel und Luxation der Patella nach lateral, gestrecktes Kniegelenk.

1 Facies patellaris femoris
2 Condylus lateralis femoris
3 Condylus medialis femoris
4 Patella
5 Corpus adiposum infrapatellare
6 Capsula articularis, Membrana synovialis
7 Capsula articularis, Membrana fibrosa

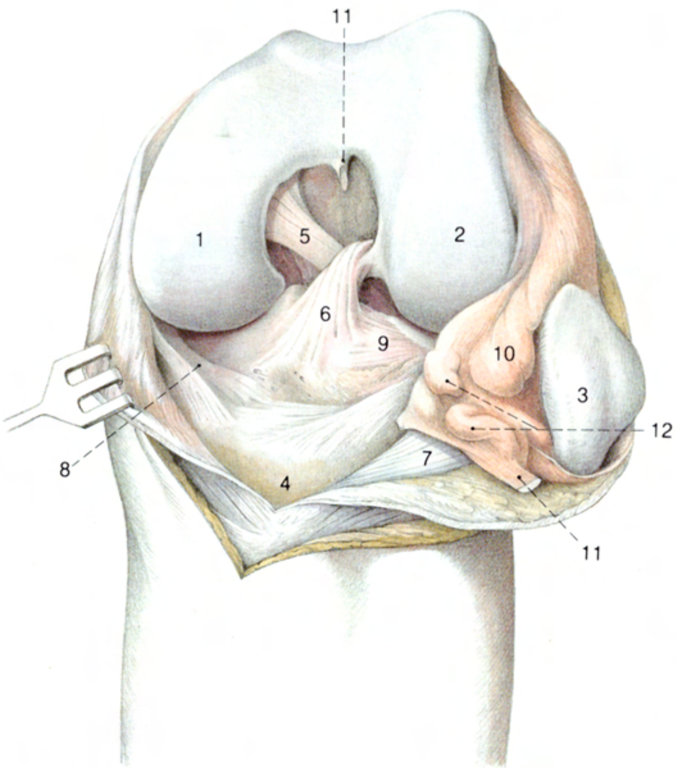


Abb. **232** Zustand nach rechtwinkeliger Beugung des Kniegelenkes, Ansicht von ventral. Die Kniescheibe wurde nach außen rotiert und luxiert.

1 Condylus medialis femoris
2 Condylus lateralis femoris
3 Patella
4 Tibia
5 Lig. cruciatum posterius
6 Lig. cruciatum anterius
7 Lig. patellae
8 Meniscus medialis
9 Meniscus lateralis
10 Corpus adiposum infrapatellare
11 Plica synovialis infrapatellaris
12 Plicae alares

Zugangserweiterung

Zur Darstellung des Pes anserinus sowie der medialen Gelenkkapsel bis zum Semimembranosuseck wird der Schnitt ab der Tuberositas tibiae 5 cm nach distal verlängert. Die Hautinzision im proximalen Bereich entspricht dem medialen parapatellaren Zugang. Nach Spaltung der Subkutis wird vorerst der R. infrapatellaris des N. saphenus aufgesucht und mit einem Nervenbändchen angeschlungen. Die mediale Arthrotomie nimmt man in typischer Weise 2 cm medial des inneren Patellarandes durch die Retinakula vor. Anschließend wird die Schicht unter dem R. infrapatellaris unterminiert, der Nerv hochgehoben und darunter die Faszie sowie der Ansatz des Pes anserinus superficialis inzidiert. Bei Bedarf kann die Inzision nach proximal in die Quadrizepssehne ausgedehnt werden (Abb. **233**). Das Kniegelenk kann nun durch Abklappen des Operationstisches um 90 Grad gebeugt werden. In dieser Position läßt sich die Faszie mit den Sehnen des Pes anserinus superficialis gut nach dorsal abpräparieren, so daß die mediale Kniegelenkkapsel übersichtlich dargestellt werden kann. Bei Ablösung des Pes anserinus superficialis von der Tibia ist der darunterliegende Ansatz des medialen Seitenbandes zu schonen.

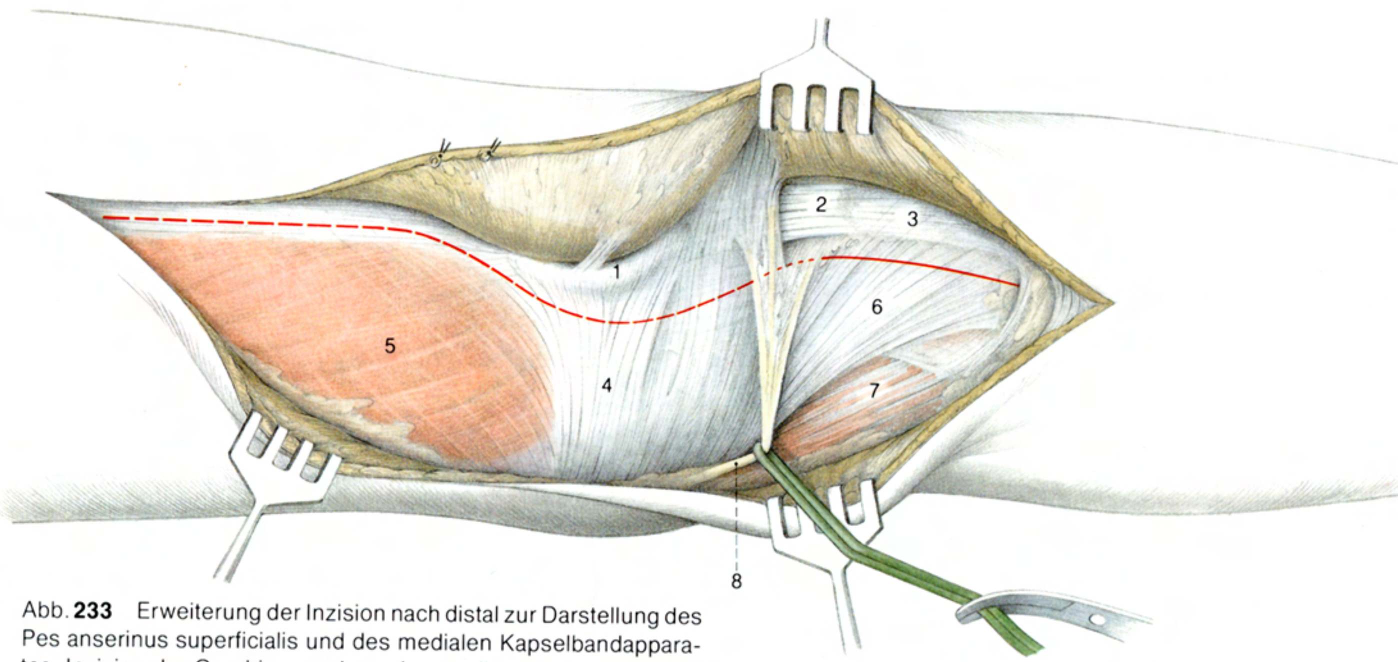


Abb. **233** Erweiterung der Inzision nach distal zur Darstellung des Pes anserinus superficialis und des medialen Kapselbandapparates. Inzision der Quadrizepssehne, des medialen Patellaretinakulums und des Pes anserinus superficialis unter dem R. infrapatellaris.

