Patellofemoral Biomechanics and Patellar Tracking

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An overview of…

Patellofemoral Biomechanics

Patellofemoral Imaging

Patellar Tracking

Most instructive for…

Fellows in musculoskeletal radiology

Senior residents in radiology

Part I:
Patellofemoral Biomechanics

(It’s relevant, I promise!)

Function of the Patella

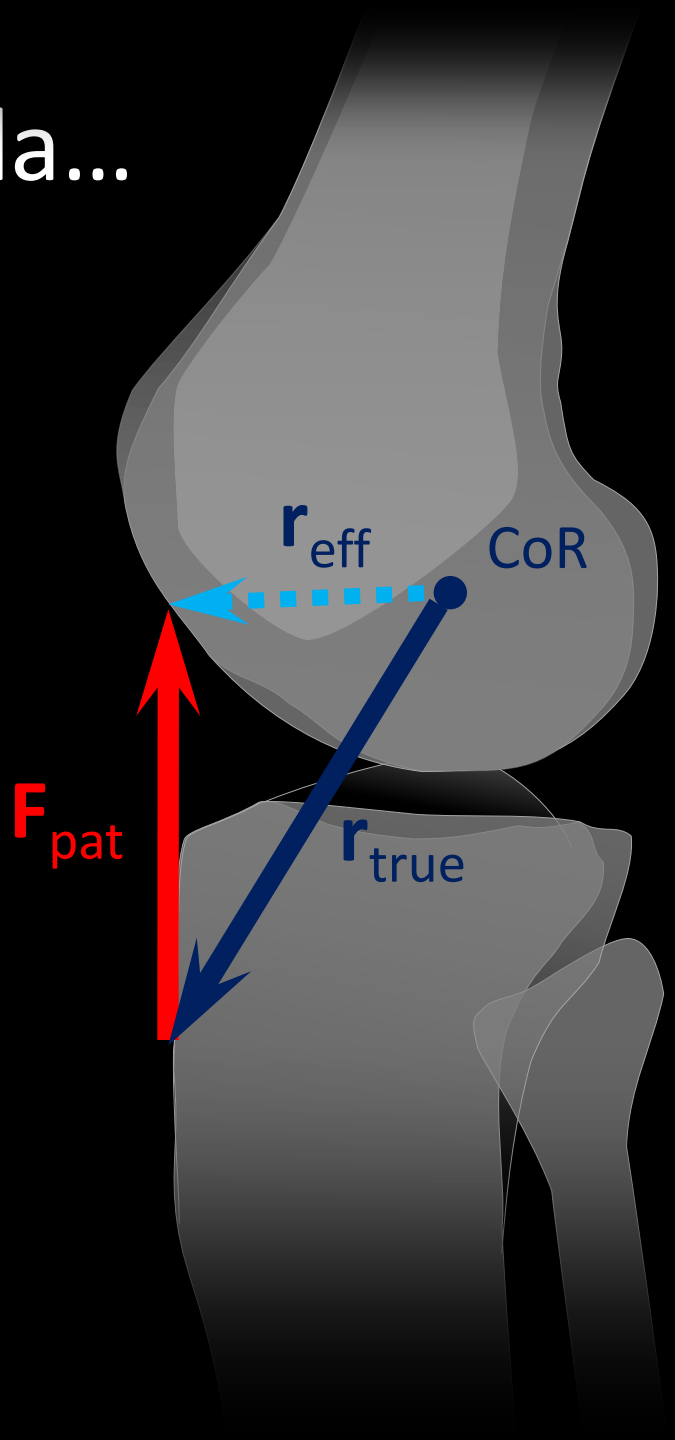
UCSD Jacobs Medical Center. From “Raising the Bar,” UCSD News, October 24, 2013.

If There Were No Patella…

$$\boldsymbol{\tau} = \mathbf{r}_{true} \times \mathbf{F}_{pat}$$

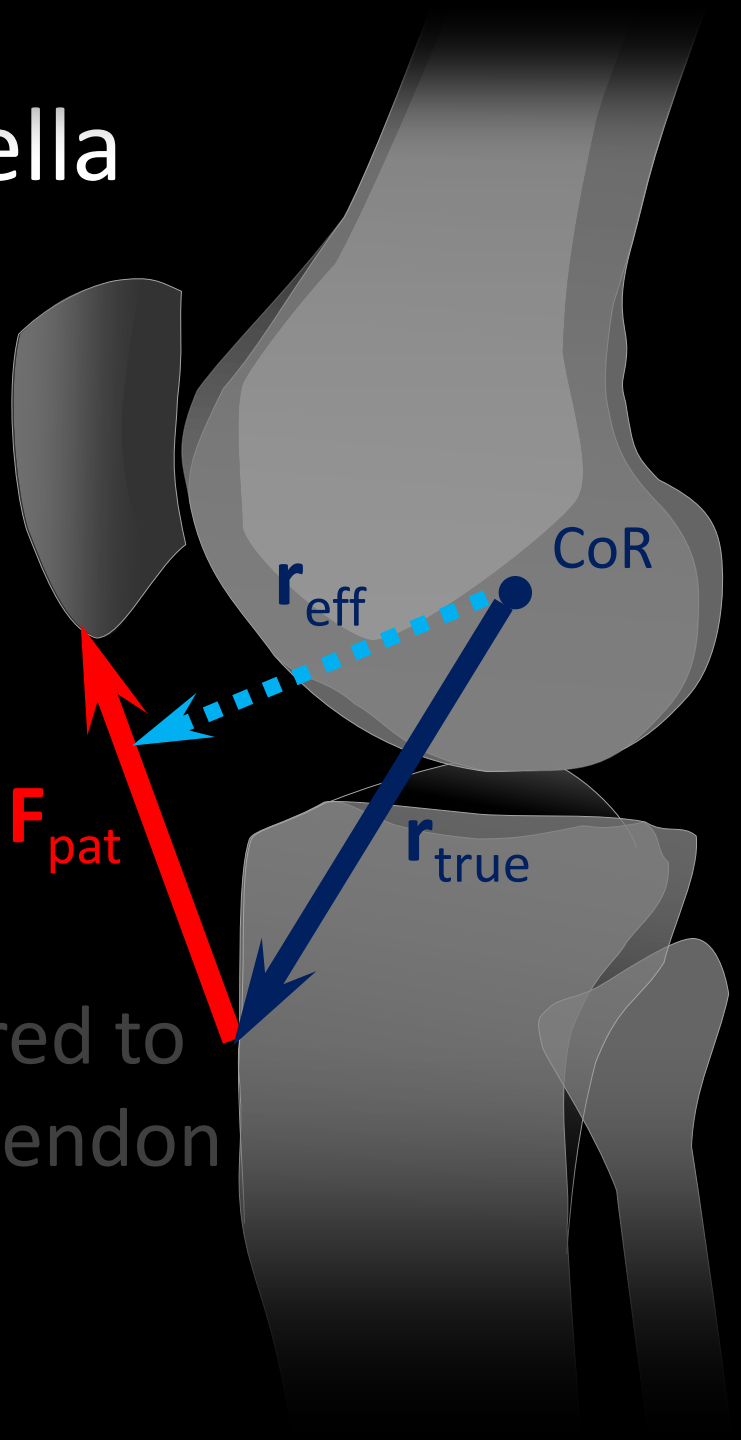
$$|\boldsymbol{\tau}| = |\mathbf{F}_{pat}|\,|\mathbf{r}_{true}| \sin\vartheta$$

$$= |\mathbf{F}_{pat}|\,|\mathbf{r}_{eff}|$$



Function of the Patella

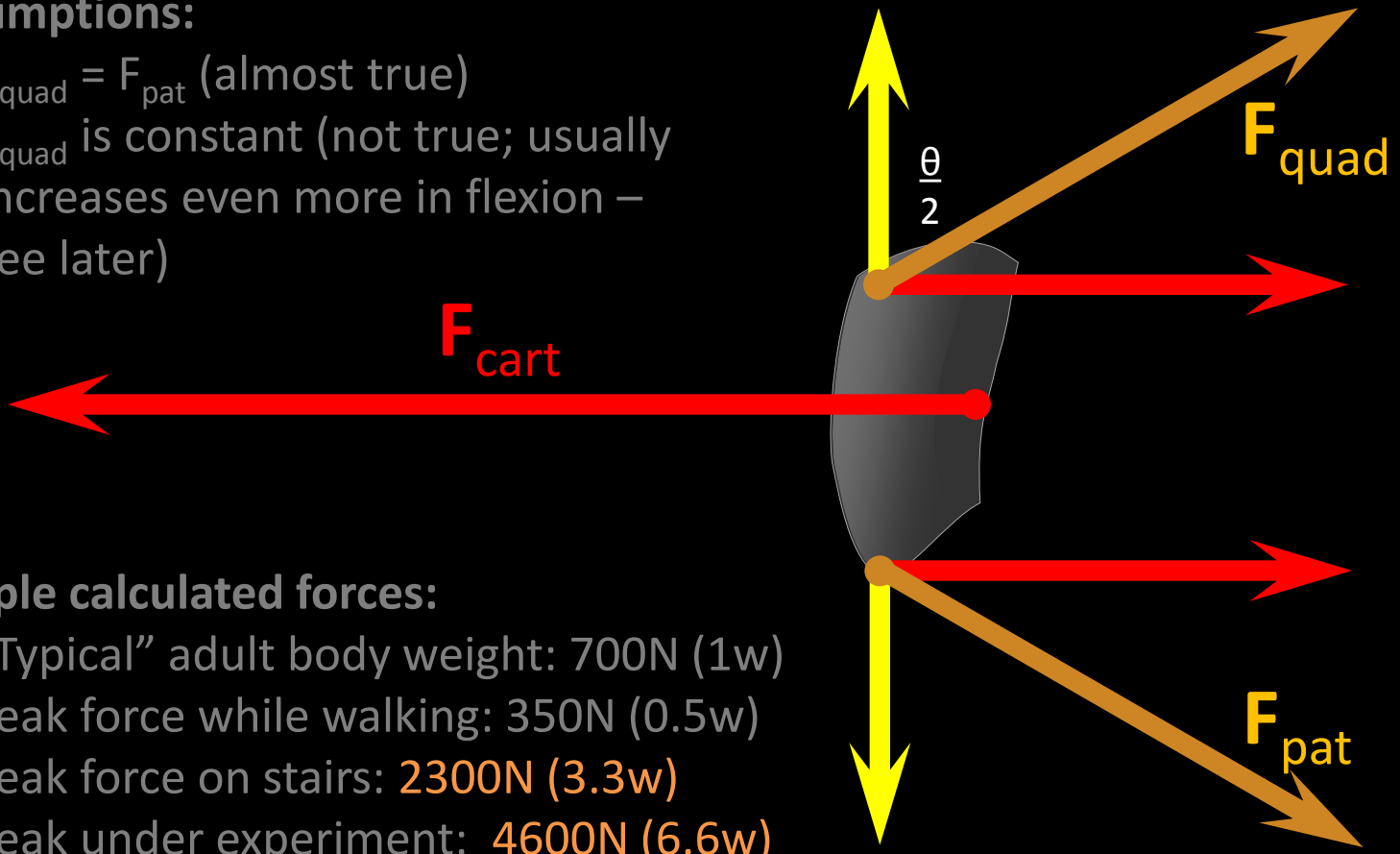
- Increases lever arm by up to 50%
- Combines muscle input from quadriceps
- Shields the anterior femoral condyles
- Reduces friction compared to continuous quadriceps tendon



Forces on the Patella

Assumptions:

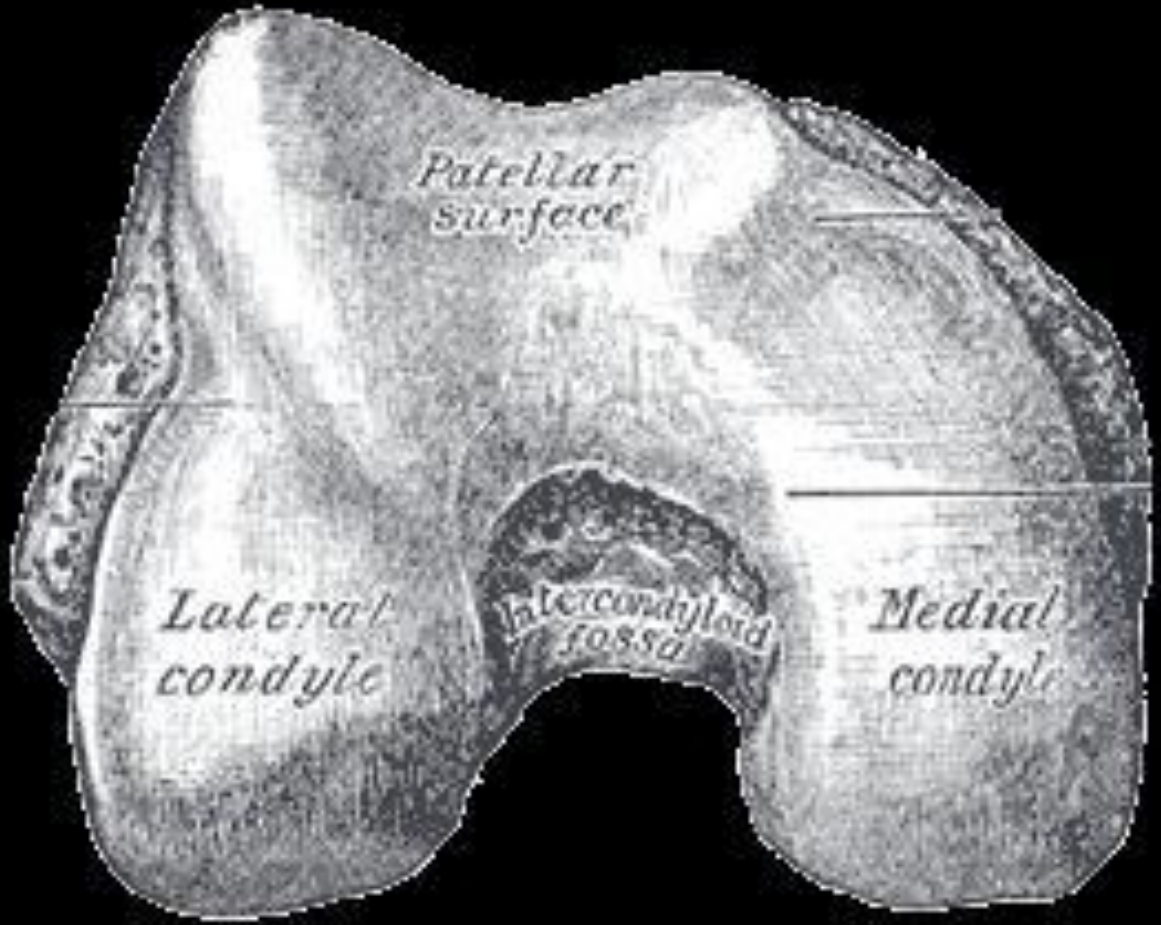
- $F_{quad} = F_{pat}$ (almost true)
- F_{quad} is constant (not true; usually increases even more in flexion – see later)



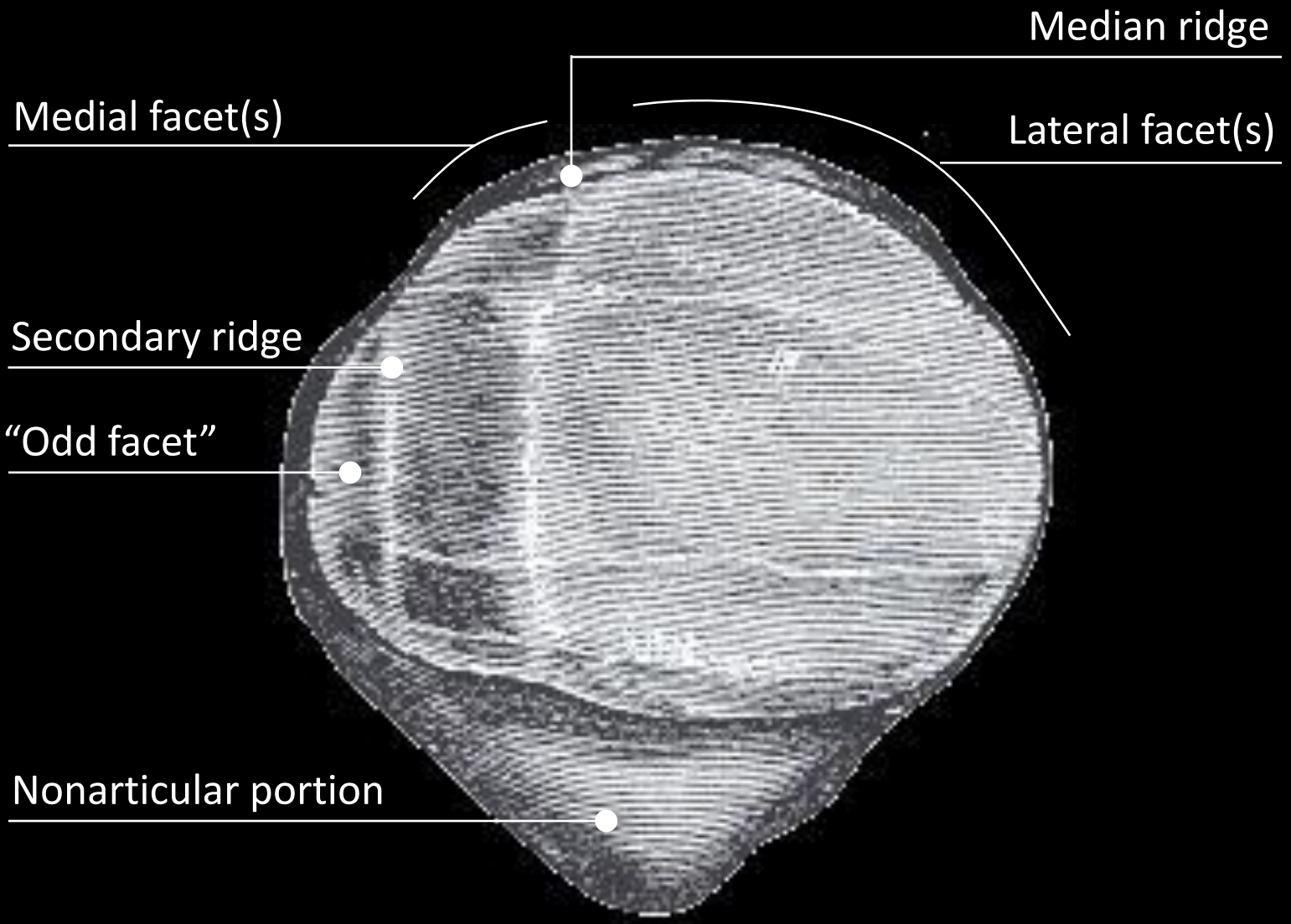
Sample calculated forces:

- "Typical" adult body weight: 700N (1w)
- Peak force while walking: 350N (0.5w)
- Peak force on stairs: 2300N (3.3w)
- Peak under experiment: 4600N (6.6w)

Huberti HH, Hayes WC. Patellofemoral contact pressures. The influence of q-angle and tendofemoral contact. J Bone Joint Surg Am. 1984 Jun;66(5):715-24.

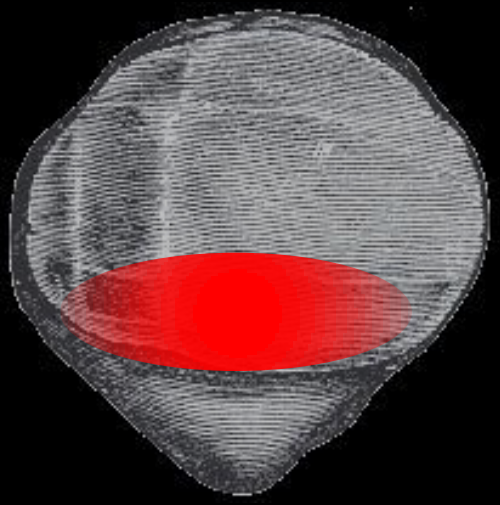


Gray's Anatomy (1918; public domain).



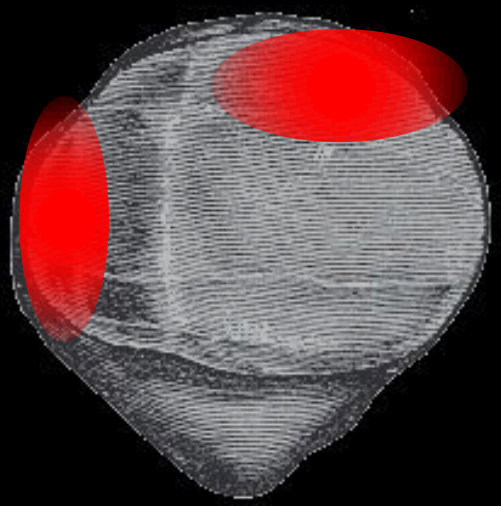
Gray’s Anatomy (1918; public domain).

Before 10°–20°,
sits laterally *above* trochlea

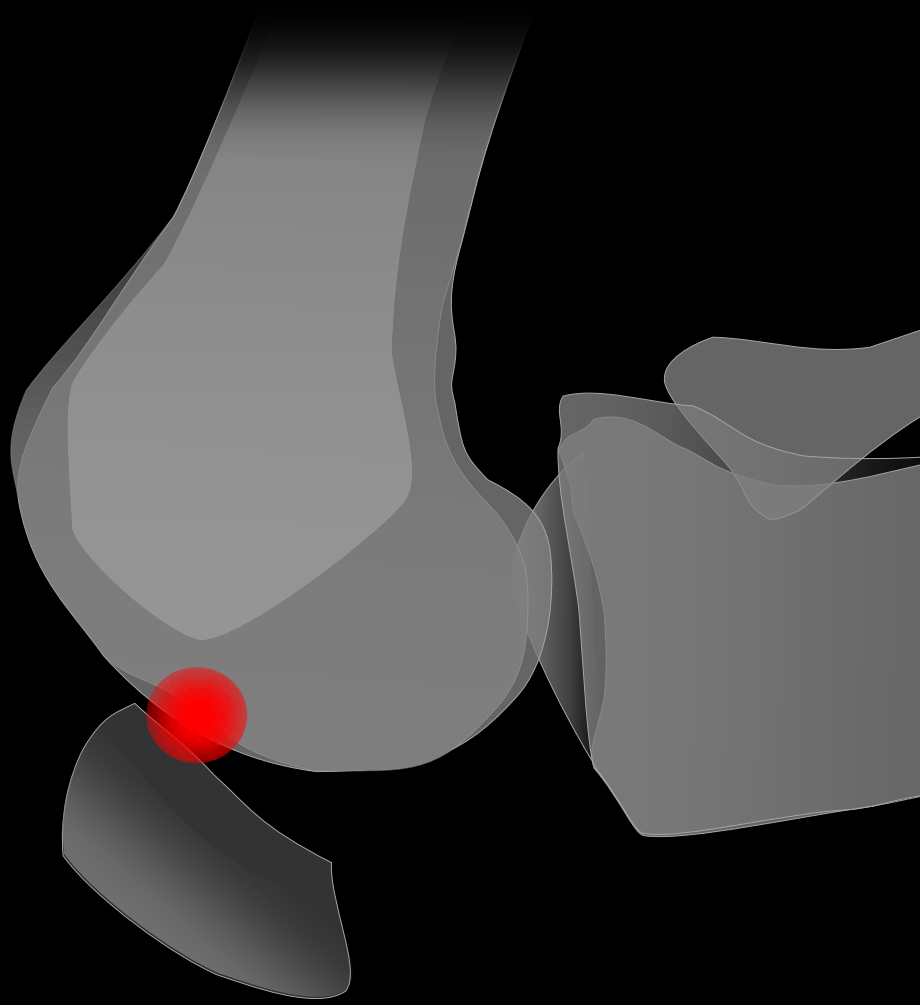


Contact area increases
with increasing forces.

Contact Areas
20°–90° of flexion

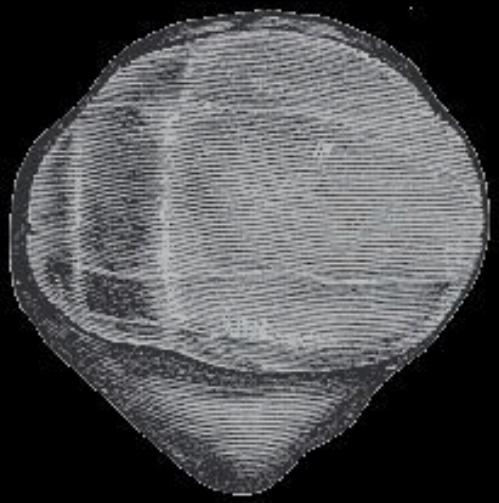


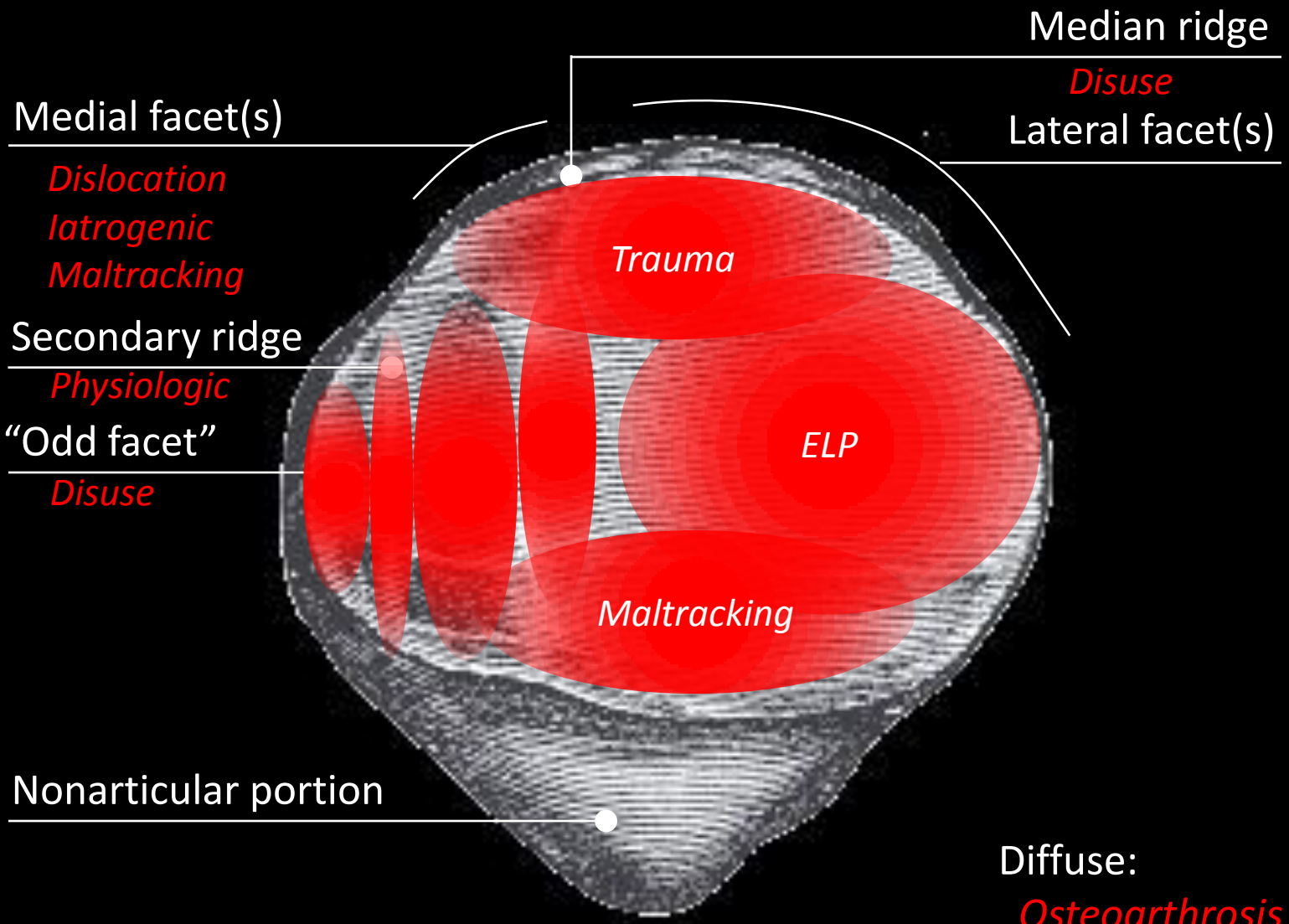
Contact crosses secondary ridge
Median ridge and medial facet free



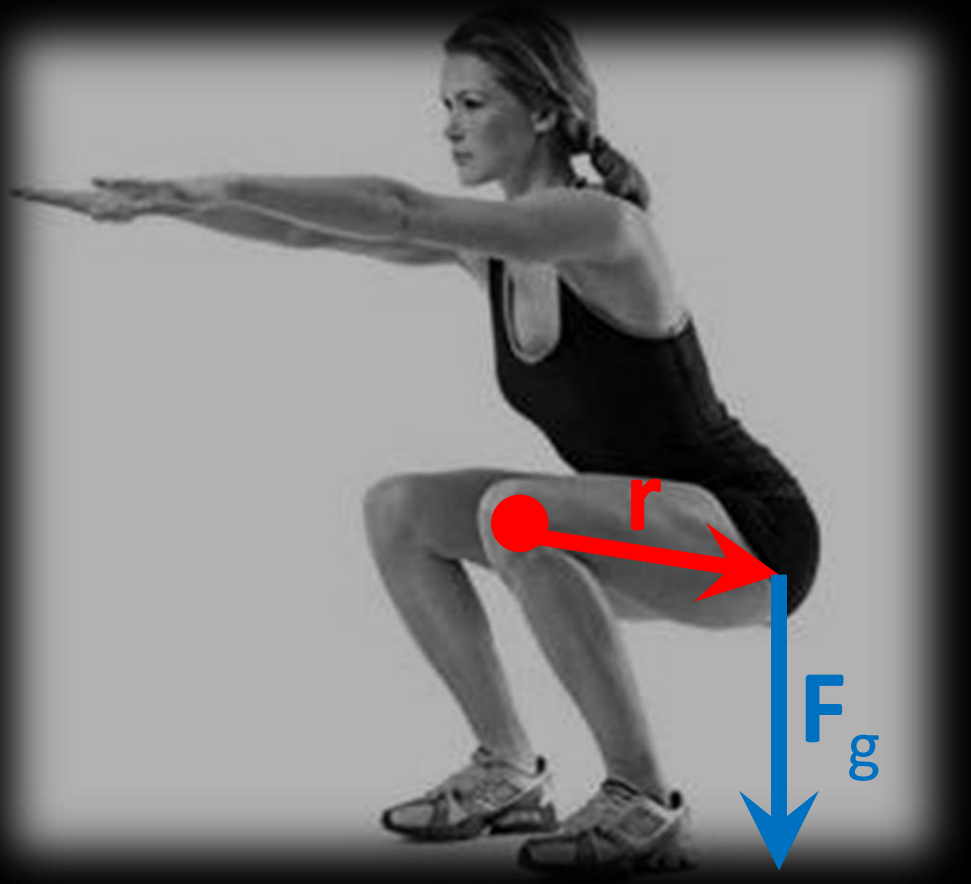
Contact Areas
135° of flexion

Central trochlea “falls away”
Patella enters femorotibial cartilage
Quadriceps t. also contacts, bears forces

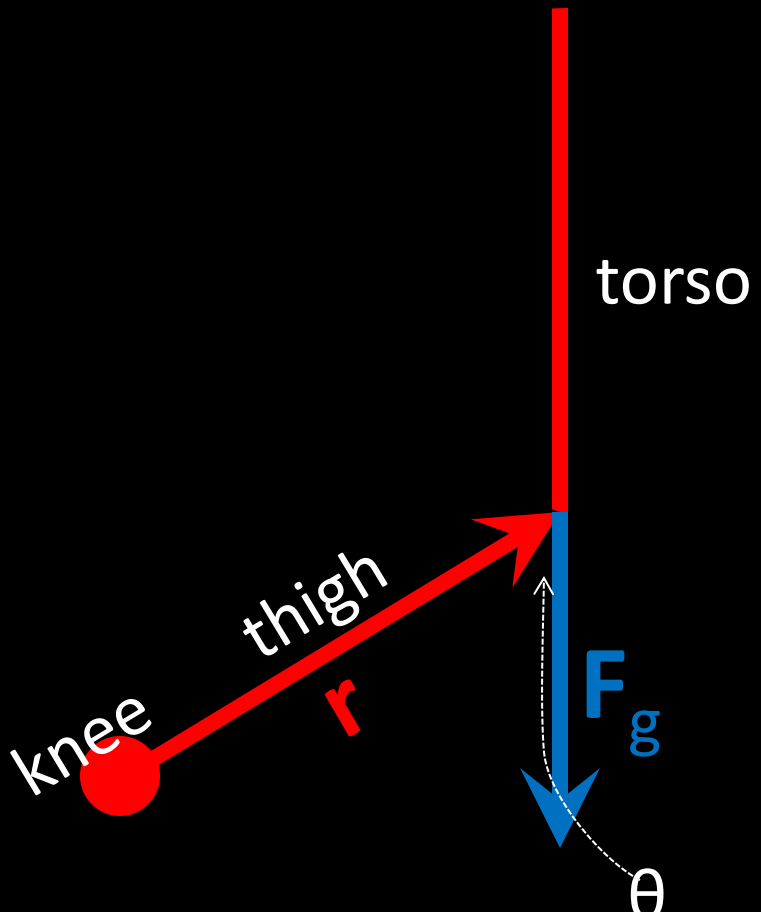


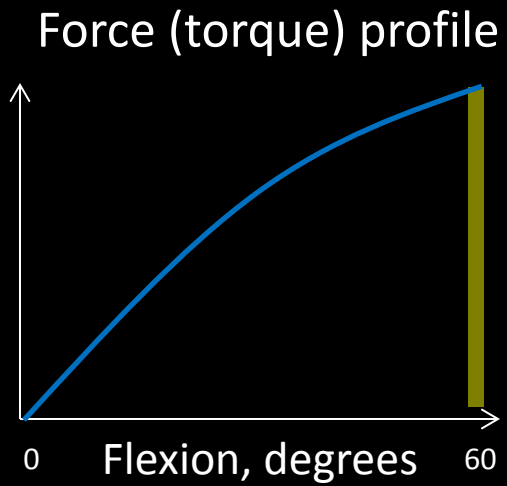

Median ridge
Disuse
Medial facet(s)
Lateral facet(s)
Dislocation
Iatrogenic
Maltracking
Trauma
Secondary ridge
Physiologic
ELP
“Odd facet”
Disuse
Maltracking
Nonarticular portion
Diffuse:
Osteoarthrosis

Physiologic Weightbearing (Squats)



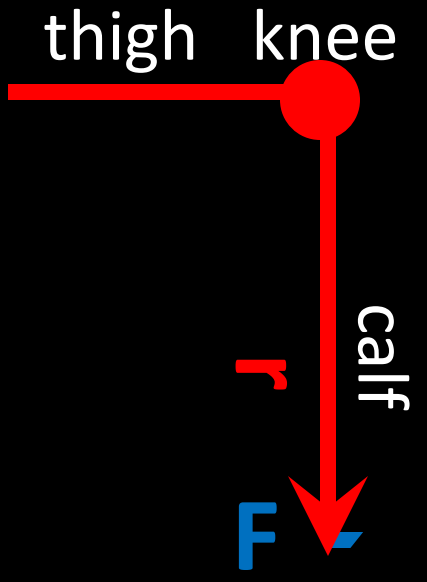
Physiologic Weightbearing (Squats)