1 Patella
2 Lig. patellae
3 Tuberositas tibiae
4 Retinaculum patellae transversum mediale
5 M. vastus medialis
6 Pes anserinus superficialis
7 Caput mediale m. gastrocnemii
8 R. infrapatellaris n. sapheni

Bei Bedarf kann nun auch der hintere Anteil des Kniegelenkes von medial inspiziert werden. Die Kniegelenkkapsel wird hinter dem Lig. collaterale mediale posterius schräg eröffnet und ein Langenbeck-Haken eingesetzt (Abb. **234**). Mit dieser Inzision ist im allgemeinen eine gute Übersicht über das posteromediale Eck des medialen Meniscus, über die hintere Kniegelenkkapsel und die tiefen Anteile des medialen Seitenbandes möglich. Ist eine Darstellung des tibialen Ansatzes des hinteren Kreuzbandes notwendig, so kann die Kapselinzision nach medial am Femur erweitert werden, wobei gleichzeitig auch ein Teil des medialen Gastroknemiuskopfes durchtrennt wird (Abb. **235**). Die Sehne des M. adductor magnus sollte bei dieser Inzision nicht verletzt werden. Der darüber verlaufende N. articularis genus sowie die Äste der A. genus superior medialis sind ebenfalls zu verschonen.

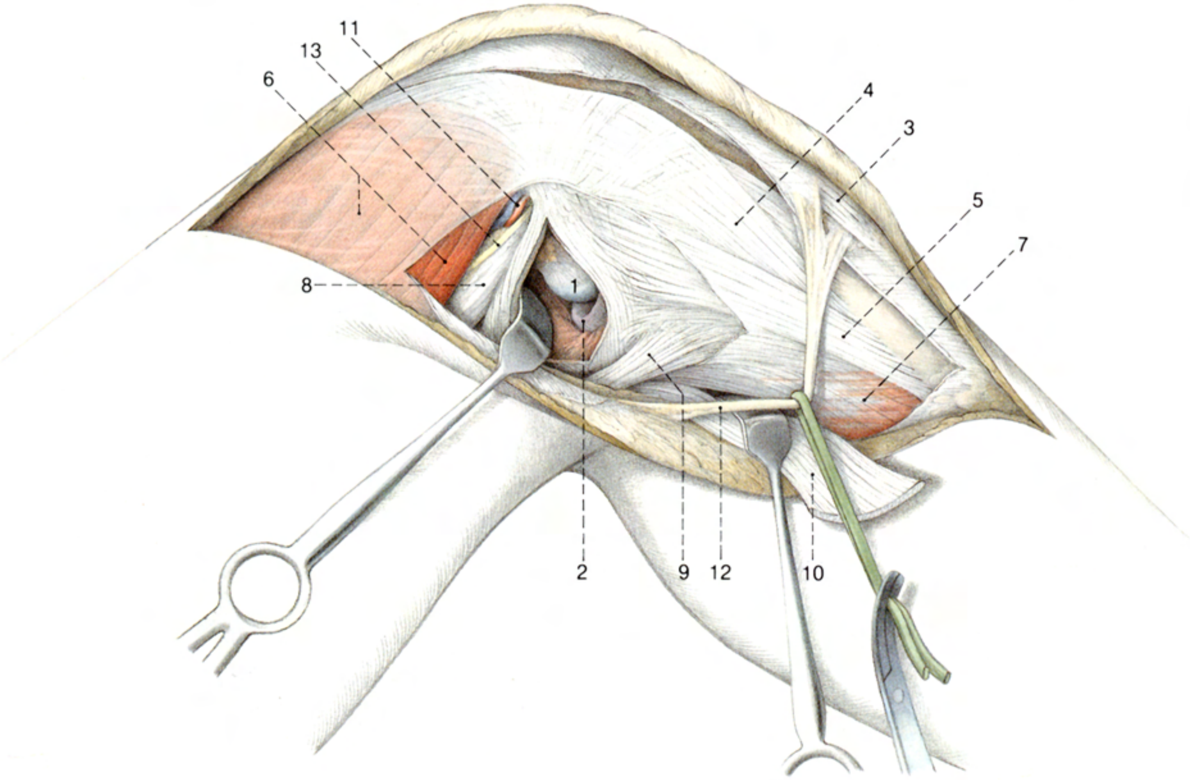


Abb. **234** Zustand nach Ablösung des Pes anserinus superficialis an der Tibia. Die hinteren Gelenkkapselanteile wurden hinter dem Lig. collaterale mediale posterius eröffnet. *Cave:* Schonung der A. genus superior medialis und des N. articularis genus.

1 Condylus medialis femoris
2 Meniscus medialis
3 Lig. patellae
4 Retinaculum patellae mediale
5 Lig. collaterale tibiale
6 M. vastus medialis
7 M. popliteus
8 Tendo m. adductoris magni
9 Tendo m. semimembranosi
10 Pes anserinus superficialis
11 A. et V. genus superior medialis
12 R. infrapatellaris n. sapheni
13 N. articularis genus

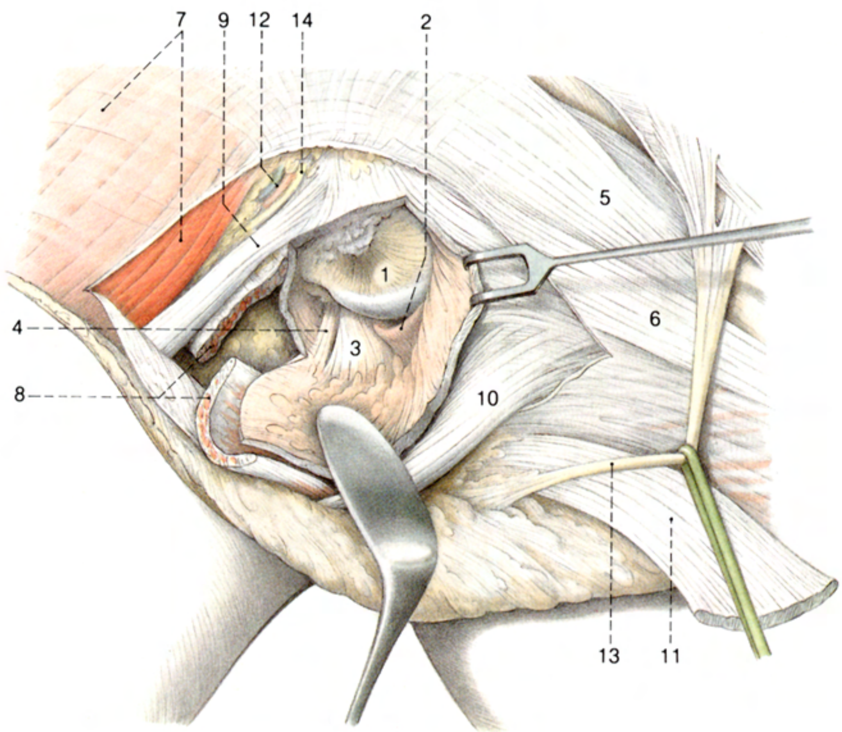


Abb. **235** Größere Eröffnung der posteromedialen Gelenkkapselanteile durch Ablösen des medialen Gastroknemiuskopfes zur Darstellung des hinteren Kreuzbandes.