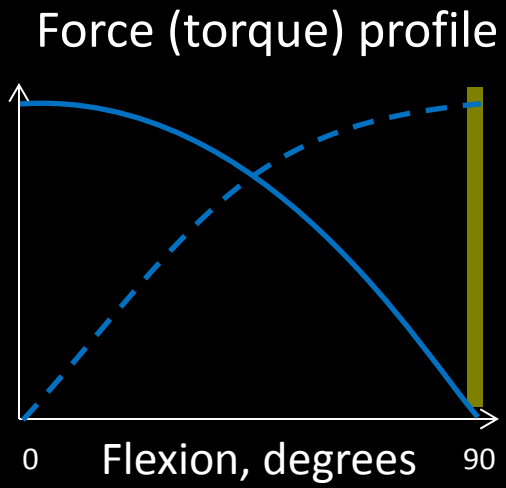




Leg Extension Machine

Leg Extension Machine





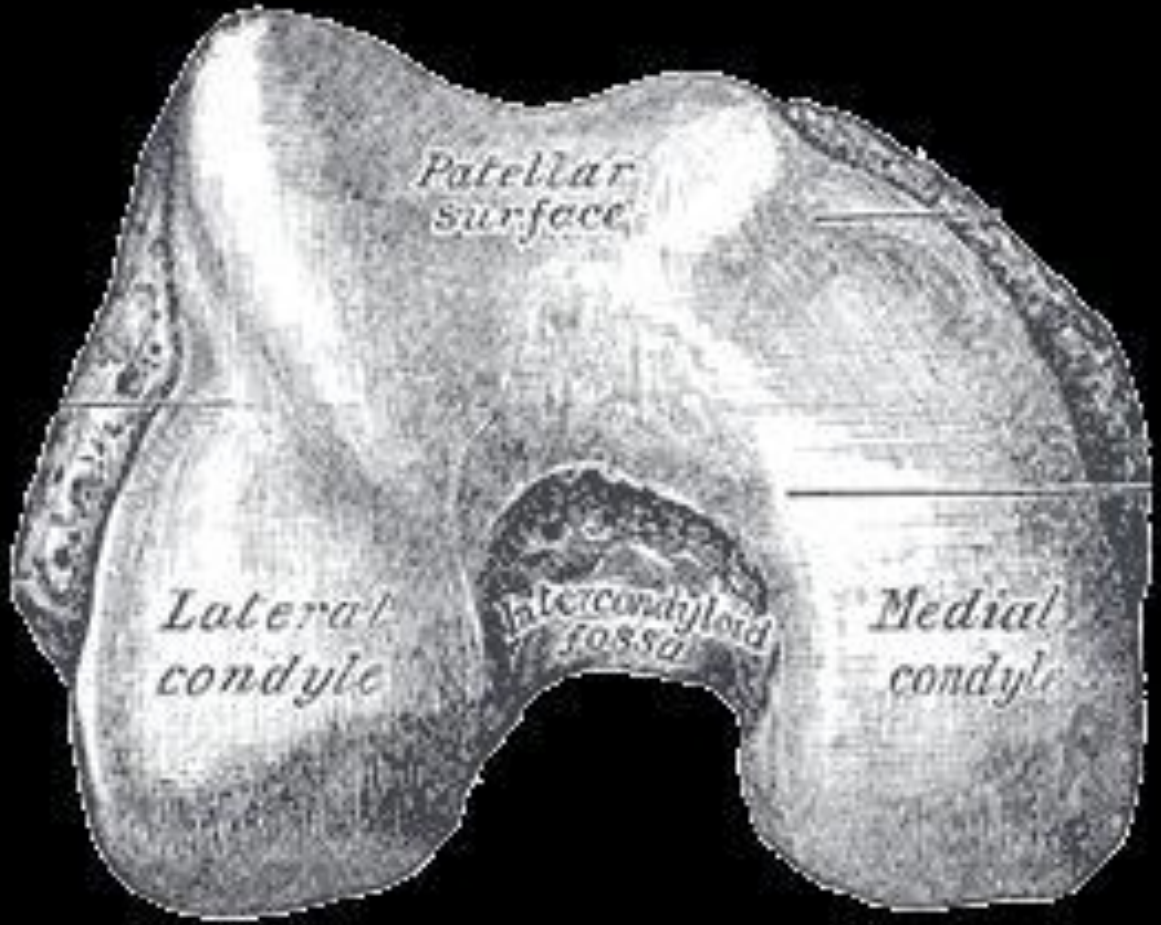
Biomechanics Takeaway Concepts

Normal patellofemoral tracking

- With minimal flexion, patella outside trochlea
  - Patella alta prolongs this phase
- With increasing flexion,
  - Trochlea progressively deepens
  - Patellar tracking usually improves

Hence, most useful view is early flexion (<30°)

Patellar cartilage forces increase with flexion



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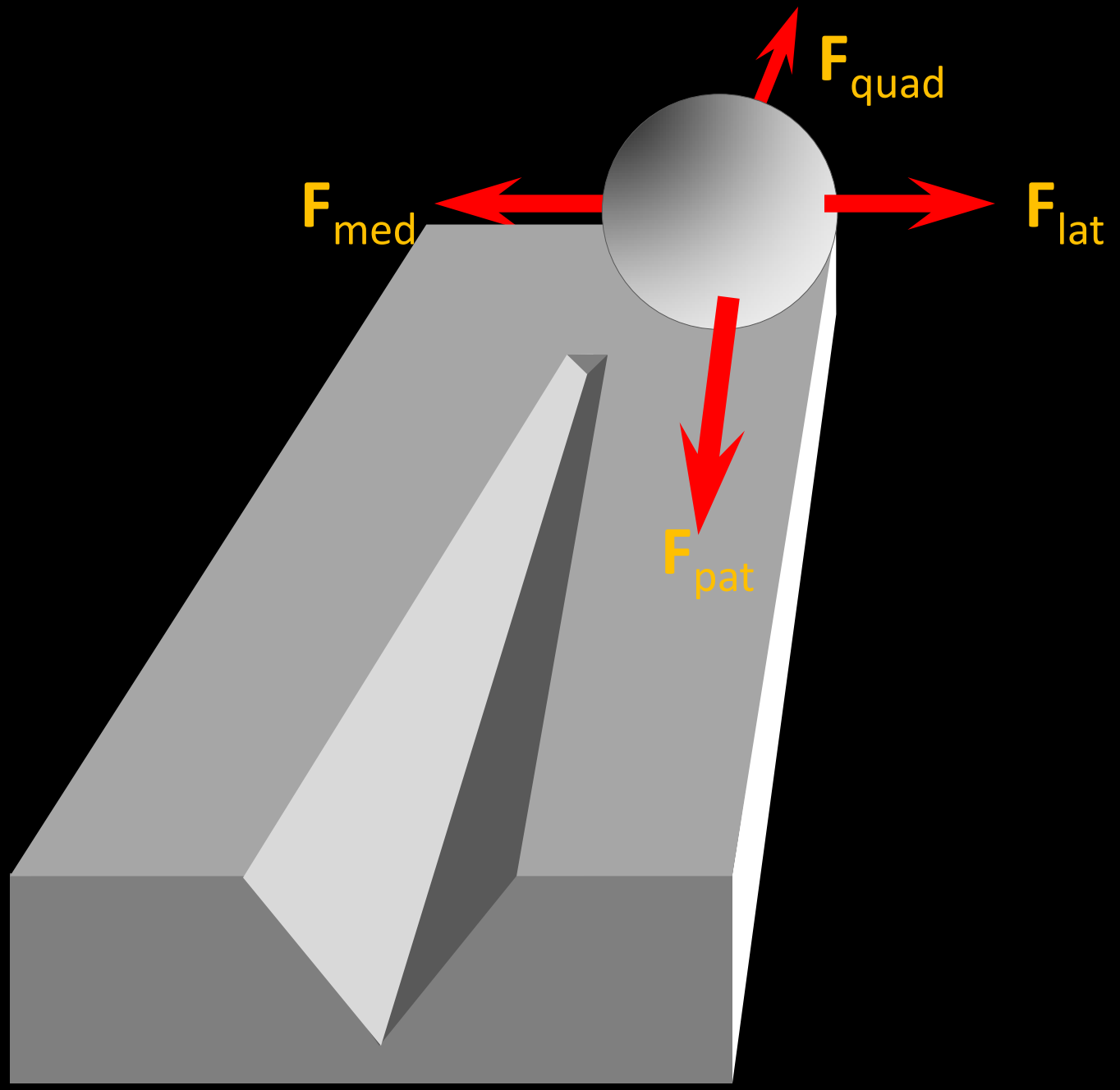

F quad
F med
F lat
F pat

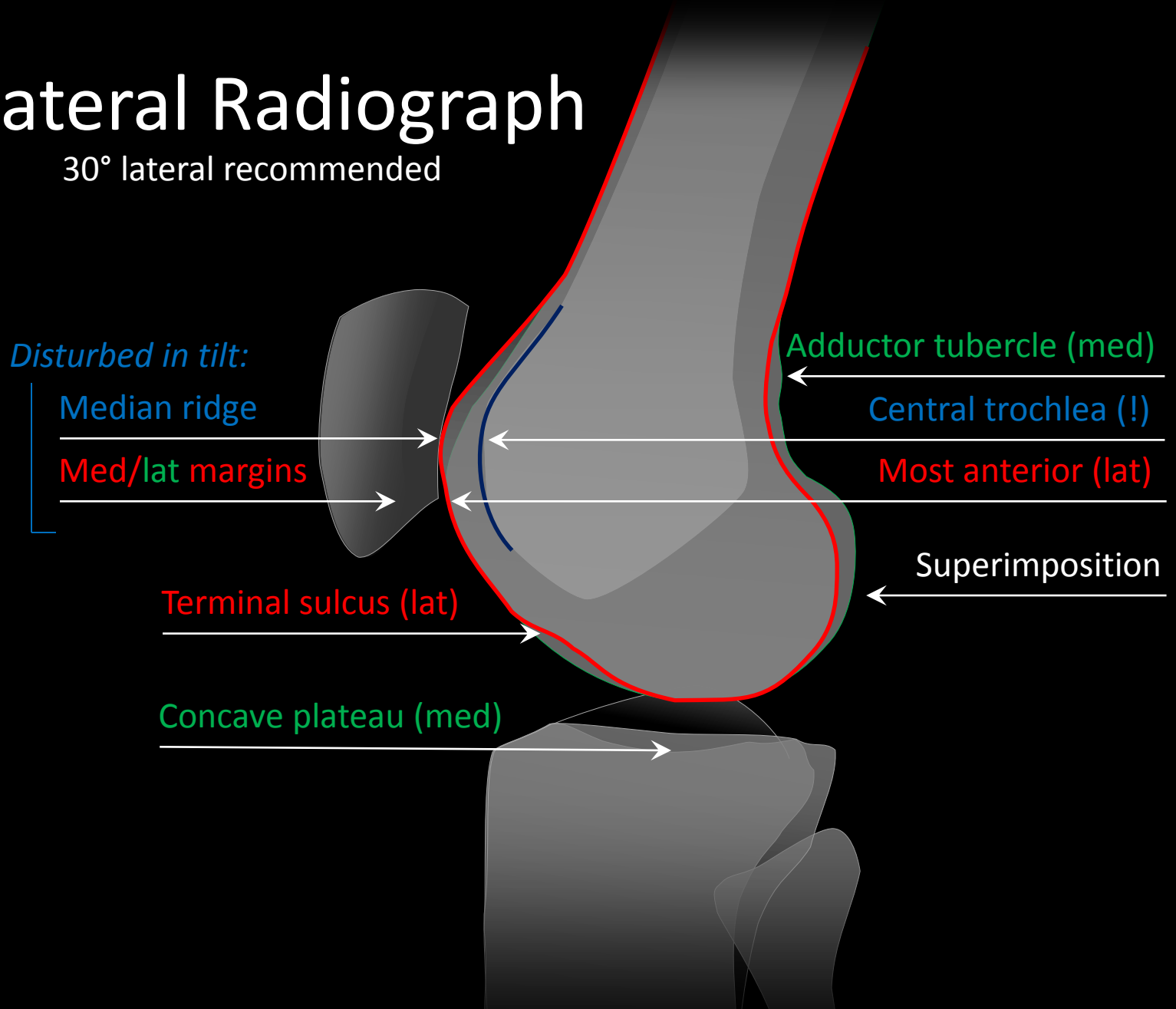
Part Ib:
Imaging Techniques

Imaging Challenges

- Patellofemoral relationship varies with
  - degree of flexion and
  - quadriceps activation (8-10mm proximally).
- Axial radiographs in early flexion are
  - technically difficult and
  - subject to distortion.
- Cross-sectional slices cannot be simply substituted for a radiograph, because of
  - Superimposition of sections, parallax, and
  - Inclusion of cartilage or other soft tissues.

Lateral Radiograph

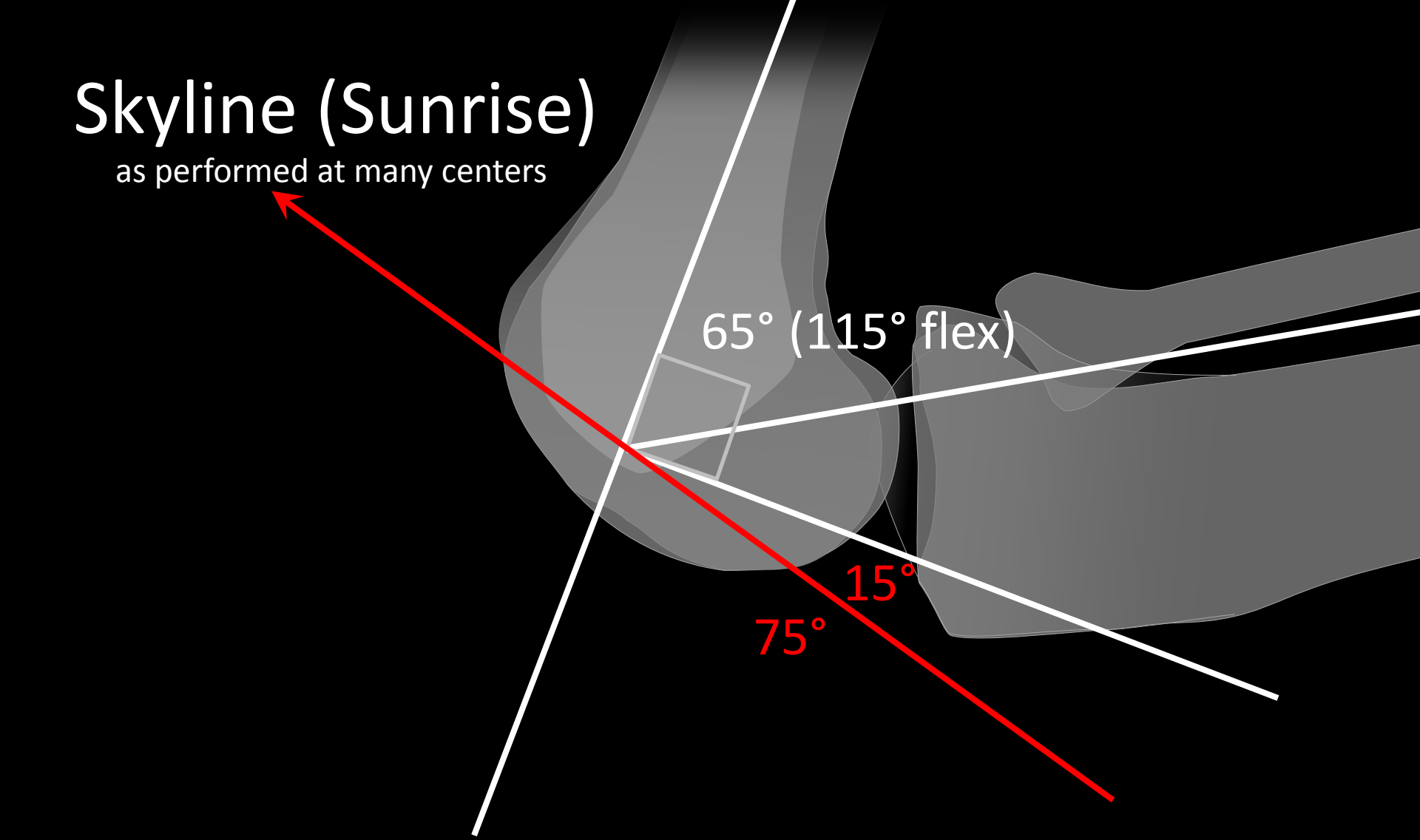
30° lateral recommended



Malghem J, Maldague B. Le profil du genou. Anatomie radiologique différentielle des surfaces articulaires. J Radiol. 1986 Oct;67(10):725-35.

Skyline (Sunrise)

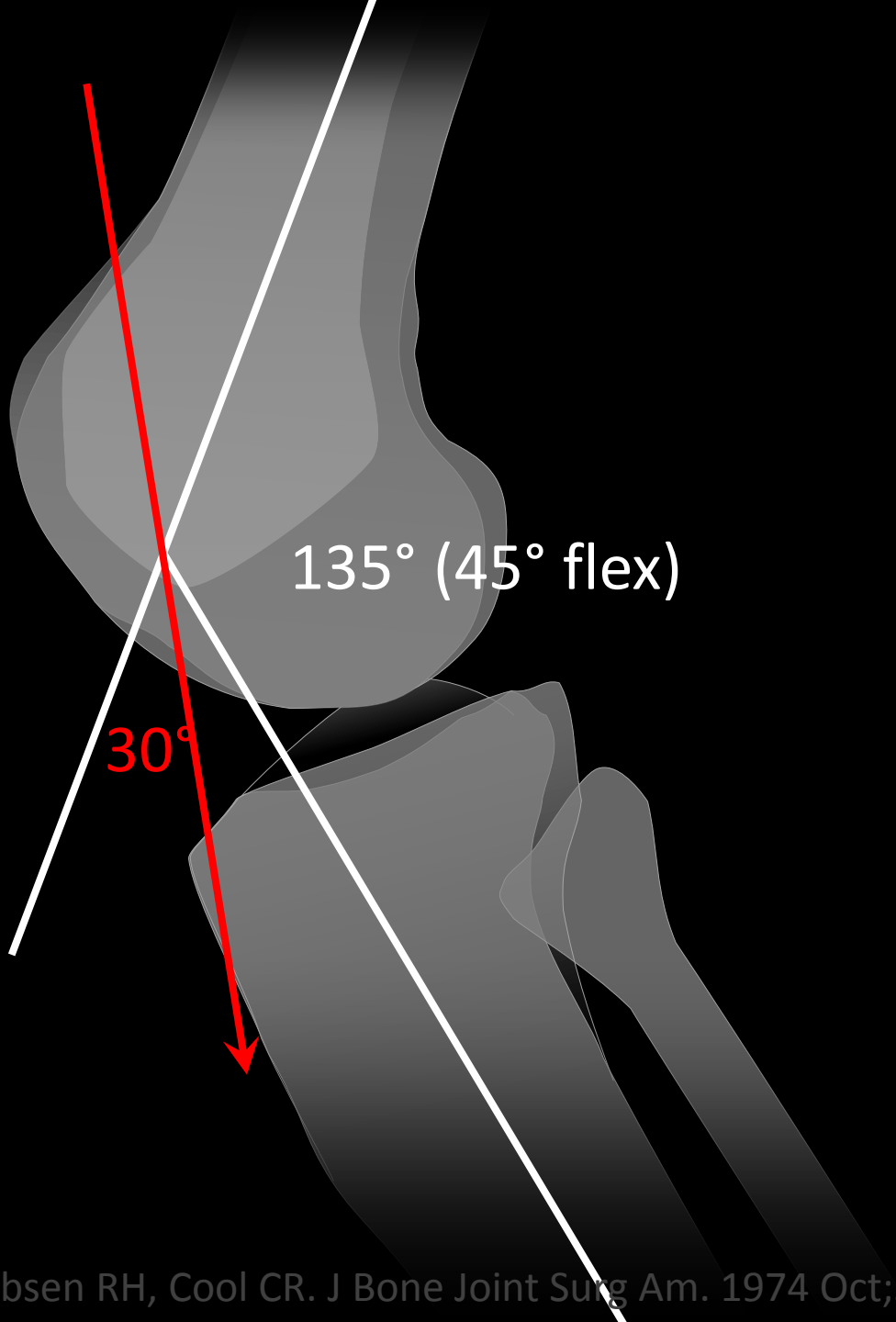
as performed at many centers



Frank ED. Merrill's Atlas of Radiographic Positioning and Procedures. 11th ed. Mosby, 2007.

Merchant

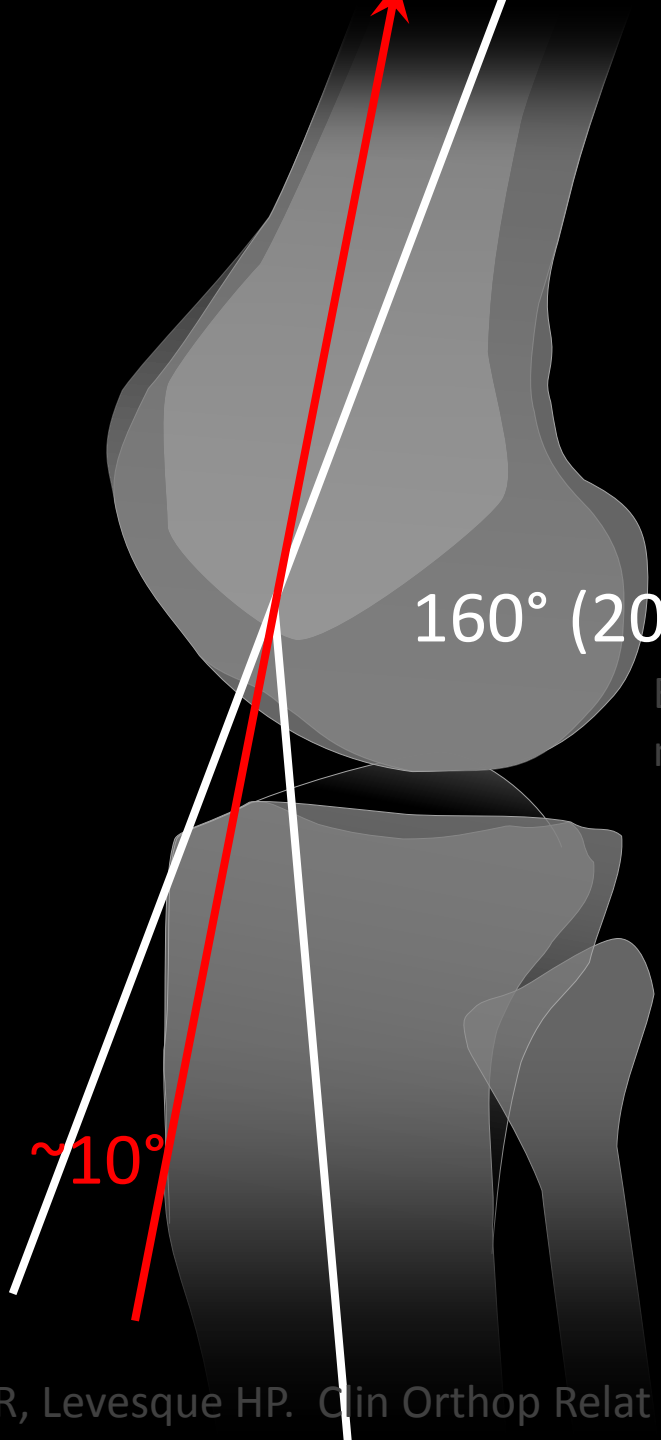
1974



Merchant AC, Mercer RL, Jacobsen RH, Cool CR. J Bone Joint Surg Am. 1974 Oct;56(7):1391-6.

Laurin

1979



Essentially impossible to extend more on axial radiograph.

Laurin CA, Dussault R, Levesque HP. Clin Orthop Relat Res. 1979 Oct;(144):16-26.

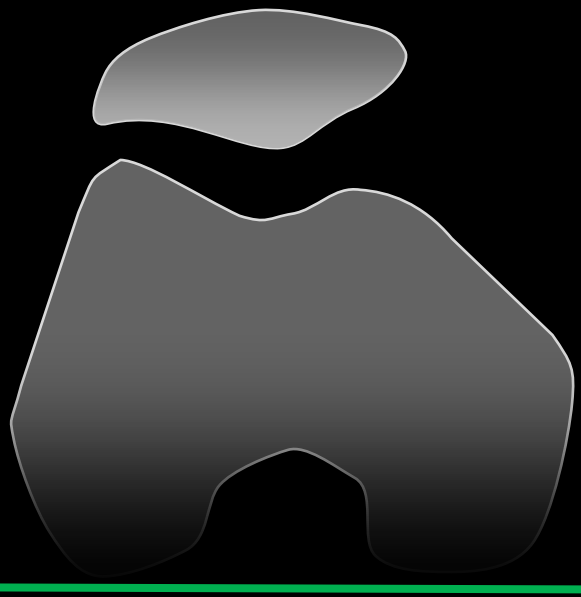
Recommendations for Radiography

- Frontal
- Lateral (precise)
  - 0° weightbearing
  - 30° or 45° weightbearing
- Axial (30° and/or 45°)

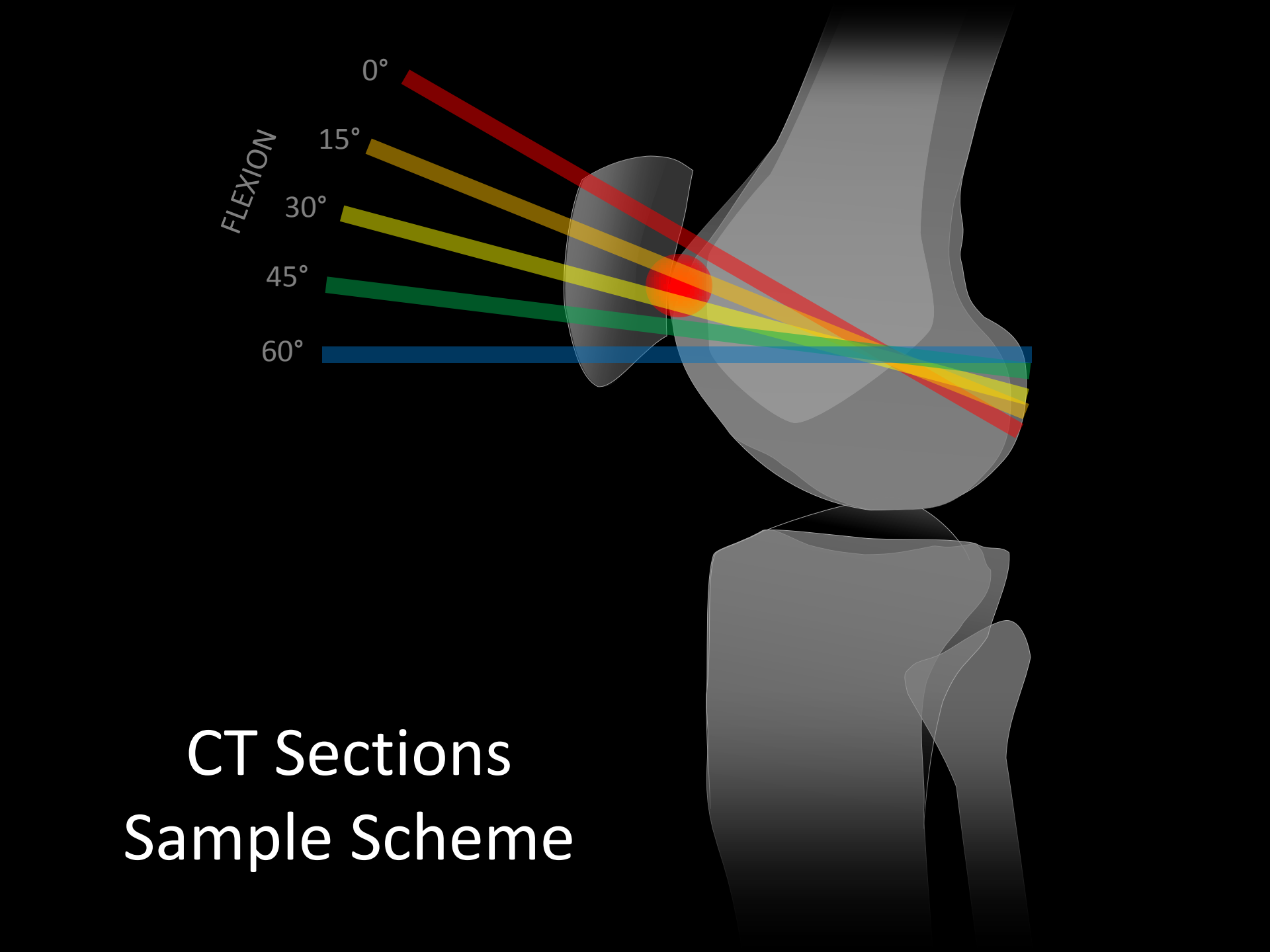
Fulkerson JP. Disorders of the Patellofemoral Joint. 4th ed. Phila., PA: LW&W, 2004.

Recommendations for CT

- Normal standing alignment
- Most important slice: midpatellar
- Reference line: posterior condyles
- At multiple flexion angles
  - 0°
  - 15° (early engagement)
  - 30°, 45° (midrange)
  - 60° (near-maximal contact)

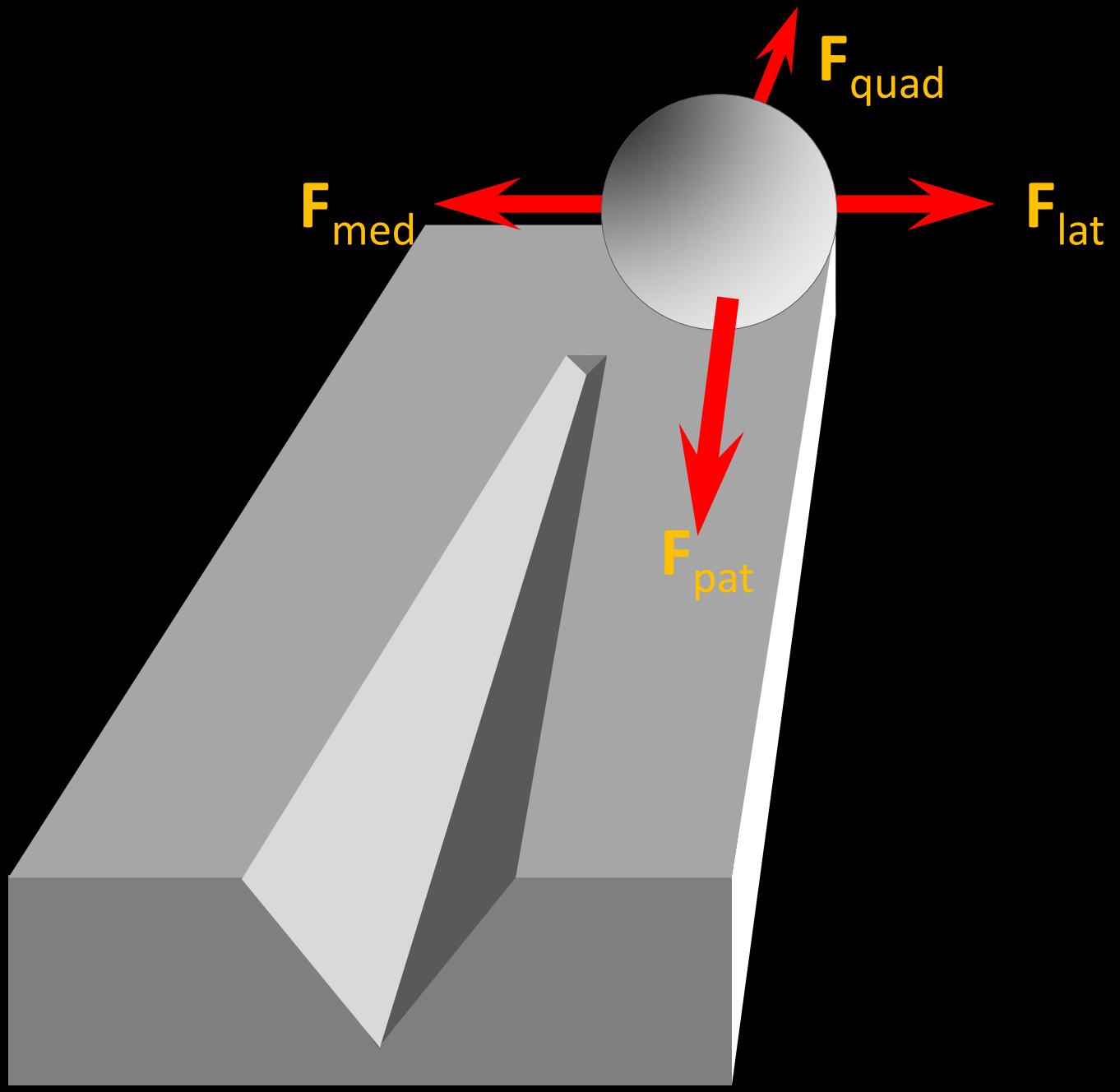


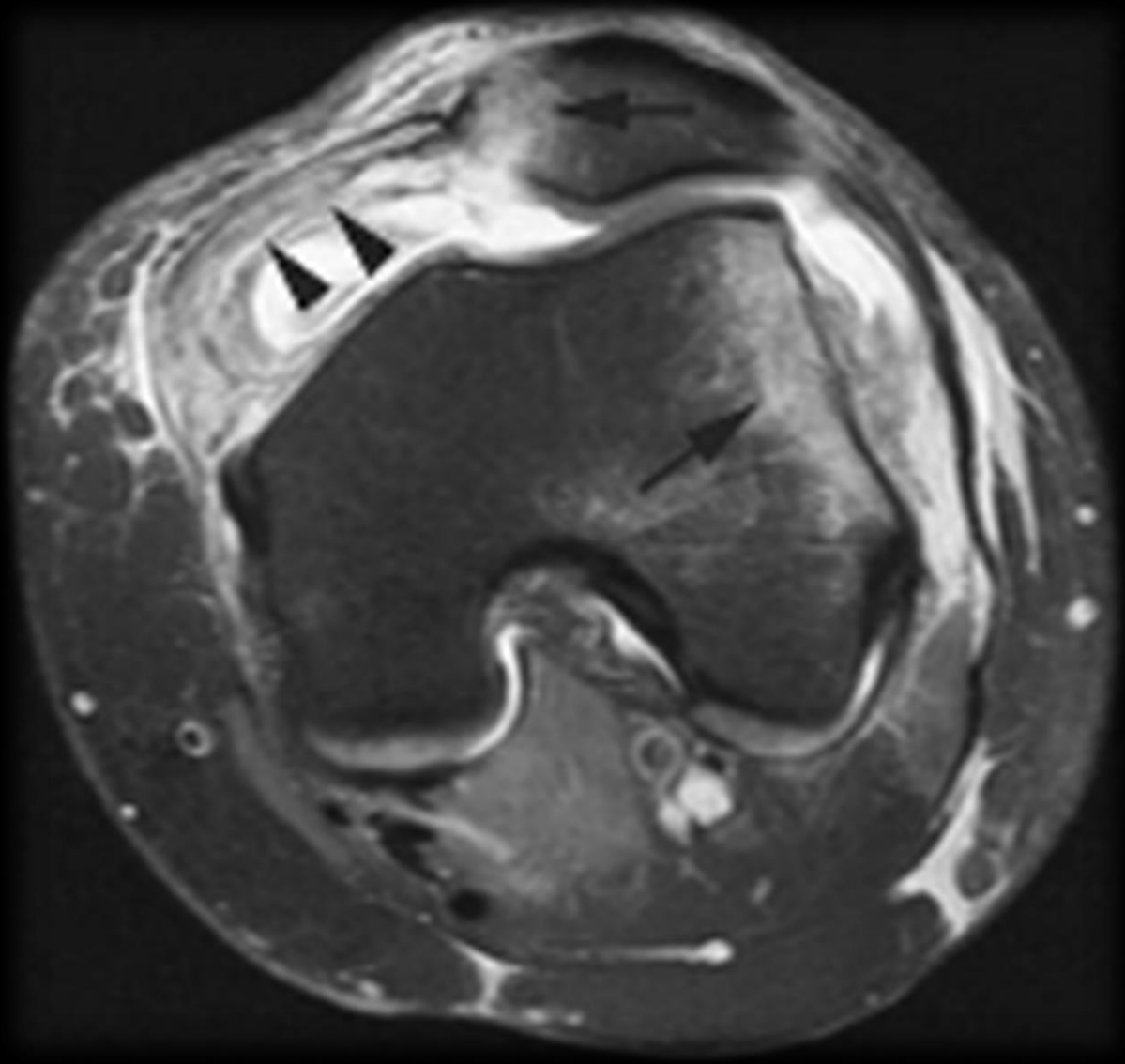
Fulkerson JP. Disorders of the Patellofemoral Joint. 4th ed. Phila., PA: LW&W, 2004.



CT Sections
Sample Scheme

Part II:
Patellar Tracking


F quad
F med
F lat
F pat



The Lyon School of Knee Surgery

L’Ecole lyonnaise de chirurgie du genou

le menu à la carte

de l'école lyonnaise de chirurgie du genou*
fondée en 1969

Plats principaux

Patella alta · TT distalization

Excessive TT-TG (Q) · TT medialization

Lateral patellar tilt · Lateral release

Trochlear dysplasia · Trochleoplasty

Desserts (autres sujets)

Lateral subluxation · Medial imbrication

*avec des modifications

Dejour H et al. Knee Surg Sports Traumatol Arthrosc. 1994;2(1):19-26.