1 Condylus medialis femoris
2 Meniscus medialis
3 Lig. cruciatum posterius
4 Lig. meniscofemorale posterius
5 Retinaculum patellae mediale
6 Lig. collaterale mediale
7 M. vastus medialis
8 M. gastrocnemius, Caput mediale
9 Tendo m. adductoris magni
10 Tendo m. semimembranosi
11 Pes anserinus superficialis
12 A. et V. genus superior medialis
13 R. infrapatellaris n. sapheni
14 N. articularis genus

Anatomischer Situs

(Abb. **236**)

Das sog. posteromediale Gelenkeck oder Semimembranosuseck hat für die Funktion des Kniegelenkes eine besondere Bedeutung. Der hintere Anteil der medialen Kniegelenkkapsel wird vom M. semimembranosus dynamisch stabilisiert. Der M. semimembranosus hat fünf Ansätze, deren Zugrichtung von der Beugung des Kniegelenkes abhängig sind: Die Pars reflecta zieht unter das mediale Seitenband an die Tibia und stabilisiert bei Beugung gegen die Außenrotation. Der direkte mediale Ansatz an der Tibia bewirkt eine Spannung der hinteren Kapsel in Streckstellung. Das Lig. popliteum obliquum ist eine Ausstrahlung der Semimembranosussehne in die hintere Gelenkkapsel. Zwei weitere Faserzüge strahlen einerseits in das Lig. collaterale mediale posterius (hinteres Schrägband) und andererseits in die Aponeurose des M. popliteus ein.

Arthrotomien im posteromedialen Gelenkanteil können sowohl vor als auch hinter dem Lig. collaterale mediale posterius angelegt werden. Dieses femorotibiale Band ist eng mit dem posteromedialen Eck des medialen Meniscus verbunden. Das Meniskushinterhorn wird durch dieses Band stabilisiert. Eine zusätzliche dynamische Stabilisierung erfährt dieses Band auch durch Ausläufer der Semimembranosussehne.

Wundverschluß

Die Gelenkkapsel, der mediale Kopf des Gastroknemius und der abgelöste Pes anserinus werden mit Einzelknopfnähten genäht. In der Regel empfiehlt sich das Aufheben der Blutleere und die Blutstillung vor dem Wundverschluß.

Alternative Hautinzision

Die Darstellung des Kniegelenkes durch eine mediale parapatellare Kapselinzision kann mit einer lateralen parapatellaren Hautinzision kombiniert werden. Die laterale parapatellare Inzision ist für Eingriffe wie Synovektomie, Arthroplastik oder Bandplastiken vorzuziehen, da die Blut- und Nervenversorgung der Haut und der Subkutis an der Knievorderseite dadurch weniger beeinträchtigt wird. Die prä- und infrapatellare Nervenversorgung der Haut erfolgt hauptsächlich von medial.

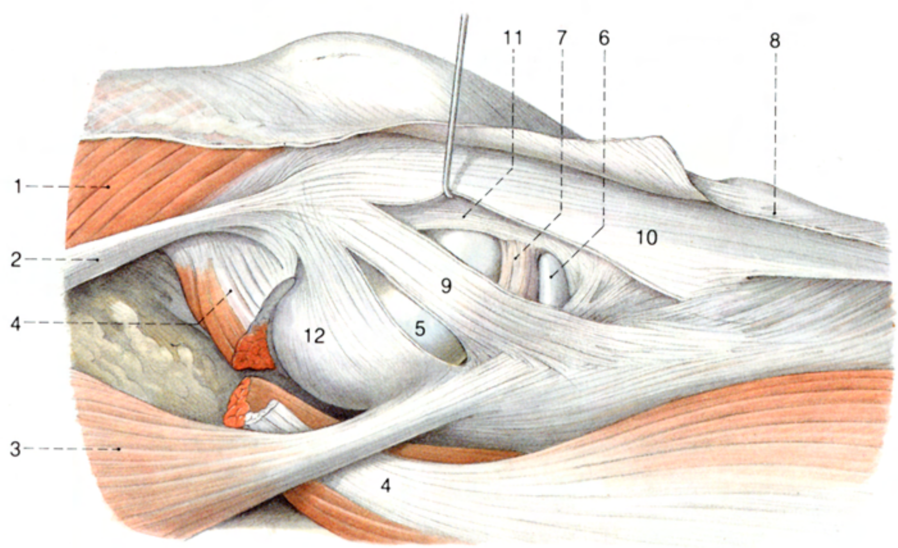


Abb. **236** Anatomischer Situs. Der mediale Kapselbandapparat des Kniegelenkes.

1 M. vastus medialis
2 Tendo m. adductoris magni
3 M. semimembranosus
4 M. gastrocnemius, Caput mediale
5 Condylus medialis femoris
6 Condylus medialis tibiae
7 Meniscus medialis
8 Pes anserinus superficialis
9 Lig. collaterale mediale posterius
10 Lig. collaterale mediale
11 „Mediales Kapselband"
12 „Kondylenkappe"

Die laterale Hautinzision kann bogenförmig oder gerade von 5 cm proximal des oberen lateralen Patellapoles bis zur Tuberositas tibiae angelegt werden (Abb. **237**). Zur schonungsvollen Präparation des medialen Hautlappens ist folgende Vorgangsweise zu empfehlen: Nach Spaltung der Subkutis wird die darunterliegende Faszie in Schnittrichtung durchtrennt. Den medialen Hautlappen präpariert man nun subfaszial nach medial ab. Wird auf diese Weise vorgegangen, können die Gefäße und Nerven der medialen Seite zuverlässig geschont werden, da diese hauptsächlich extrafaszial verlaufen (Abb. **238**). Die mediale Arthrotomie erfolgt in typischer Weise nach Spaltung des medialen Patellaretinakulums sowie der Quadrizepssehne. Von dieser Inzision können bei Bedarf auch eine laterale parapatellare Arthrotomie, ein lateraler Release oder laterale Bandrekonstruktionen ausgeführt werden (Abb. **239**).

Abb. **237** Laterale parapatellare Hautinzision, gerade oder geschwungene Schnittführung möglich (linkes Kniegelenk).