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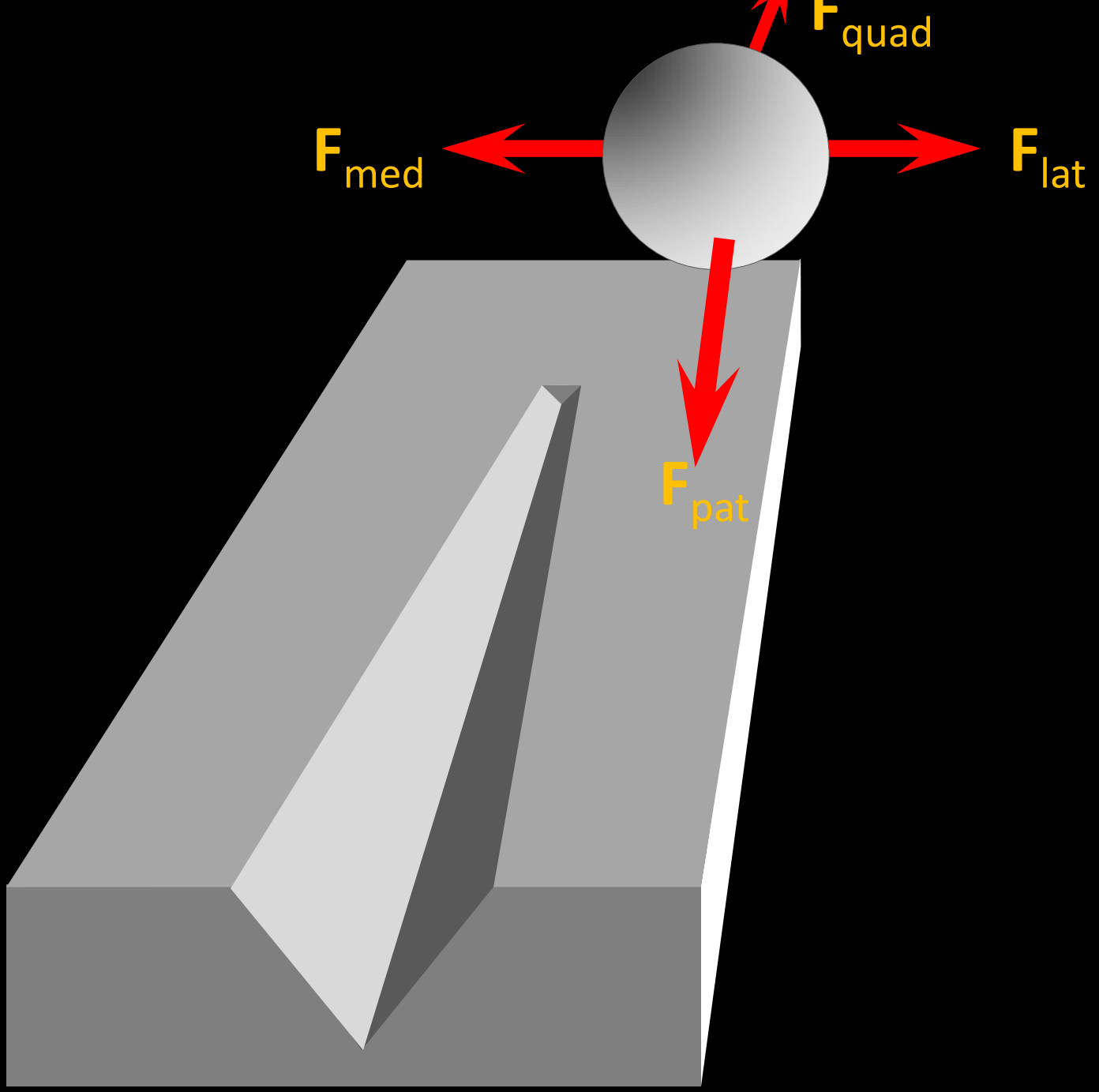
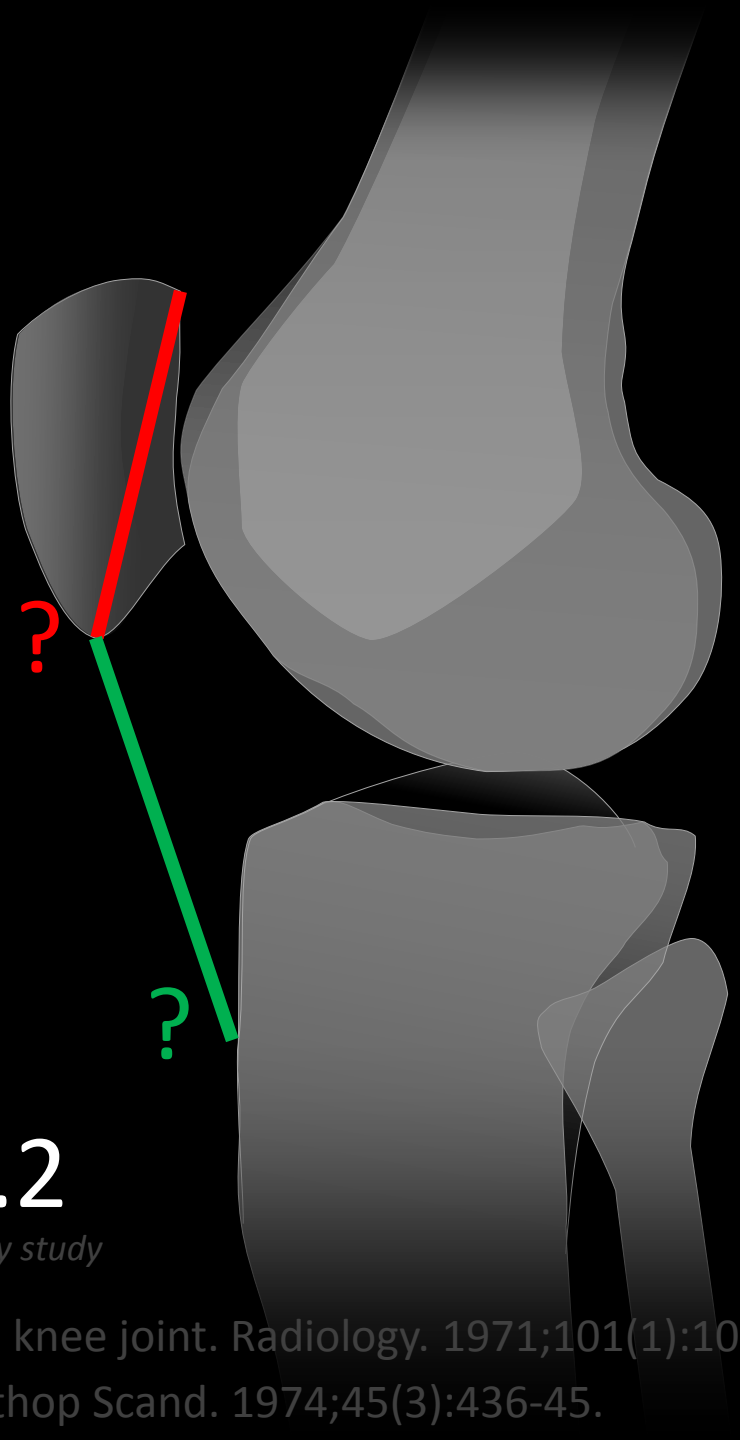

F quad
F med
F lat
F pat

Insall–Salvati

1971



$A/B \leq 1.2$

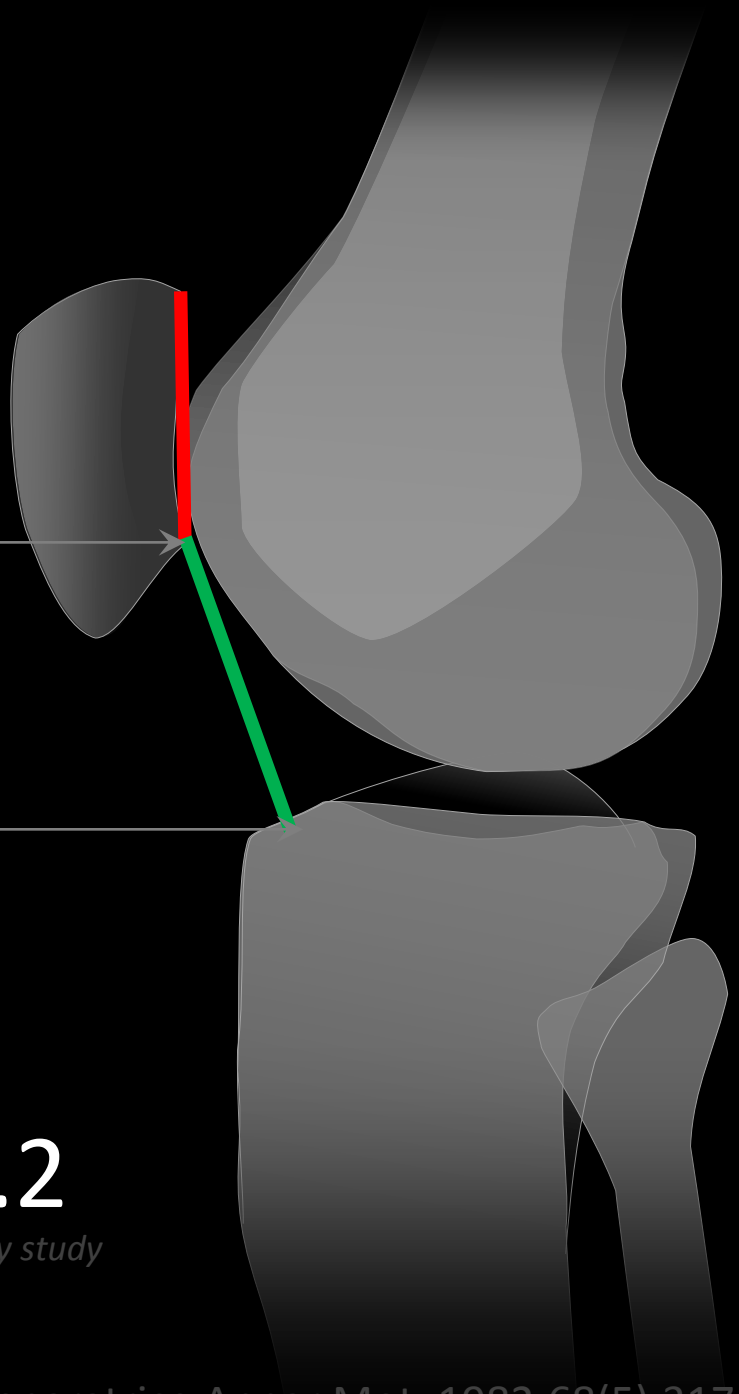
**cutoffs vary slightly by study*

Insall J, Salvati E. Patella position in the normal knee joint. Radiology. 1971;101(1):101-4.

Jacobsen K, Bertheussen K. Acta Orthop Scand. 1974;45(3):436-45.

Caton–Deschamps

1977, 1981; official index of Lyon School



Deschamps (1981):
Inferior pole of articular surface

Caton (1977):
Anterior border of tibial plateau

(with deCarvalho variant)

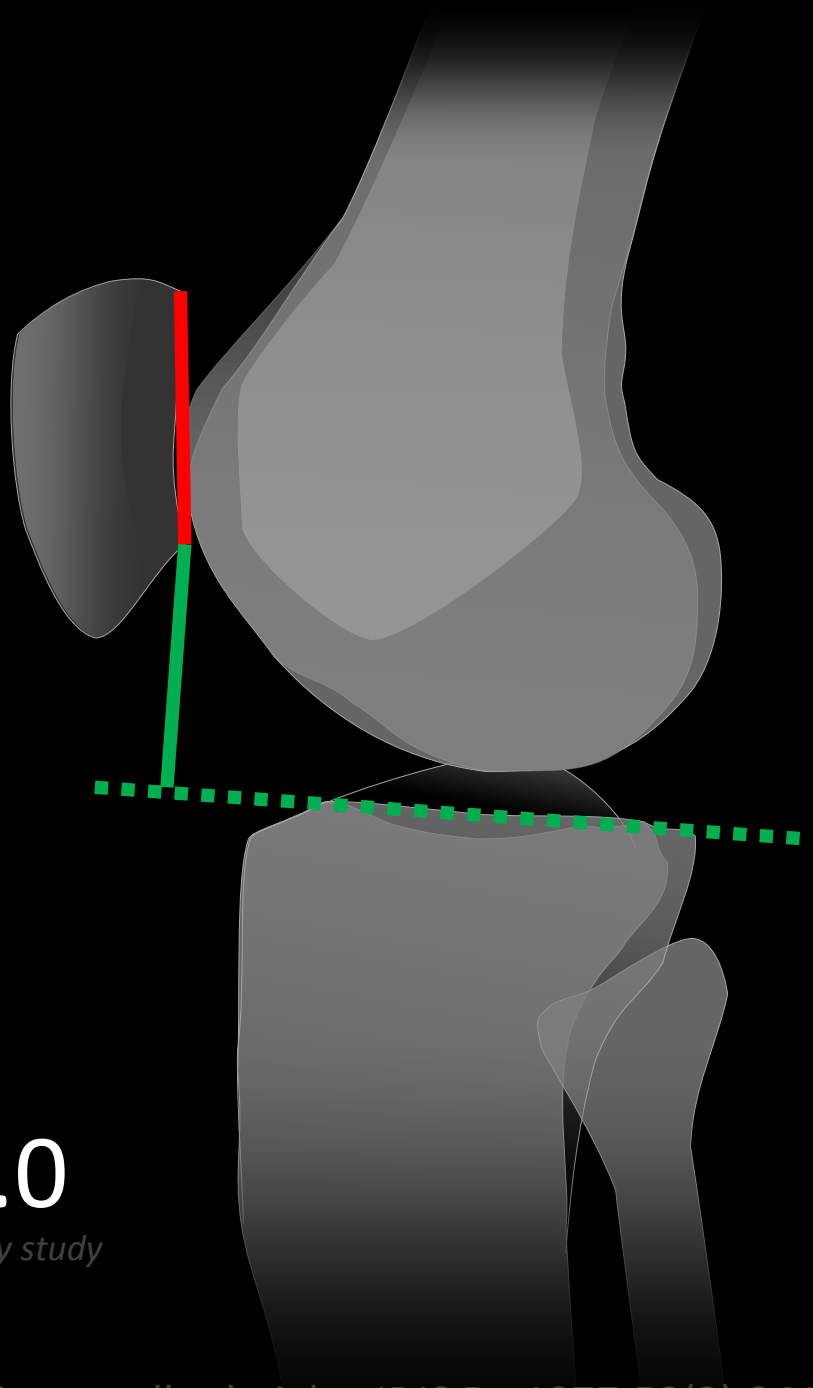
$$A/B \leq 1.2$$

**cutoffs vary slightly by study*

Caton J, Deschamps G et al. Rev Chir Orthop Reparatrice Appar Mot. 1982;68(5):317-25.

Blackburne–Peel

1977



$A/B \leq 1.0$

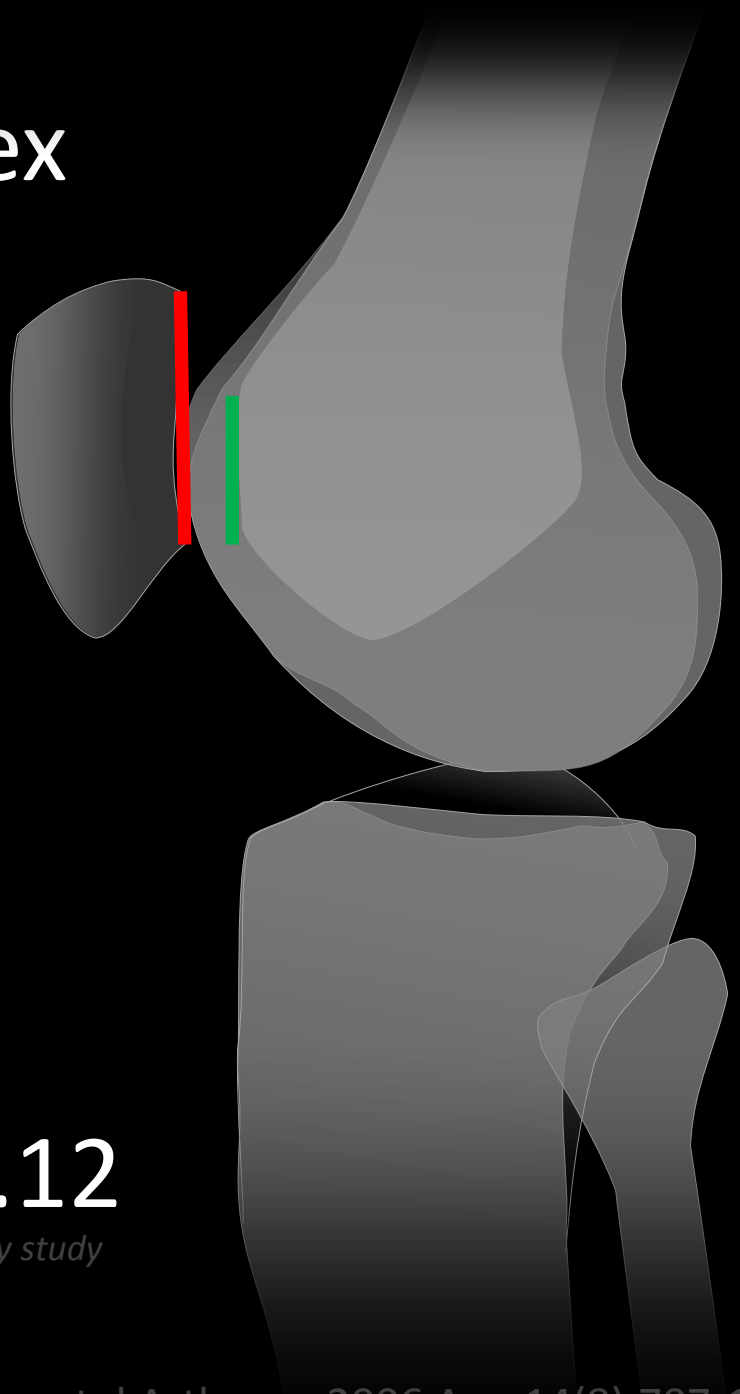
**cutoffs vary slightly by study*

Blackburne JS, Peel TE. A new method of measuring patellar height. JBJS Br. 1977;59(2):241-2.

Patellotrochlear Index

2006

- Direct measurement
- Requires visualization of cartilage (ie MRI).



$A/B \geq 0.12$

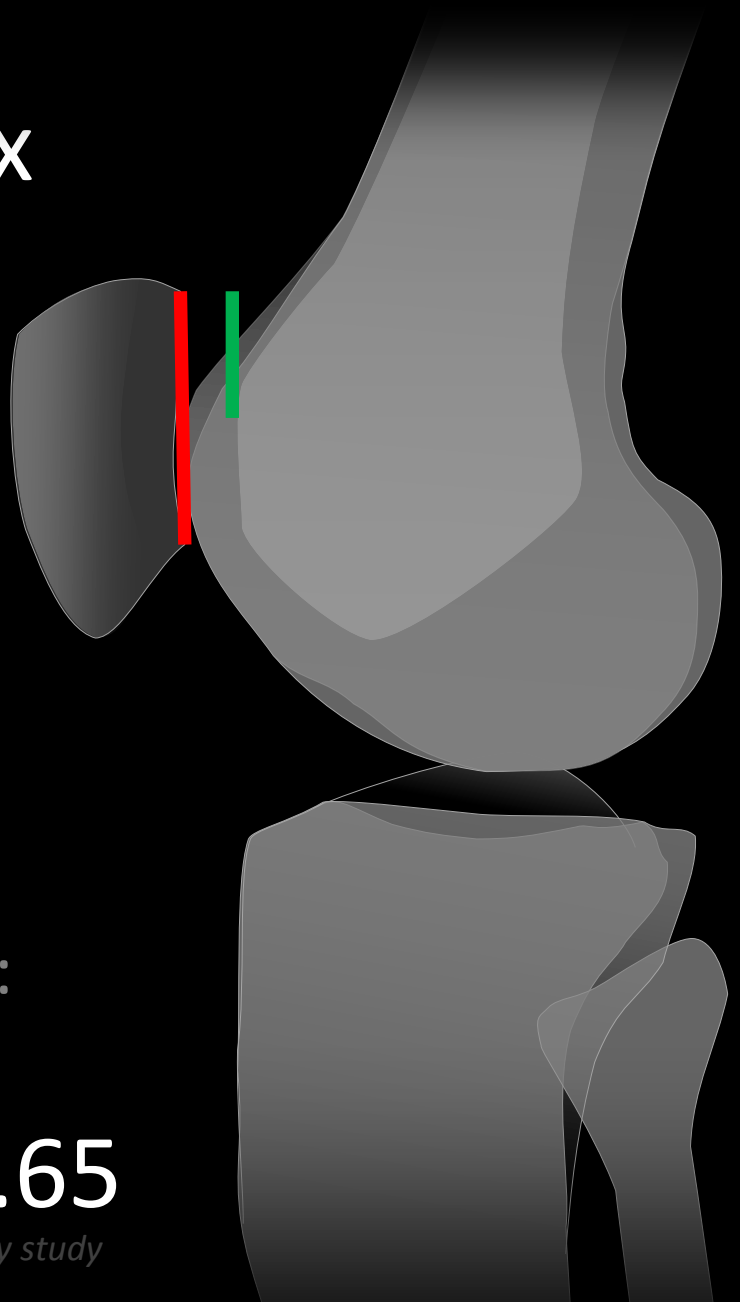
**cutoffs vary slightly by study*

Biedert RM, Albrecht S. Knee Surg Sports Traumatol Arthrosc. 2006 Aug;14(8):707-12.