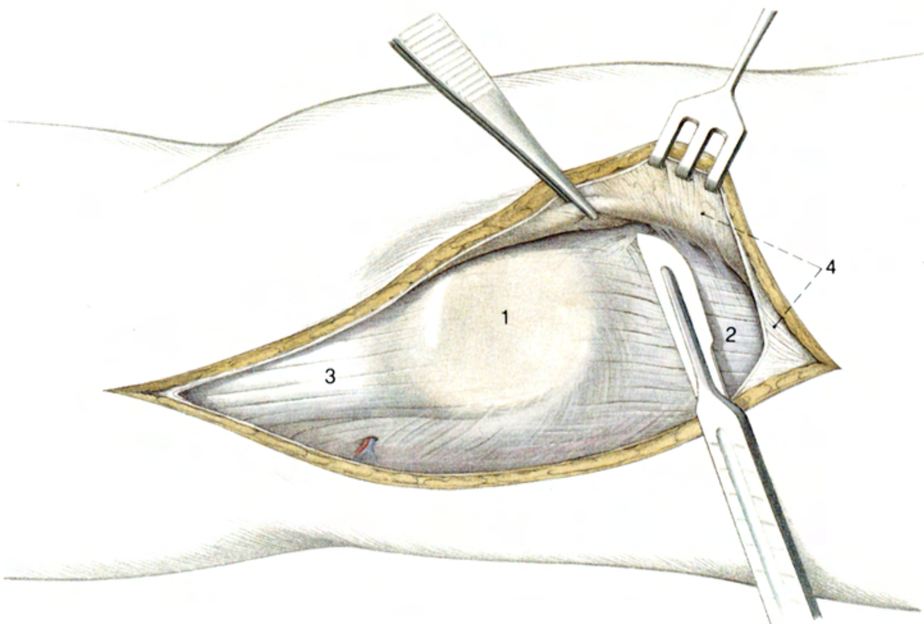


Abb. **238** Nach Spaltung der Faszie wird der mediale Hautlappen subfaszial abpräpariert.

1 Patella
2 Tendo m. quadricipitis
3 Lig. patellae
4 Fascia

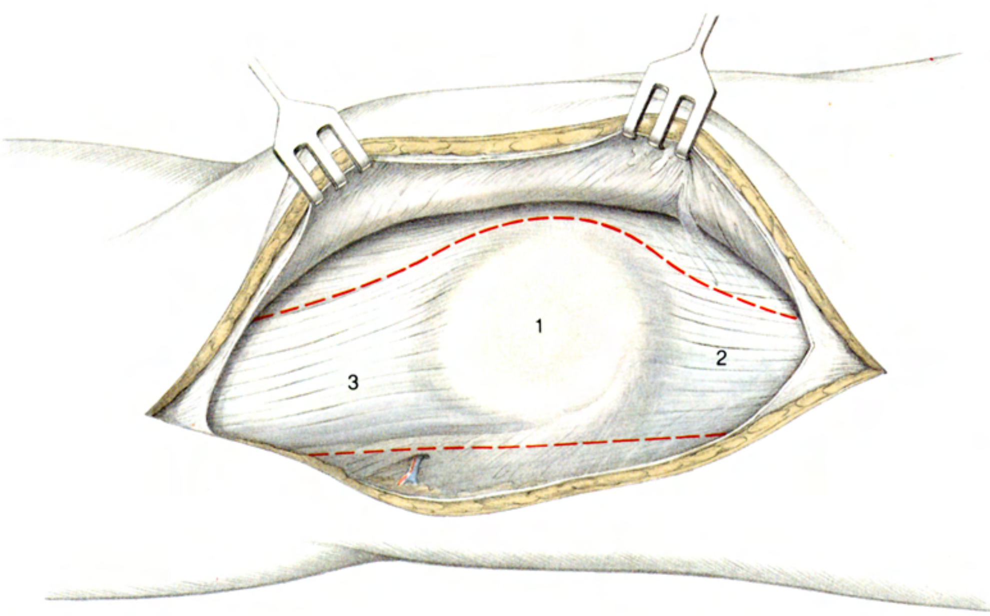


Abb. **239** Parapatellare Inzision des Streckapparates (wahlweise medial oder lateral).

1 Patella
2 Tendo m. quadricipitis
3 Lig. patellae

■ REVIEW ARTICLE

Alignment in total knee replacement

J. M. Sikorski

From the University of Notre Dâme, Fremantle, Western Australia

The advent of computer-assisted knee replacement surgery has focused interest on the alignment of the components. However, there is confusion at times between the alignment of the limb as a whole and that of the components. The interaction between them is discussed in this article. Alignment is expressed relative to some reference axis or plane and measurements will vary depending on what is selected as the reference. The validity of different reference axes is discussed. Varying prosthetic alignment has direct implications for surrounding soft-tissue tension. In this context the interaction between alignment and soft-tissue balance is explored and the current knowledge of the relationship between alignment and outcome is summarised.

Three challenges must be met to produce an acceptable result from a knee replacement, namely perfect alignment of the components, good soft-tissue balance and compatibility between the femorotibial articulation and the quadriceps mechanism. The surgeon seeks to produce a replacement which is ideally aligned in the coronal, sagittal and axial planes, with the femoral component matched to the tibial in rotation, with a joint line at the appropriate level, with the soft tissues balanced in flexion and extension and tensioned sufficiently to produce stability, but without limiting the range of movement or producing excessive compression on the polyethylene, and with the patella tracking in the correct plane. This is a daunting task. All the variables listed interact so that a small error in one parameter can produce considerable changes in the others. There is a paucity of information on the quantitative aspects of any of them and we are only just beginning to develop surgical techniques which can control them with accuracy. To date, we have made progress by using an intuitive approach and this has paid considerable dividends. We have refined total knee replacement (TKR) to the stage at which it produces good, but not perfect, relief from pain and reasonable, but not outstanding, function. The current standards will not suffice in the future because the expectations of our patients and the mechanical demands on knee prostheses are increasing.

The recent concentration on alignment and the development of computer-assistance technologies have opened a new pathway to progress. We now have accurate and quantitatively defined control over several of the important parameters of a replacement. We can set up outcome studies using this information. Now that we have control of some of the variables we can begin to manage the others in a similar fashion. This article attempts to summarise our current knowledge of the requirements for alignment in TKR and explores how alignment interacts with some of the other variables which must be considered.

Parameters of alignment

Alignment is relative. The position of a prosthetic component is adjusted relative to another component or to a defined but theoretical construct, an axis or a plane. In TKR there are two separate concepts of alignment, that of the limb as a whole and that of the component. We reference alignment to either theoretical constructs or anatomical landmarks. The theoretical axes are the mechanical axes of the limb and that of the femur and the tibia. The mechanical axis of the limb (Fig. 1) represents the entire limb from the hip to the ankle and is a straight line drawn from the centre of the femoral head to the centre of the ankle. It can be measured with appropriate software very accurately (to within 1°).[1] From the perspective of the knee its path is determined by intra-articular and extra-articular factors. The most common demonstration of the mechanical axis of the limb is the standing Maquet view.[2] The mechanical axis of the femur is a straight line from the centre of the

■ J. M. Sikorski, BSc, MD, FRACS, Adjunct Professor
Hollywood Specialist Medical Centre, 8/95 Monash Avenue, Nedlands, Western Australia 6009, Australia.

Correspondence should be sent to Professor J. M. Sikorski; e-mail: jsikorski@iinet.net.au

doi:10.1302/0301-620X.90B9.20793 $2.00

J Bone Joint Surg [Br] 2008;90-B:1121-7.

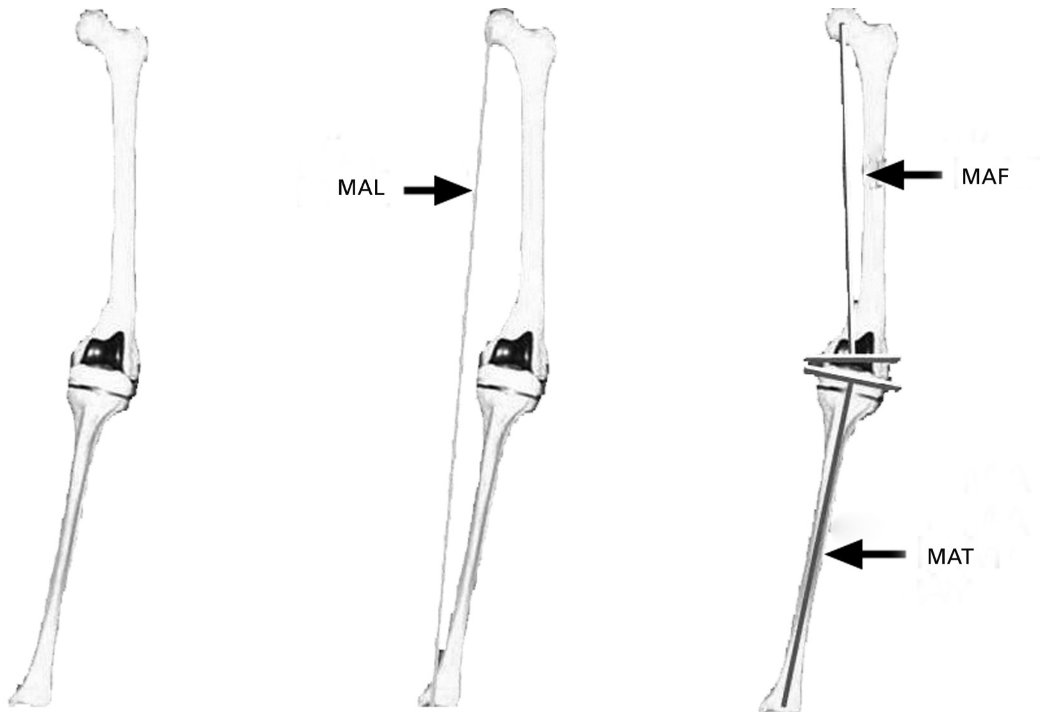


Fig. 1

Diagrams of the impact of varus deformity of the lower femur on the mechanical axes of the knee in the coronal plane showing a) a varus deformity in the supracondylar region of the femur, b) the medial displacement of the mechanical axis of the limb (MAL) which results and c) the mechanical axis of the femur (MAF) and mechanical axis of the tibia (MAT). Lines drawn at right angles to the MAF and the MAT show the resulting opening of the lateral side of the joint.

femoral head to the middle of the intercondylar region. The mechanical axis of the tibia is a straight line from the centre of the tibial plateau to the middle of the ankle (Fig. 1). In a mechanically-neutral limb the mechanical axes of the femur and tibia lie along that of the limb. These axes are applicable in the coronal and sagittal planes.

There are many anatomically-based reference lines and planes which are used in TKR. For alignment of the femoral component these include the distal one-third of the medullary canal of the femur, the anterior cortex of the femur, the intercondylar groove of the femur and the plane of the posterior parts of the femoral condyles. For alignment of the tibial component there are the upper two-thirds of the medullary canal of the tibia, the anterior cortex of the tibial flare and lines connecting the posterior cruciate ligament variable parts of the tibial tuberosity. Unfortunately, all the anatomical reference systems show a wide degree of inconsistency, with the exception of Whiteside's line.[3]

The transepicondylar axis of the femur is unique in being both the mechanical axis around which knee flexion occurs and being clearly defined by anatomical landmarks. It therefore falls into both the mechanical and anatomical groups.

The third reference system is soft-tissue tension. It is used by some to position the femoral component. This is a hybrid approach in which the position of the tibial component is determined by reference to the mechanical axis of the tibia and the femoral component is placed according to the position which the femur assumes when soft tissues are stretched. It is the basis of the Oxford (Biomet UK Ltd, Swindon, United Kingdom) and LCS (DePuy Mitek Inc., Raynham, Massachusetts) Knees.

Reviews of the literature have shown a wide variability in the reference systems used both during TKR and in the subsequent analysis of alignment. Any report which deals with alignment needs to be interpreted with regard to the reference axes which have been used. Thus, reporting the sagittal alignments of the femoral component will produce different results depending on whether the reference axis is the mechanical axis of the femur, the medullary canal or the anterior cortex of the femoral shaft.

The mechanical constructs provide more rational, reproducible and consistent references than the anatomical alignments. There is debate about the relative accuracy of the soft-tissue reference system relative to the other two. Direct comparisons suggest that it is not as reliable as using mechanical reference axes,[3] although this view has not been tested by a well-controlled clinical trial. The surgical technique on which it relies provides reasonable results, but the resultant longevity of the implant is no better than that achieved by using the mechanical constructs as reference axes.[4]

Table I. Summary of the impact of variations in, and by implication the bone cuts of components on the alignment and the gaps produced (+, indicates an increase in gap, -, a decrease and 0, no change)

			Joint space change			
Plane	**Component**	**Displacement**	**Medial**	**Lateral**	**Flexion**	**Extension**
Coronal	Femoral or tibial	Varus angulation	+	-	0	0
		Valgus angulation	-	+	0	0
Sagittal	Femoral	Anterior	0	0	+	0
		Posterior	0	0	-	0
		Proximal	0	0	0	+
		Distal	0	0	0	-
	Tibial	Post slope increase	0	0	+	-
Axial	Femoral	Internal rotation	0	+	+	0
		External rotation	+	0	+	0

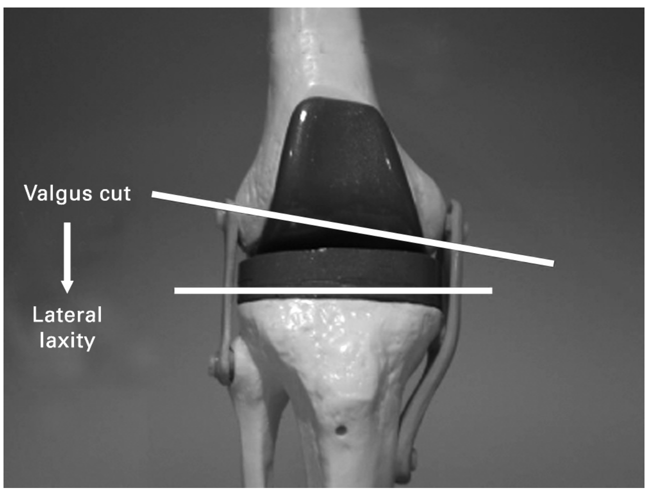


Fig. 2

Photograph showing the impact of a valgus femoral cut on the joint gaps. Lateral laxity results if the tibial cut remains in neutral.