Patellophyseal Index

2009

- Direct measurement
- Assumes that trochlear cartilage begins at the physis
- Hence evaluable on radiographs
- Related to patellotrochlear: should be near 1–PT.



$$A/B \leq 0.65$$

**cutoffs vary slightly by study*

Ali SA, Helmer R, Terk MR. Patella alta: lack of correlation between patellotrochlear cartilage congruence and commonly used patellar height ratios. AJR. 2009 Nov;193(5):1361-6.

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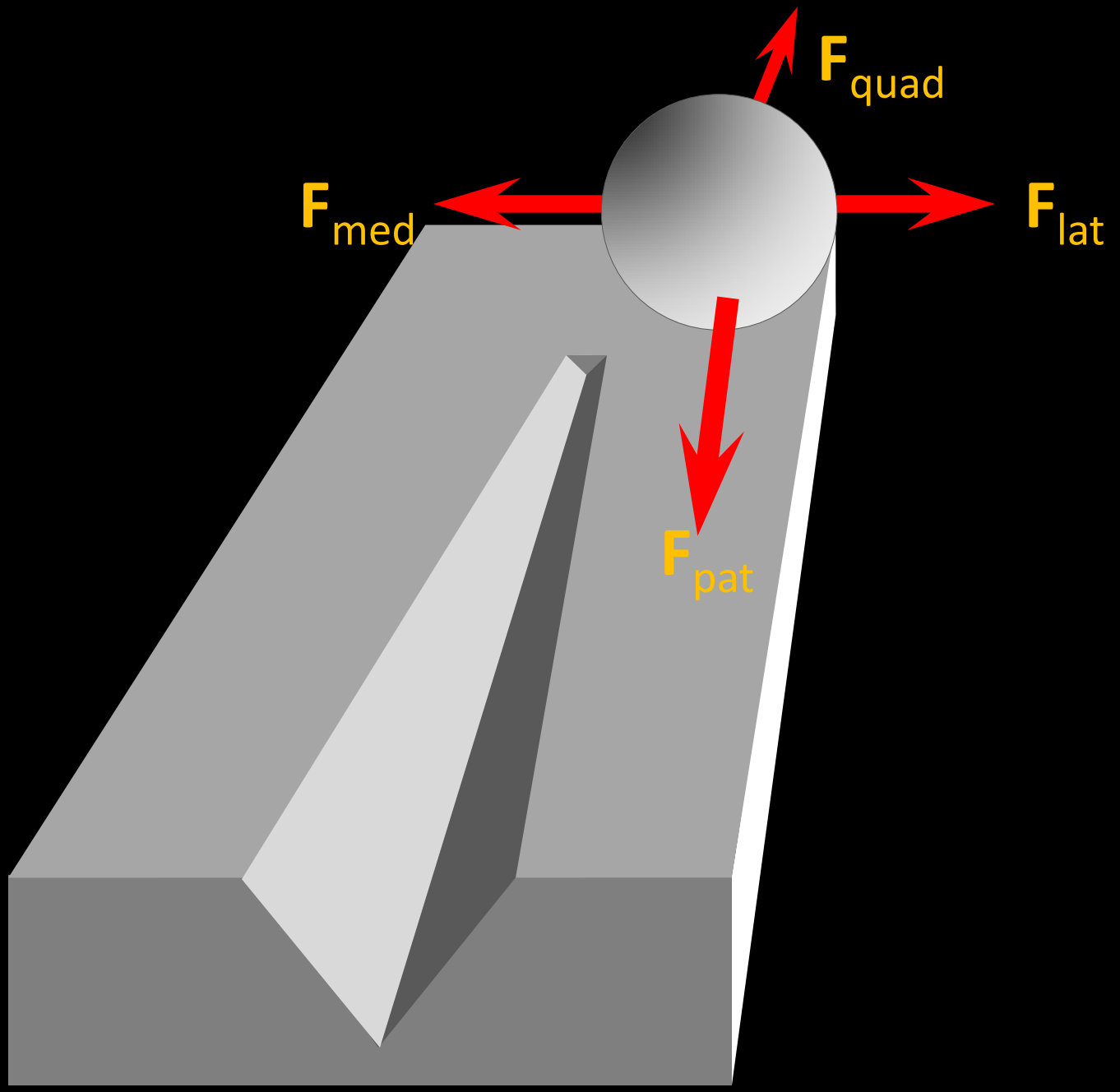
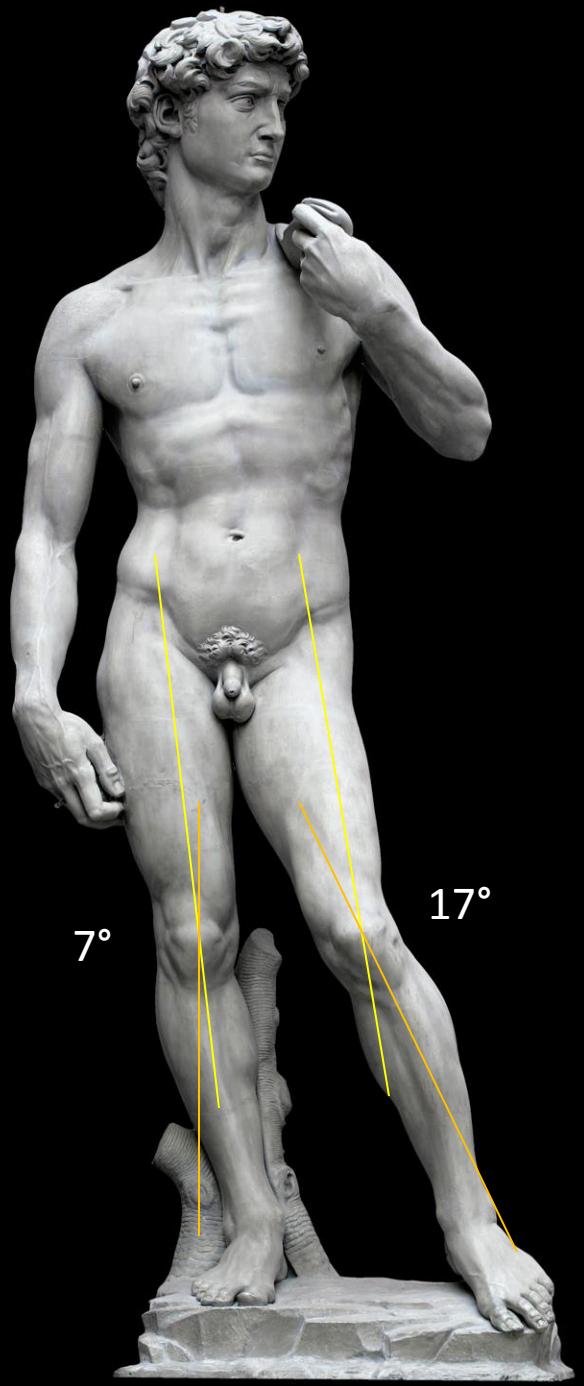
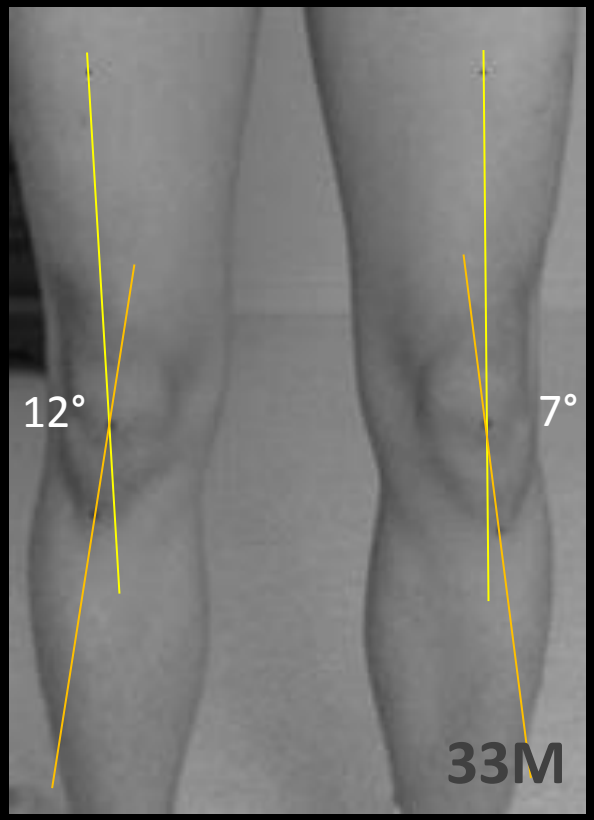
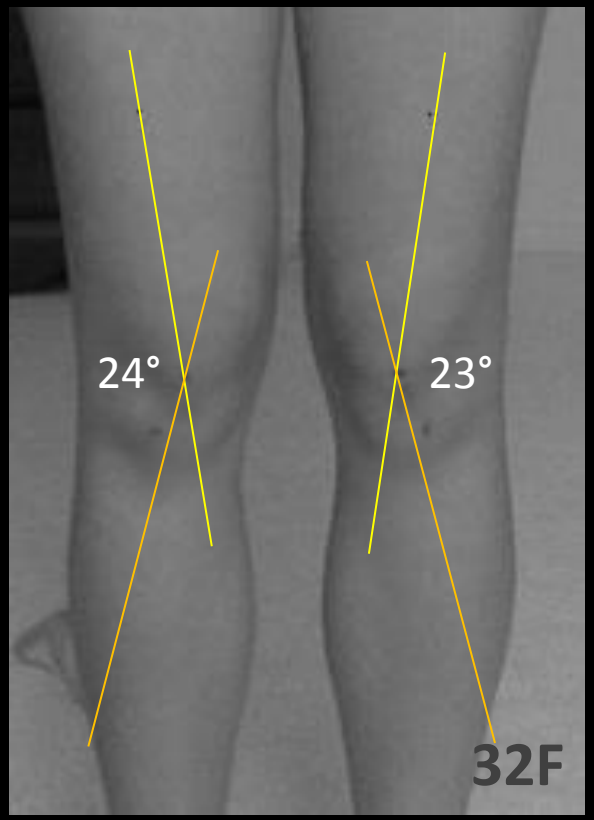

F quad
F med
F lat
F pat

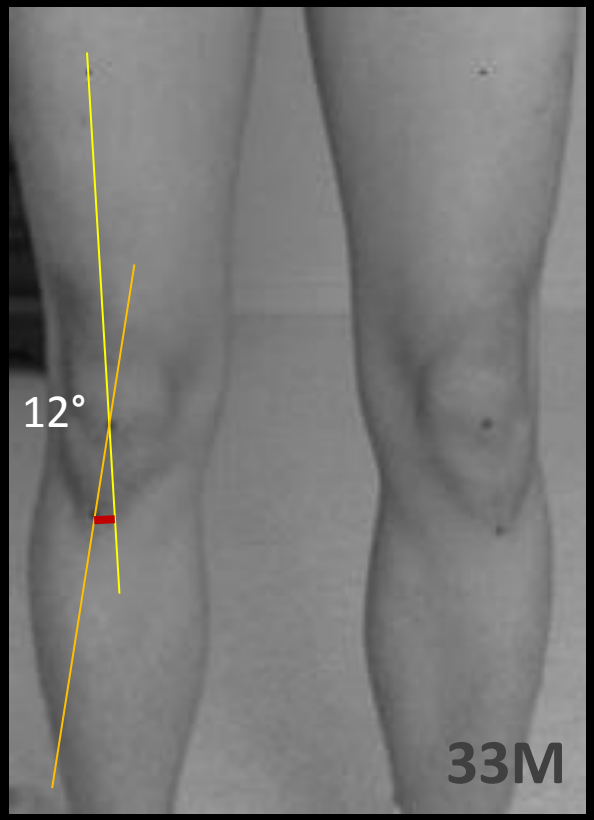
Q-Angle

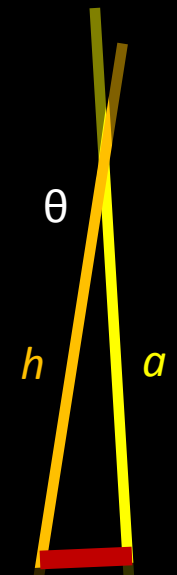
Quadriceps Angle




12°
7°
33M


24°
23°
32F





TTTG = $h \sin \vartheta \approx h\vartheta$

$= a \tan \vartheta \approx a\vartheta$

TTTG ≤ 2.0cm

Tibial Tuberosity–Trochlear Groove

- Radiographic surrogate for (
  - Elaborate Neyret radiographi
- Originally described on 30°
  - Now cross-sectional versions
- Marked variability in slice/la
  - Femoral cut: Highest complete cartilage? Deepest? Roman arch? Posterior condyles?
    - Cartilaginous or bony trochlea? (Wilcox, Schoettle)
  - Tuberosity: Anteriormost? Center of pat. tendon?

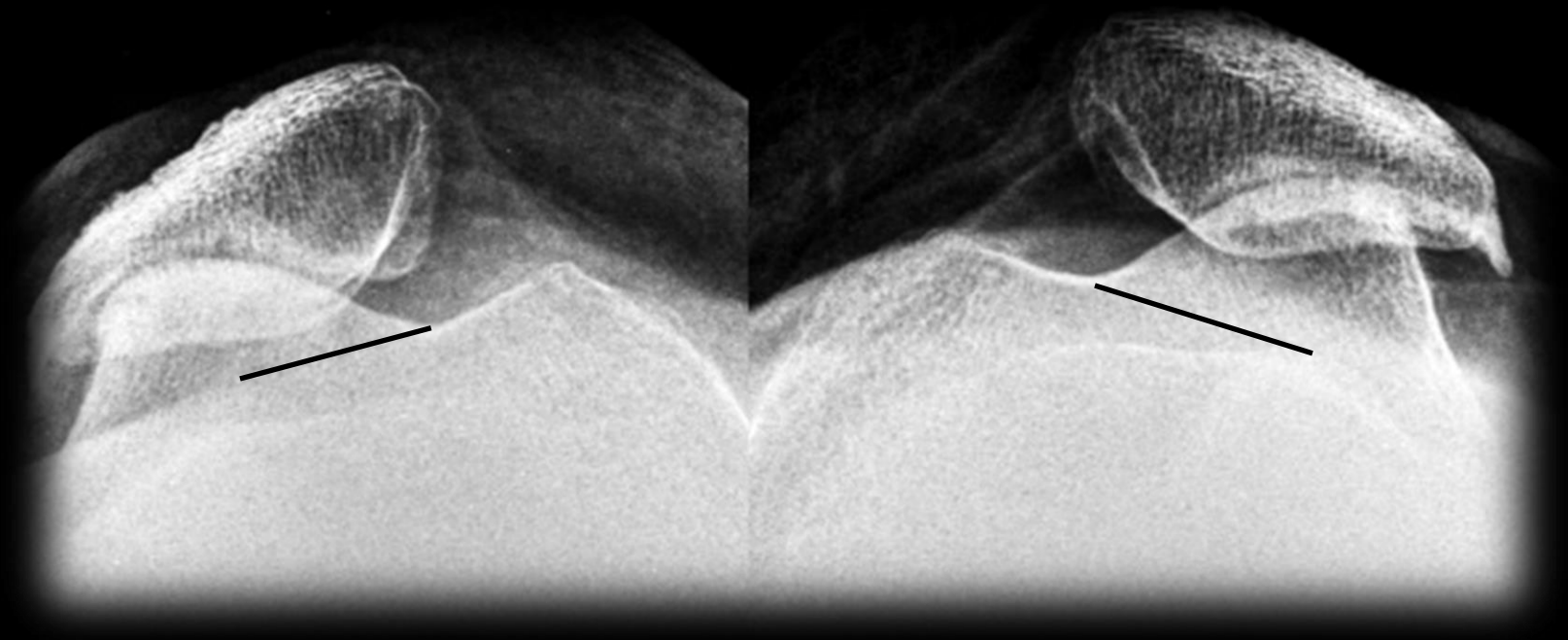
HIGHEST COMPLETE CARTILAGE
Aarvold A. Skeletal Radiol. 2014 Mar;43(3):345-9.
Balcarek P. Am J Sports Med. 2011 Aug;39(8):1756-61.
Schoettle PB. Knee. 2006 Jan;13(1):26-31.
Dejour DH. KSSTA. 2013 Jul;21(7):1482-94.