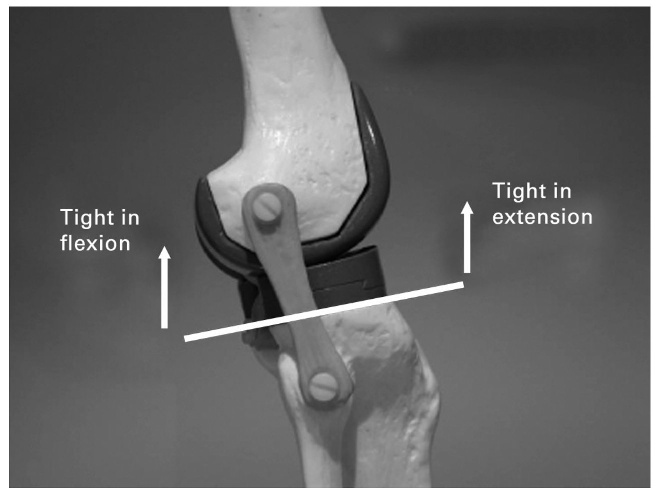


Fig. 3

Photograph showing the effect of varying the sagittal tibial cut on the flexion and extension gaps. Increased posterior slope increases the flexion space and decreases the extension space. The opposite occurs with a greater anterior slope.

Dimensions

A knee replacement should have technical success in six dimensions. The first three are the coronal, sagittal and axial planes and static alignment needs to be correct in all of them. The fourth dimension is the proximodistal positioning of the implant. In addition, these positions have to reflect the appropriate kinematics, both weight-bearing and non-weight-bearing, and the whole construct needs to be stable in time which is expressed as longevity.

The alignment of each component has to be controlled in three planes (coronal, sagittal and axial). There is universal agreement that in the coronal plane both the femoral and the tibial components should lie along the mechanical axis of the bones. If this is achieved, and if there is no extra-articular deformity, this will produce a mechanical axis of the limb which runs through the centre of the component. In the sagittal plane the mechanical axes of the femur and tibia are also the appropriate reference axes. In the axial plane the transepicondylar axis of the femur is used to assess rotation of the femoral component because it is the functional axis of flexion.[5] The alternative is to use the intercondylar groove of the femur which is at right angles to the transepicondylar axis of the femur. This is the antero-posterior axis. There is good, but not perfect,[6] agreement between the two. The posterior condylar axis should not be used since it is too variable.[7,8] For the tibia, finding a suitable axis of reference for the axial plane is difficult since none of those proposed has been shown to be reliable.[9] This has resulted in the widely-held view that the position of the tibial component in rotation should be that which best

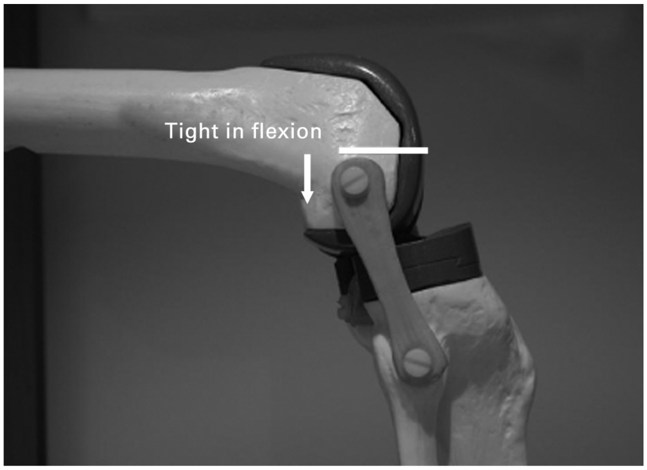


Fig. 4

Photograph showing the impact of moving the femoral component in an anteroposterior plane on the flexion gap. Anterior displacement produces an increase in the flexion space. The same effect is produced by using a smaller femoral component placed in the same position. Posterior displacement or a larger femoral component tightens the flexion space without affecting the extension. Moving the femoral component proximally by cutting more off the femur increases the extension gap without affecting the flexion space.

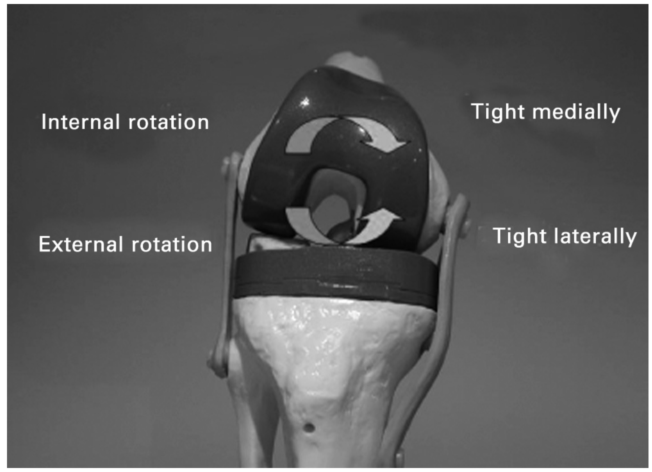


Fig. 5

Photograph showing the effect of femoral rotation in flexion. Internal rotation of the femoral component increases the lateral gap while external rotation increases the medial gap.

aligns with the femoral component or femoral landmarks.[6,10,11]

The interaction of alignment and soft-tissue balance

It is important to achieve correct tension of the periarticular soft tissues for optimum function of a knee replacement. It must be adequate to prevent the joint from subluxing or dislocating, but high tensions may cause excessive wear of polyethylene or even limit movement. Currently, we do not know the tensions which should be achieved in the various soft tissues around the knee. It is widely assumed that there should be a uniform tension around the circumference of the knee which should be maintained in both flexion and extension. This is the concept of soft-tissue 'balance'. There is very little direct evidence to support this view. Certainly, tensions are not uniform in the normal knee or after resection of the anterior cruciate ligament.[12] Furthermore, symmetrical gaps will only cause symmetrical tensions when a femoral component of a single radius is implanted. Irrespective of whether 'ligament balance' is fact or fiction it is important to realise that the placement of the components affects the tensions in the soft tissues. The complexity of the interactions is summarised in Table I.

In the coronal plane a valgus femoral or tibial cut will increase the laxity of the lateral compartment (Fig. 2). If both cuts are valgus or varus the laxity will be greater being the sum of the two errors. If one is valgus and the other is varus the laxity will be symmetrical, but there will be a sloping joint line.

In the sagittal plane the slope of the tibial component affects the balance between flexion and extension gaps (Fig. 3). Increasing the posterior slope reduces the extension and increases the flexion gaps. Decreasing or reversing the slope produces tight flexion and lax extension. In the flexed knee, moving the centre of rotation of the femoral component by either displacing the prosthesis in the anteroposterior plane or by changing its size, will affect the flexion but not the extension gap (Fig. 4). Movement of the femoral component proximally will increase the extension gap without changing the flexion gap.

Femoral axial misalignment affects not only the patellofemoral relationships but also the coronal laxity in flexion. Internal rotation of the femoral component will result in lateral condylar lift-off at 90° of flexion (Fig. 5). However, this is not easy to detect at surgery because the dislocation or retraction of the patella tightens up the lateral side in a non-representative manner. External rotation of the femur will cause medial condylar lift-off and varus coronal laxity in flexion.