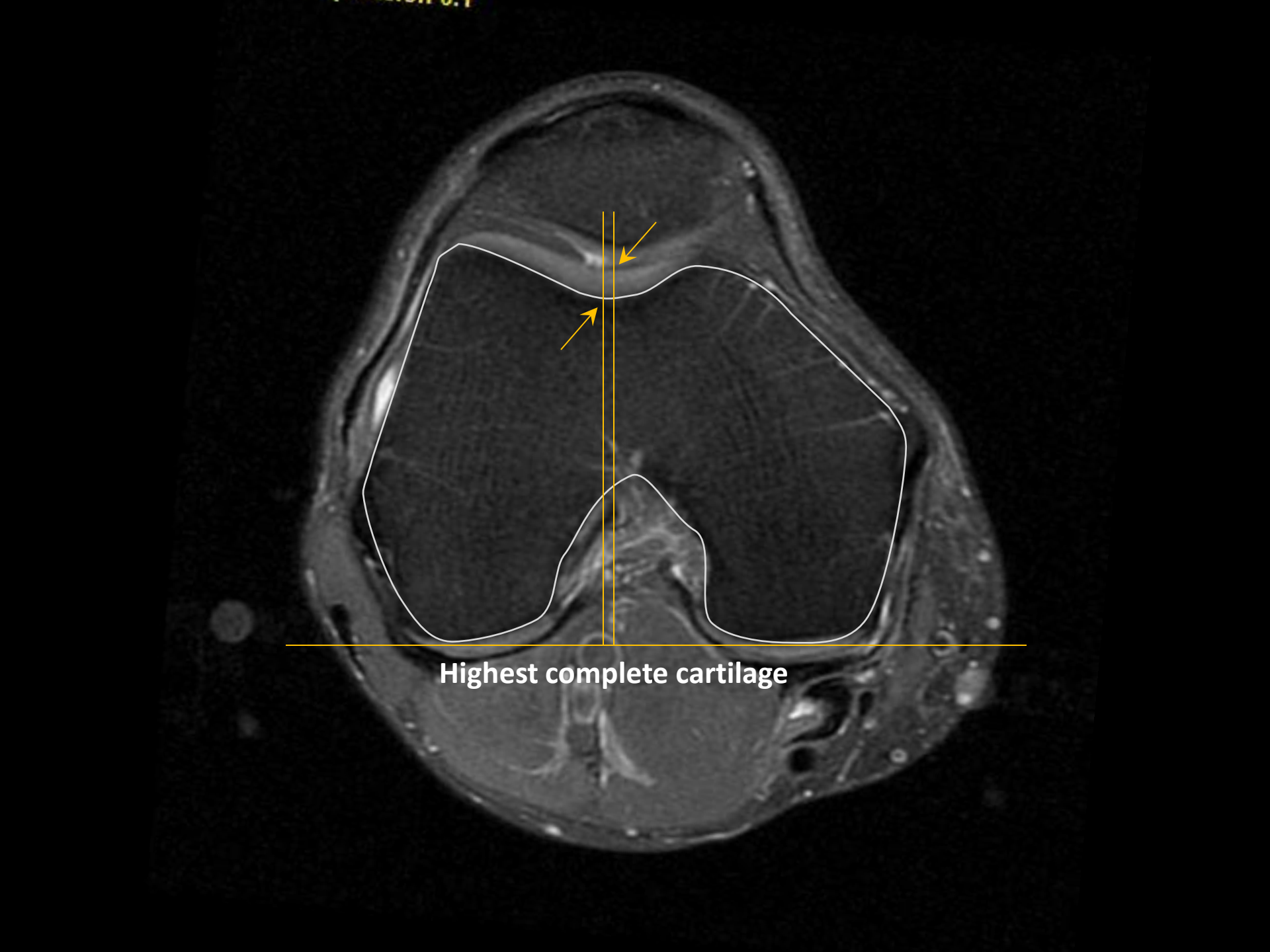
ROMAN ARCH
Wilcox JJ. CORR. 2012 Aug;470(8):2253-60.
Dejour H. KSSTA. 1994;2(1):19-26.
(Dejour DH. KSSTA. 2013 Jul;21(7):1482-94.)

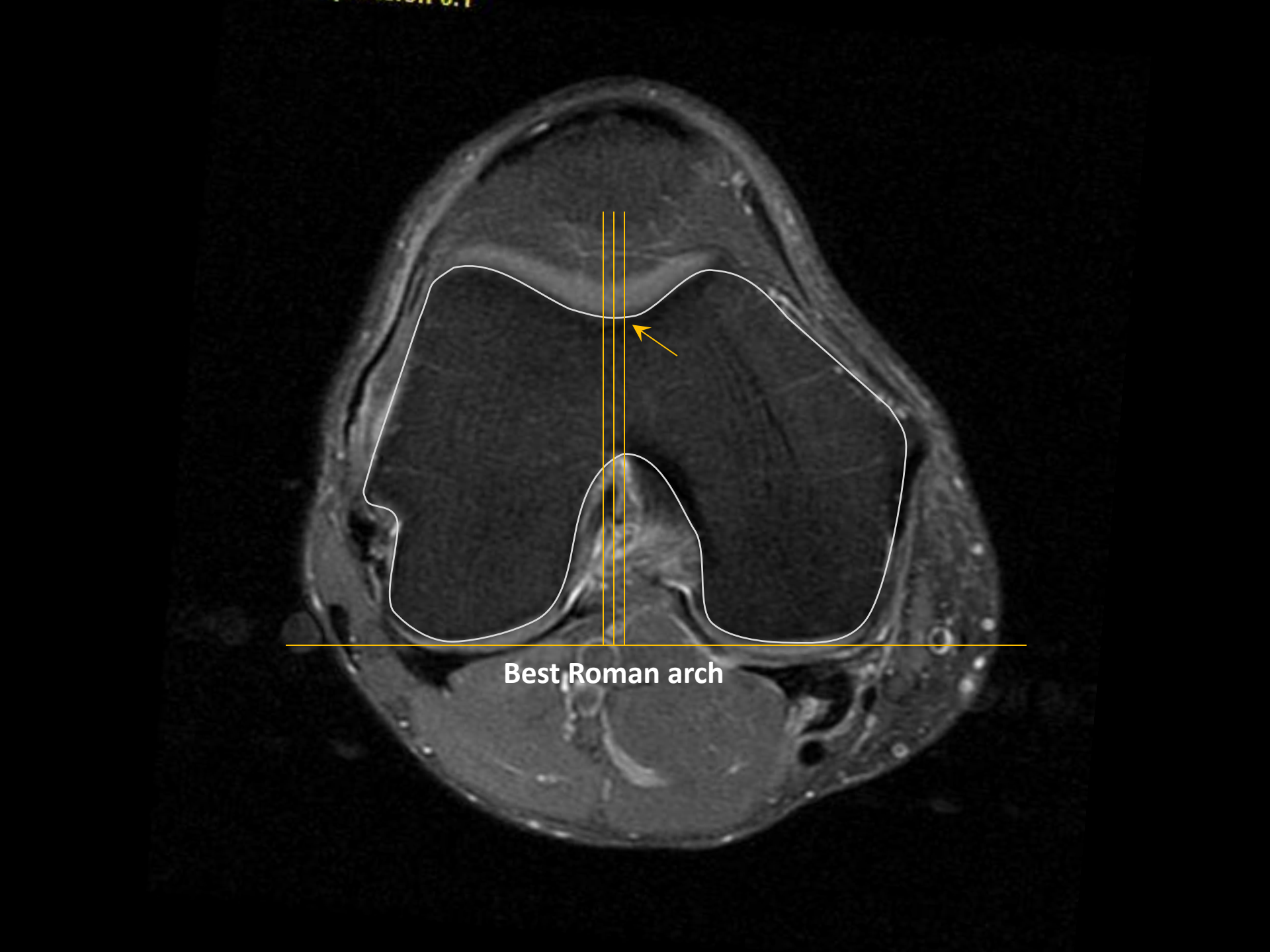
POSTERIOR CONDYLES
Camp CL. Am J Sports Med. 2013 Aug;41(8):1835-40.
Schoettle PB. Knee. 2006 Jan;13(1):26-31. (?)

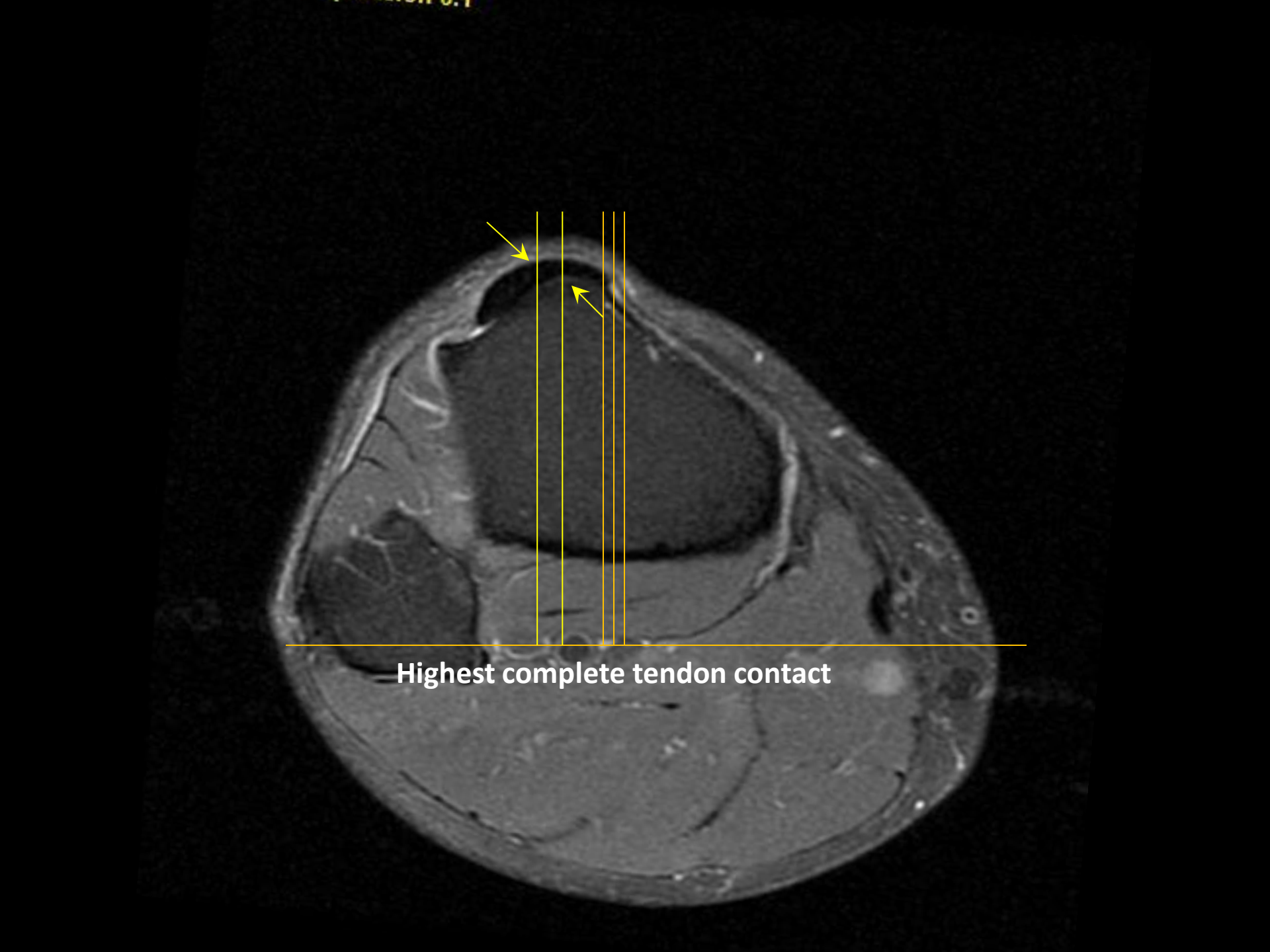
DEEPEST
McNally EG. Eur Radiol. 2000;10(7):1051-5.
Yao L. AJR Am J Roentgenol. 2014 Jun;202(6):1291-6.

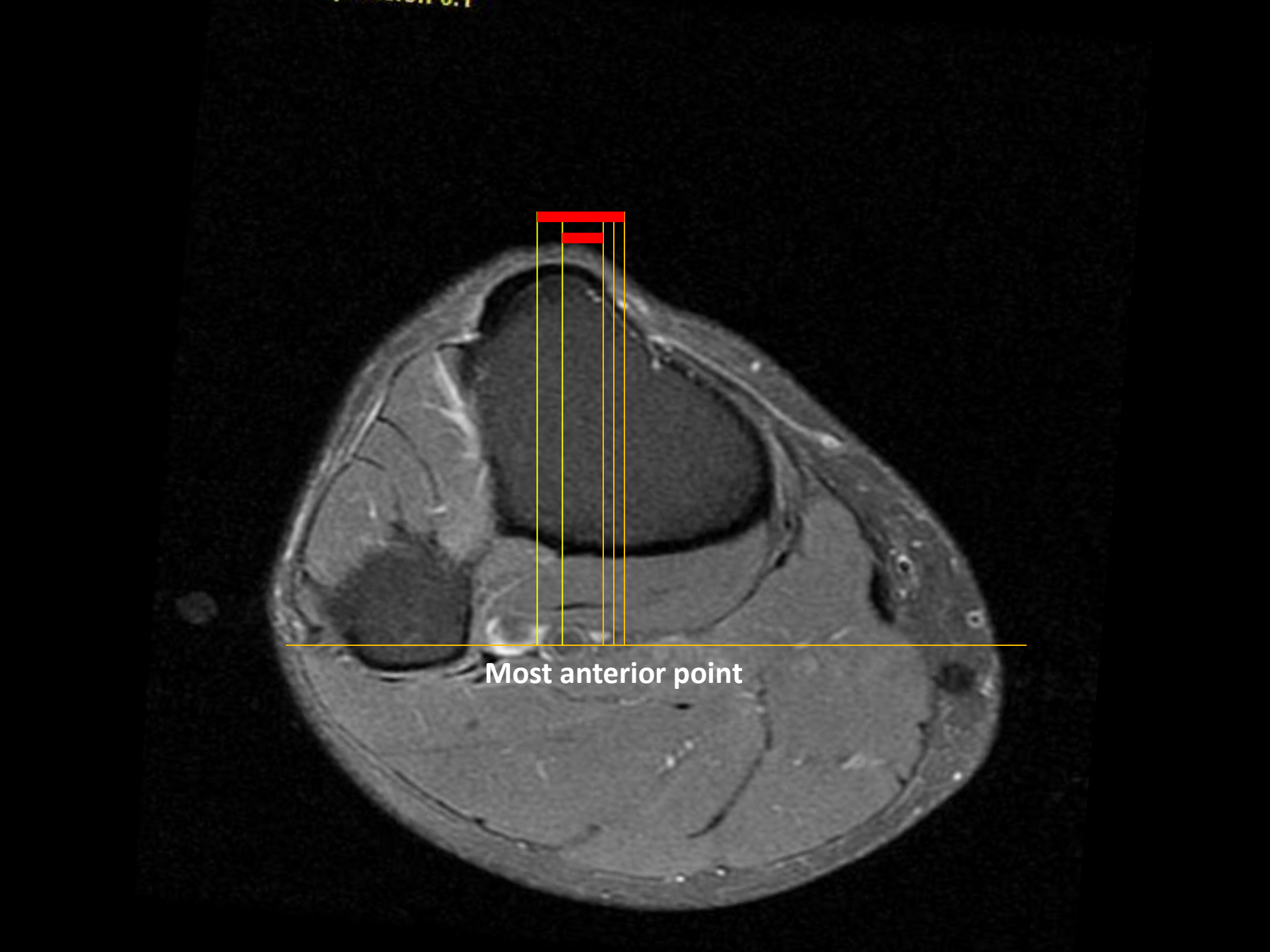
Goutallier D, Bernageau J, Lecudonnec B. Mesure de l'écart tubérosité tibiale antérieure-gorge de la trochlée (TA-GT)…. Rev Chir Orthop Reparatrice Appar Mot. 1978 Jul-Aug;64(5):423-8.




Highest complete cartilage


Best Roman arch


Highest complete tendon contact


Most anterior point

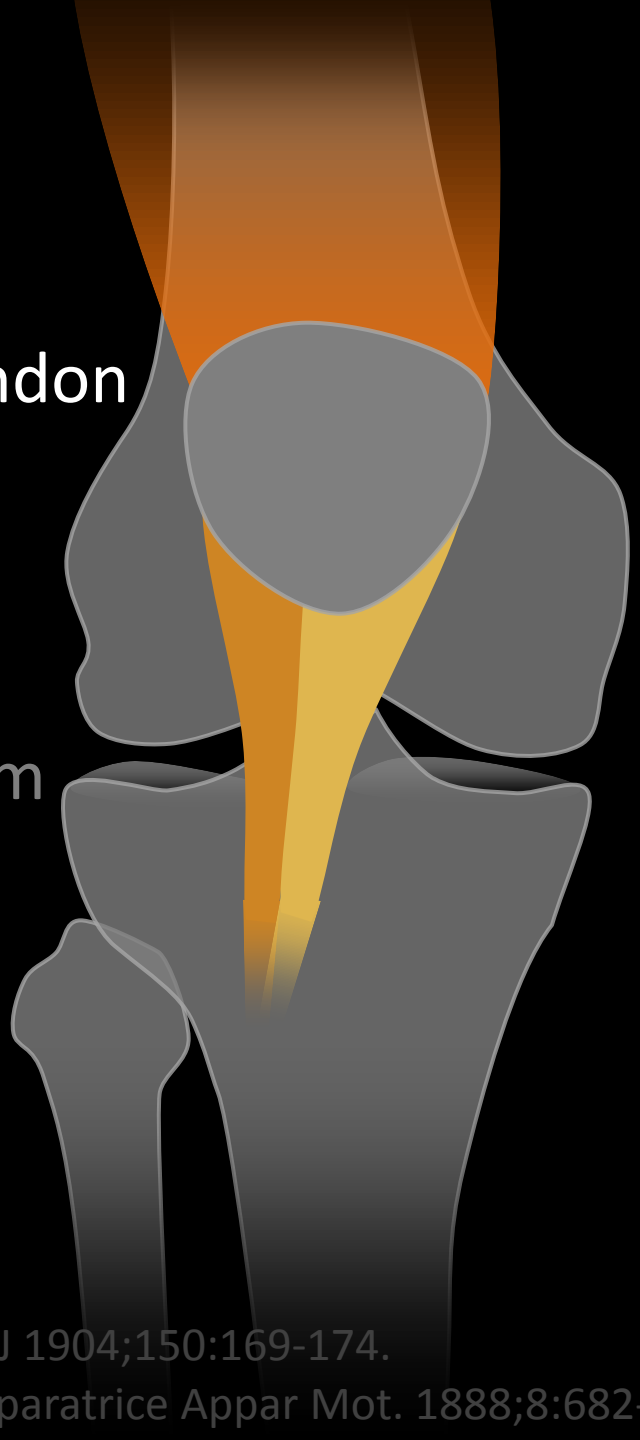
Distal Realignment

Tibial Tuberosity Medialization/Distalization

Roux(–Goldthwait)

1888, Switzerland

- Medial transfer of patellar tendon
  - May induce lateral tilt
- Release of lateral retinaculum and vastus lateralis
- Plication of medial retinaculum
- Advancemt of vastus medialis



Goldthwait JE. Boston Med Surg J 1904;150:169-174.
Roux C. Luxation récidivante…. Rev Chir Orthop Reparatrice Appar Mot. 1888;8:682-689.

Hauser

1938, United States

Previously popular,
but one part problematic

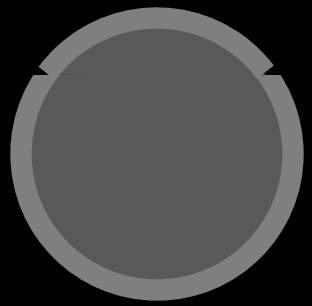
- Medialization
- (Distalization)
- Posteriorization
  - Inadvertent, as bone is curved
  - aka “posteromedial transfer”
  - Simulates increased flexion
  - Increases contact pressure!

Hauser ED. Total tendon transplant for slipping patella. Surg Gynaicol Obstet 1938;66:199-214.