If soft tissue releases are indicated and performed in the well-aligned knee, and no structures of functional importance are destroyed, the effect will probably be beneficial. However, restoration of the balance in a knee which is malaligned, especially if important structures such as the medial collateral ligament and the iliotibial tract are destroyed, may be unsatisfactory. It is also important to remember that the anatomical relationship of the components may change after soft tissue release. This is especially true of rotational alignment and therefore it is wise not to finalise the rotational

Table II Mean (SD) angular deviations of 23 failed total knee replacements in degrees, expressed in absolute terms, from the ideal values

Parameter*	Alignment deviation: Early failure < 10 years (n = 16)		Late failure ≥ 10 years (n = 7)		p-value†
Femoral coronal	2.81	(1.56)	1.29	(1.38)	0.0367
Femoral sagittal	2.06	(1.84)	1.57	(1.81)	0.5610
Femoral axial	1.88	(1.86)	1.86	(2.04)	0.9837
Tibial coronal	1.75	(1.48)	1.14	(1.35)	0.3644
Tibial sagittal	2.94	(2.43)	2.57	(1.81)	0.7260
Femorotibial mismatch	6.38	(5.30)	1.14	(1.21)	0.0017

* for tibial sagittal the ideal is taken as the manufacturer's recommended value for that particular prosthesis. For all other parameters the ideal value is taken as zero. The reference axes are mechanical axis of the femur for femoral coronal and femoral, sagittal, transepicondylar axis of the femur for femoral axial, and mechanical axis of the tibia for tibial coronal

† Students' *t*-test

position of the tibial component until all the soft tissue releases have been performed.

The interaction of intra- and extra-articular deformity

Established and advanced intra-articular deformities seem to predispose to secondary extra-articular deformities, although the extent and nature of the associations have not been fully elucidated. Correction of intra-articular deformity does not affect any extra-articular parameter, at least in the short term. When extra-articular deformity is a considerable contributor to overall malalignment it is possible to restore a neutral mechanical axis of the limb by intra-articular techniques. These involve altering the alignment of the component and/or performing soft-tissue release. It is not clear to what extent such techniques should be used. Severe extra-articular deformities should probably be corrected at the site of the deformity in order not to compromise the TKR.

The interaction of extra-articular deformity and soft-tissue imbalance

If there is considerable extra-articular deformity, correct placement of the components will result in soft-tissue imbalance. This is most obvious in the coronal plane (Fig. 1). If the extra-articular deformity is varus, placement of the femoral component along the mechanical axis of the femur and of the tibial component along the mechanical axis of the tibia will result in a mechanical axis of the limb which passes medially to the joint and produces a relative lateral laxity. Theoretically, this can be corrected by performing a medial release, the extent of which is proportional to the extent of the initial extra-articular deformity. The release involves the cutting of normal tissue and then the insertion of a thick tibial plateau. For valgus deformities the releases should be on the lateral side.

The interaction of alignment and prosthetic design

The technical goals of TKR need to be viewed in the context of the design of the implant. While most current designs share a fundamentally common approach, there are variations which need to be accommodated intellectually and in the surgical technique used. The most important design variable is the degree of inbuilt restraint in order to produce extra stability and thus prevent subluxation or dislocation. However, the restraining interface is almost invariably polyethylene, which will be exposed to high forces that can cause it to fail. These implants vary from the heavily-restrained hinge designs with only one degree of freedom to the posterior stabilised and deep-dished variants. Mobile-bearing designs aim to reduce restraint in rotation and therefore produce less wear of polyethylene and delay loosening. At present it is unclear how critical prosthetic alignment is in these variants or whether different designs require adjustment of the alignment of components.

The relationship between femorotibial and patellofemoral articulations

The positioning of the femorotibial articulation in relation to the patellofemoral has three determining parameters; the rotary (axial) position of the femorotibial complex, the relative balance of the actions of muscles and the tightness of ligaments acting across the patella and the position of the joint line. This defines the relative positions of the joint line and the patella. The position of the joint line is virtually uncontrolled in TKR.

The relationship between technical success and outcome

The impact of coronal alignment has been frequently described. To date, controlled studies have failed to show that an improvement in the coronal alignment of the components is associated with any short-term clinical benefit. However, most of the studies quoted have been seriously underpowered.[13,14] It is widely accepted that a deviation of the mechanical axis of the limb of more than 3° from the neutral is associated with reduced longevity of the implant. However, there is very little direct evidence to support this view. It was first reported in 1991[2] in the context of a very unusual knee design, but has been supported by finite model analysis,[15] in laboratory studies using a knee simulator,[16] in cadaver studies[17,18] and in a limited number of outcome studies.[19] However, 3° is an arbitrary figure and there is no reason to believe that it represents a definitive value for the acceptability of alignment. It is more likely that any deviation from neutral will reduce longevity by an amount which is proportional to the malalignment.

It is more difficult to achieve good sagittal than coronal alignment[20,21] yet the impact of sagittal malalignment has been studied relatively little. However, sagittal instability does occur[22] and has been associated with an excessive tibial slope.[23] Since variations in tibial slope produce reciprocal alterations in the flexion and extension gaps, the complications of sagittal malalignment are probably the consequences of flexion-extension mismatch.

Rotary alignment

Excessive internal rotation of the femoral component is associated with undue lateral laxity in flexion and clinically gives rise to femorotibial instability,[24] while excessive internal rotation of the tibiofemoral joint is associated with patellar maltracking and patellofemoral complications including subluxation and dislocation.[25]

It is the practice in my unit for TKRs which come to revision to have the alignment of the failed components determined using the Perth CT Protocol.[20] It has been shown that when the failures were subdivided into premature, with mechanical failure in less than ten years, and expected, with mechanical failure after ten years or more, there were only two alignment parameters which differed significantly in the two groups, the most marked being mismatch of the femoral and tibial components in rotation (Table II).

Soft-tissue balance

Re-tensioning of soft tissues which occurs during TKR improves proprioception.[26] It is generally considered that knees which are unduly lax in any one direction fare badly. Instability is thought to be a result of combined errors in alignment and soft-tissue balance.[27] Flexion instability is sometimes blamed on unequal gaps in flexion and extension,[22] but no controlled studies have confirmed this. There is little evidence to show that there is a quantitative relationship between soft-tissue balance and outcome, partly because evaluation of 'balance' is totally subjective.

Joint line

As the joint line is moved distally relative to the patella, producing a patella alta, the patellofemoral contact forces increase by 3% per millimetre of displacement.[28] Patella infera, a raised joint line, is a cause of a reduced range of movement.[29] Errors in location of the joint line increase with each revision.[30,31] However, control of the position of the joint line is difficult since the only useful reference is the transepicondylar axis of the femur.[30,32,33] It is difficult to translate this into guidance at surgery, without computer assistance. The relationship between the level of the joint line, patellofemoral pain and the range of movement requires further investigation.

Summary

It is clear that there are substantial and important gaps in our knowledge of alignment of a TKR. Alignment can be regarded as significant for both the initial function and the longevity of the prosthesis. Alignment and soft-tissue balance are inextricably linked and in the absence of injury may be different manifestations of the same reality. The concept of soft-tissue balance will not become clearer until ligament balance is expressed quantitatively and longitudinal outcome studies have been undertaken. It is not known how sensitive patients are to malalignment, and how much effort is needed to achieve perfect alignment.

Alignment is a multidimensional concept and it is appropriate to consider only the mechanical axis of the limb. The sagittal and axial alignment of the components will probably prove to be as, or more, important in achieving a satisfactory TKR. In the design and assessment of studies quoted, alignments need to be considered in relation to the reference axes used and the studies should be judged by the validity of these axes. At present, it appears that the mechanical axes should be preferred to the others.

In the early post-operative phase the primary manifestation of malalignment is instability. More subtle variations in outcome, such as pain, range of movement and overall function will require very large series to detect differences because so many other factors affect these parameters. The relationship between the longevity of the components and alignment will require studies which measure alignment in all its variables soon after the initial surgery and then give a follow-up of ten to 15 years.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References

1. **Pitto RP, Graydon AJ, Bradley L, et al.** Accuracy of a computer-assisted navigation system for total knee replacement. *J Bone Joint Surg [Br]* 2006;88-B:601-5.
2. **Jeffrey RS, Morris RW, Denham RA.** Coronal alignment after total knee replacement. *J Bone Joint Surg [Br]* 1991;73-B:709-14.
3. **Hanada H, Whiteside LA, Steiger J, Dyer P, Naito M.** Bone landmarks are more reliable than tensioned gaps in TKA component alignment. *Clin Orthop* 2007;462:137-42.
4. **Graves SE, Davidson D, Ingerson L, et al.** The Australian Orthopaedic Association National Joint Replacement Registry. *Med J Aust* 2004;180 (5 Suppl):31-4.
5. **Asano T, Akagi M, Nakamura T.** The functional flexion-extension axis of the knee corresponds to the surgical epicondylar axis: in vivo analysis using a biplanar image-matching technique. *J Arthroplasty* 2005;20:1060-7.
6. **Uehara K, Kadoya Y, Kobayashi A, Ohashi H, Yamano Y.** Bone anatomy and rotational alignment in total knee arthroplasty. *Clin Orthop* 2002;402:196-201.
7. **Luo CF.** Reference axes for reconstruction of the knee. *Knee* 2004;11:251-7.
8. **Luo CF, Zeng BF, Koshino T.** Transepicondylar line and condylar line as parameters for axial alignment in knee arthroplasty. *Knee* 2004;11:213-17.
9. **Bindelglass DF.** Rotational alignment of the tibial component in total knee arthroplasty. *Orthopedics* 2001;24:1049-51.
10. **Dalury DF.** Observations of the proximal tibia in total knee arthroplasty. *Clin Orthop* 2001;389:150-5.
11. **Incavo SJ, Coughlin KM, Pappas C, Beynnon BD.** Anatomic rotational relationships of the proximal tibia, distal femur, and patella: implications for rotational alignment in total knee arthroplasty. *J Arthroplasty* 2003;18:643-8.
12. **Tanaka K, Muratsu H, Mizuno K, et al.** Soft tissue balance measurement in anterior cruciate ligament-resected knee joint: cadaveric study as a model for cruciate-retaining total knee arthroplasty. *J Orthop Sci* 2007;12:149-53.
13. **Ensini A, Catani F, Leardini A, Romagnoli M, Giannini S.** Alignments and clinical results in conventional and navigated total knee arthroplasty. *Clin Orthop* 2007;457:156-62.
14. **Spencer JM, Chauhan SK, Sloan K, Taylor A, Beaver RJ.** Computer navigation versus conventional total knee replacement: no difference in functional results at two years. *J Bone Joint Surg [Br]* 2007;89-B:477-80.
15. **D'Lima DD, Chen PC, Colwell CW Jr.** Polyethylene contact stresses, articular congruity, and knee alignment. *Clin Orthop* 2001;392:232-8.
16. **D'Lima DD, Hermida JC, Chen PC, Colwell CW Jr.** Polyethylene wear and variations in knee kinematics. *Clin Orthop* 2001;392:124-30.

17. **Green GV, Berend KR, Berend ME, Glisson RR, Vail TP.** The effects of varus tibial alignment on proximal tibial surface strain in total knee arthroplasty: the posteromedial hot spot. *J Arthroplasty* 2002;17:1033-9.

18. **Werner FW, Ayers DC, Maltesky LP, Rullkoetter PJ.** The effect of valgus/varus malalignment on load distribution in total knee replacements. *J Biomech* 2005;38:349-55.

19. **Berend MR, Ritter MA, Meding JB, et al.** Tibial component failure mechanisms in total knee arthroplasty. *Clin Orthop* 2004;428:26-34.

20. **Chauhan SK, Clark GW, Lloyd S, et al.** Computer-assisted total knee replacement: a controlled cadaver study using a multi-parameter quantitative CT assessment of alignment (the Perth CT Protocol). *J Bone Joint Surg [Br]* 2004;86-B:818-23.

21. **Sikorski JM, Blythe MC.** Learning the vagaries of computer-assisted total knee replacement. *J Bone Joint Surg [Br]* 2005;87-B:903-10.

22. **Clarke HD, Scuderi GR.** Flexion instability in primary total knee replacement. *J Knee Surg* 2003;16:123-8.

23. **Sah AP, Scott RD, Iorio R.** Angled polyethylene insert exchange for sagittal tibial malalignment in total knee arthroplasty. *J Arthroplasty* 2008;23:141-4.

24. **Romero J, Stähelin T, Binkert C, et al.** The clinical consequences of flexion gap asymmetry in total knee arthroplasty. *J Arthroplasty* 2007;22:235-40.

25. **Berger RA, Crossett LS, Jacobs JJ, Rubash HE.** Malrotation causing patellofemoral complications after total knee arthroplasty. *Clin Orthop* 1998;356:144-53.

26. **Swanik CB, Lephart SM, Rubash HE.** Proprioceptions, kinesthesia, and balance after total knee arthroplasty with cruciate-retaining and posterior stabilized prostheses. *J Bone Joint Surg [Am]* 2004;86-A:328-34.

27. **Clarke HD, Scott WN.** Knee: axial instability. *Orthop Clin North Am* 2001;32:627-37.

28. **Singerman R, Davy DT, Goldberg VM.** Effects of patella alta and patella infera on patellofemoral contact forces. *J Biomech* 1994;27:1059-65.

29. **Gandhi R, de Beer J, Leone J, et al.** Predictive risk factors for stiff knees in total knee arthroplasty. *J Arthroplasty* 2006;21:46-52.

30. **Laskin RS.** Joint line position restoration during revision total knee replacement. *Clin Orthop* 2002;404:169-71.

31. **Partington PF, Sawhney J, Rorabeck CH, Barrack RL, Moore J.** Joint line restoration after revision total knee arthroplasty. *Clin Orthop* 1999;367:165-71.

32. **Griffin FM, Math K, Scuderi GR, Insall JN, Poilvache PL.** Anatomy of the epicondyles of the distal femur: MRI analysis of normal knees. *J Arthroplasty* 2000;15:354-9.

33. **Mountney J, Karamfiles R, Breidahl W, Farrugia M, Sikorski JM.** The position of the joint line in relation to the trans-epicondylar axis of the knee: complementary radiologic and computer-based studies. *J Arthroplasty* 2007;22:1201-7.