Elmslie–Trillat

England; popularized 1947–1964, France

- Osteotomy
- Pure medialization
  - However, may still shift load to damaged medial cartilage

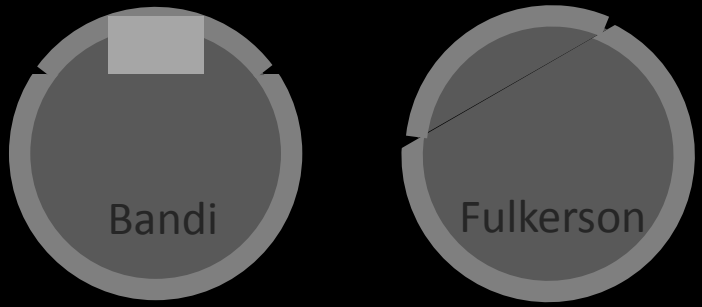


Trillat A, Dejour H, Couette A. Diagnosis and treatment of recurrent dislocations of the patella. Rev Chir Orthop Reparatrice Appar Mot. 1964 Nov-Dec;50:813-24.

Bandi–Maquet

1972–1976

- Insertion of bone graft for elevation (anteriorization) of tibial tuberosity
  - Simulates reduced flexion
  - Reduces forces on damaged cartilage, especially distally



- Similar: Fulkerson osteotomy

Maquet P. Clin Orthop Relat Res. 1976;(115):225-30.
Fulkerson JP. Clin Orthop Relat Res. 1983 Jul-Aug;(177):176-81.

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Plats principaux

Patella alta · TT distalization

Excessive TT-TG (Q) · TT medialization

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Lateral subluxation · Medial imbrication

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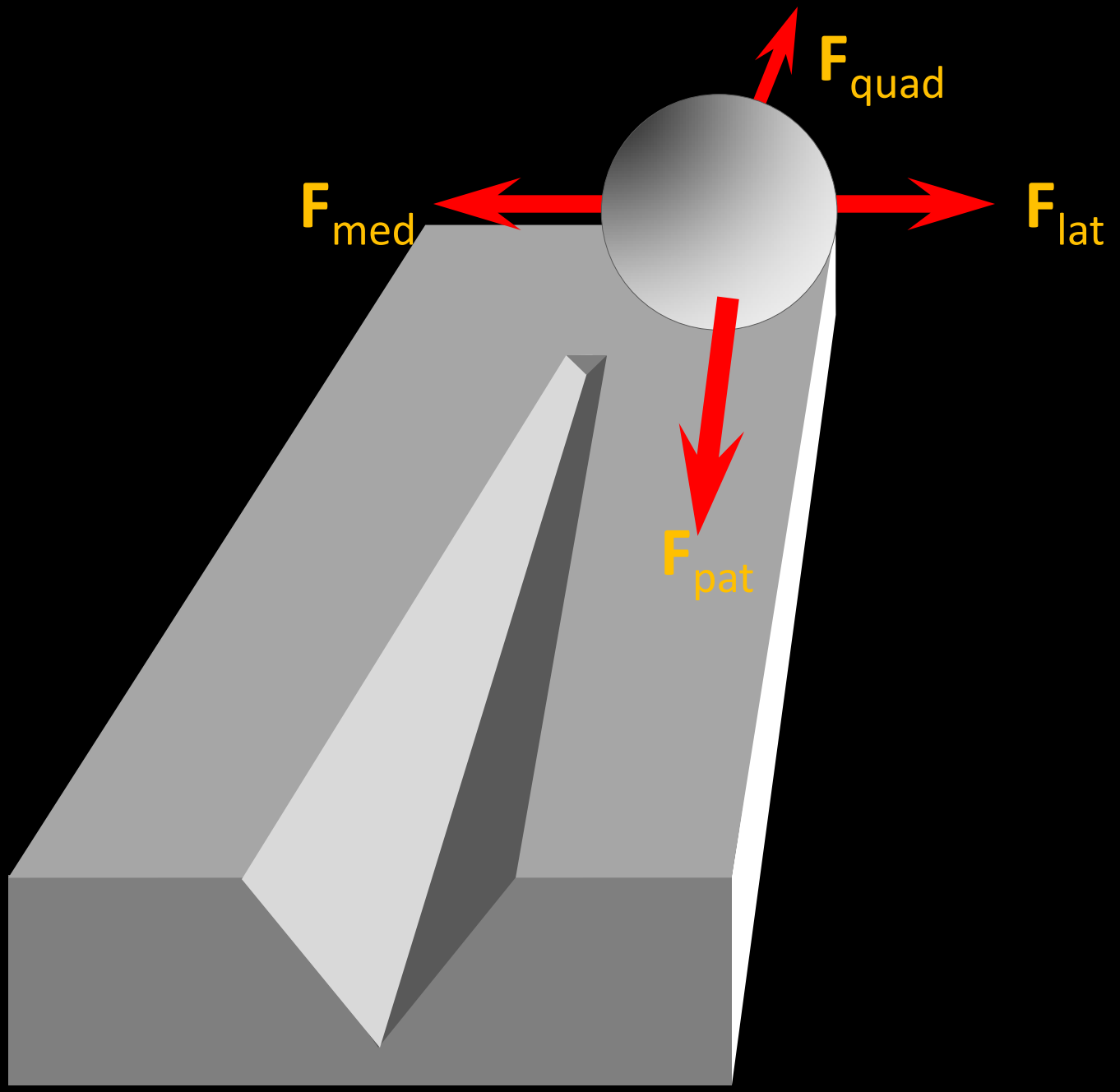
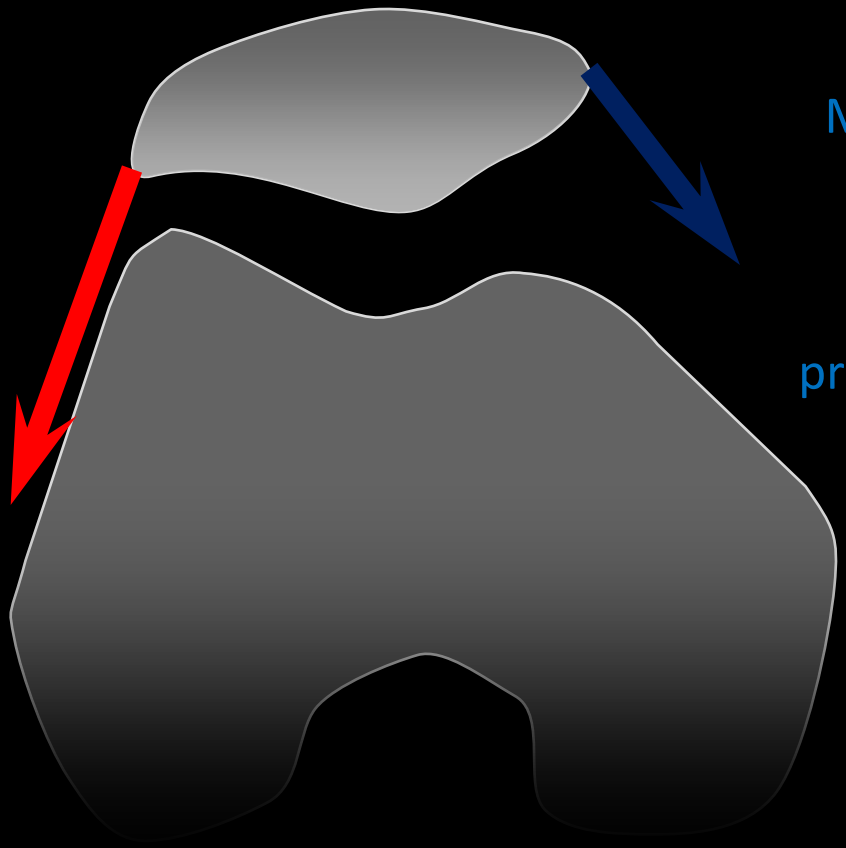

F quad
F med
F lat
F pat

Separating Tilt from Subluxation

Indiscriminate lateral release, as previously practiced, leads to poor results.

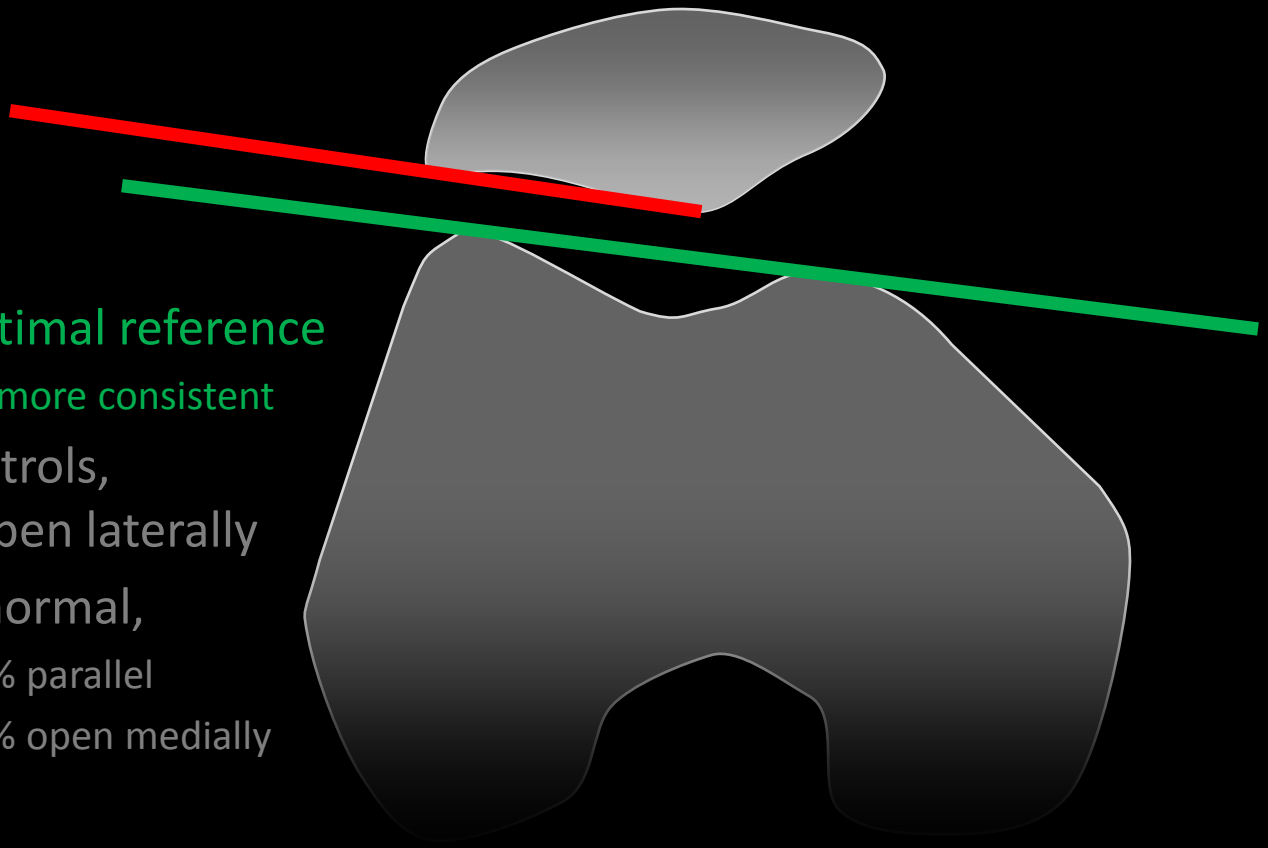
Lateral retinaculum is directed more anteroposteriorly and therefore tends to produce **tilt**



Medial retinaculum is directed more mediolaterally and therefore tends to produce **subluxation**

Lateral Patellofemoral Angle of Laurin

For Patellar Tilt

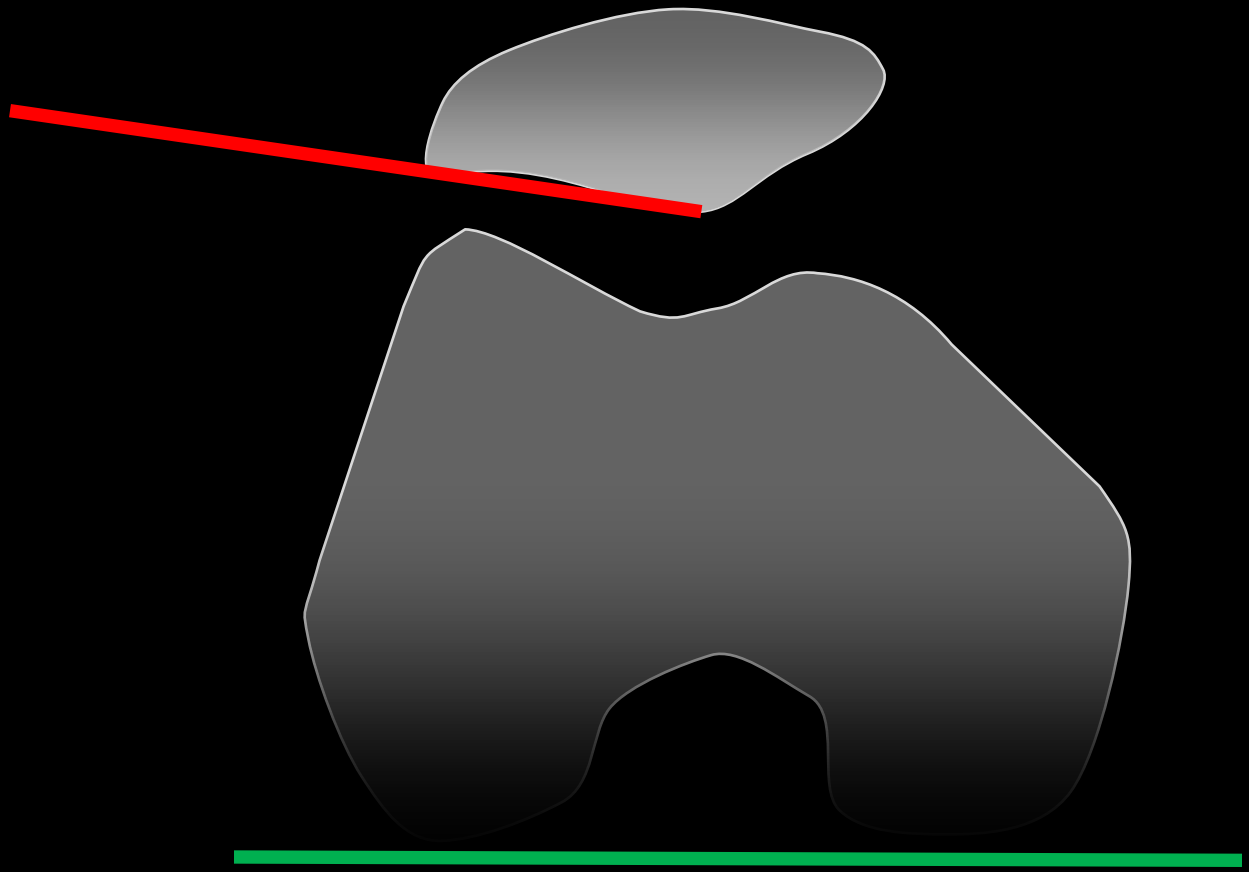


- Suboptimal reference
  - CT more consistent
- Of controls, 97% open laterally
- Of abnormal,
  - 60% parallel
  - 40% open medially

Laurin CA, Dussault R, Levesque HP. Clin Orthop Relat Res. 1979 Oct;(144):16-26.

Patellar Tilt Angle (CT/MRI)

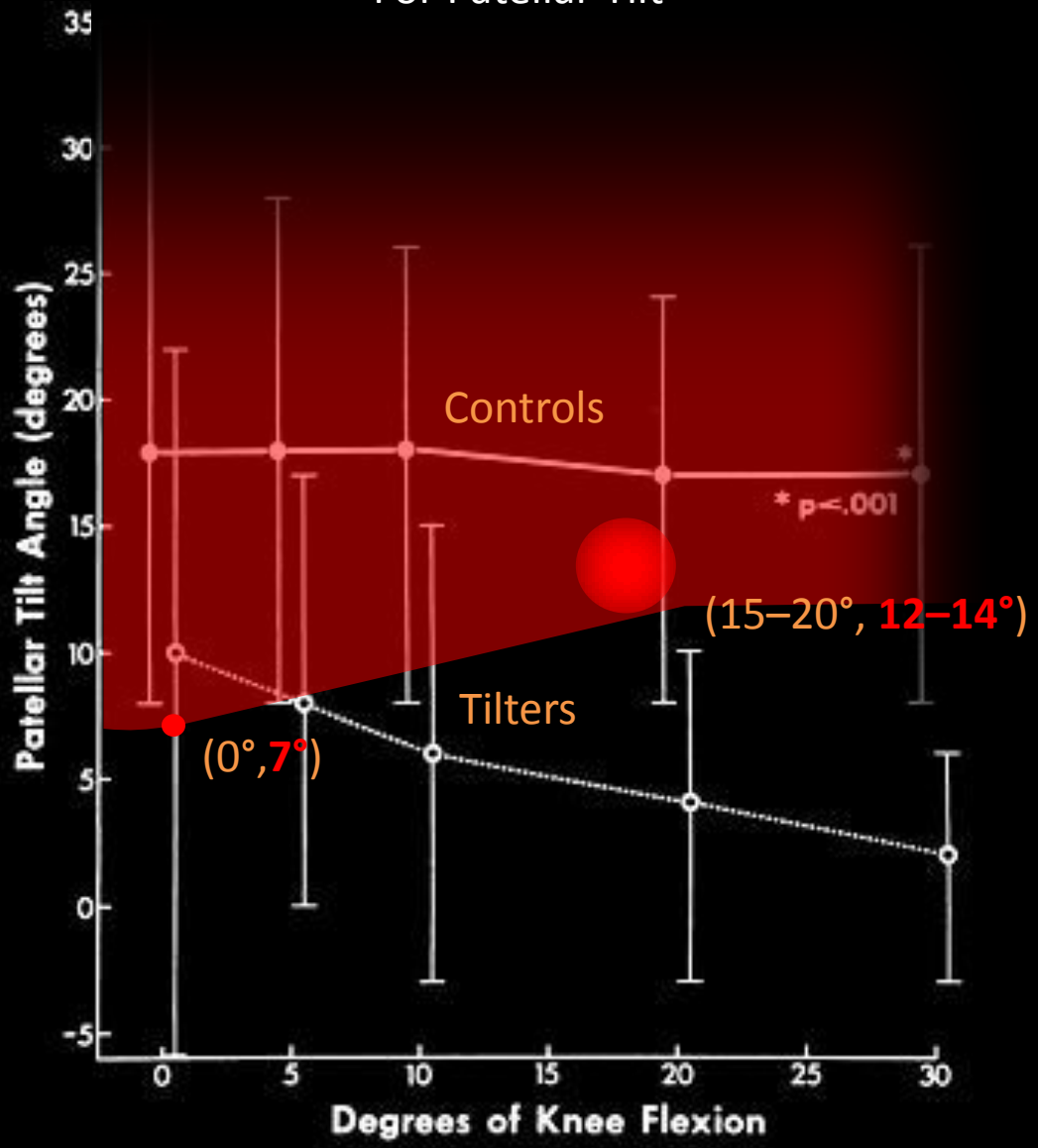
For Patellar Tilt



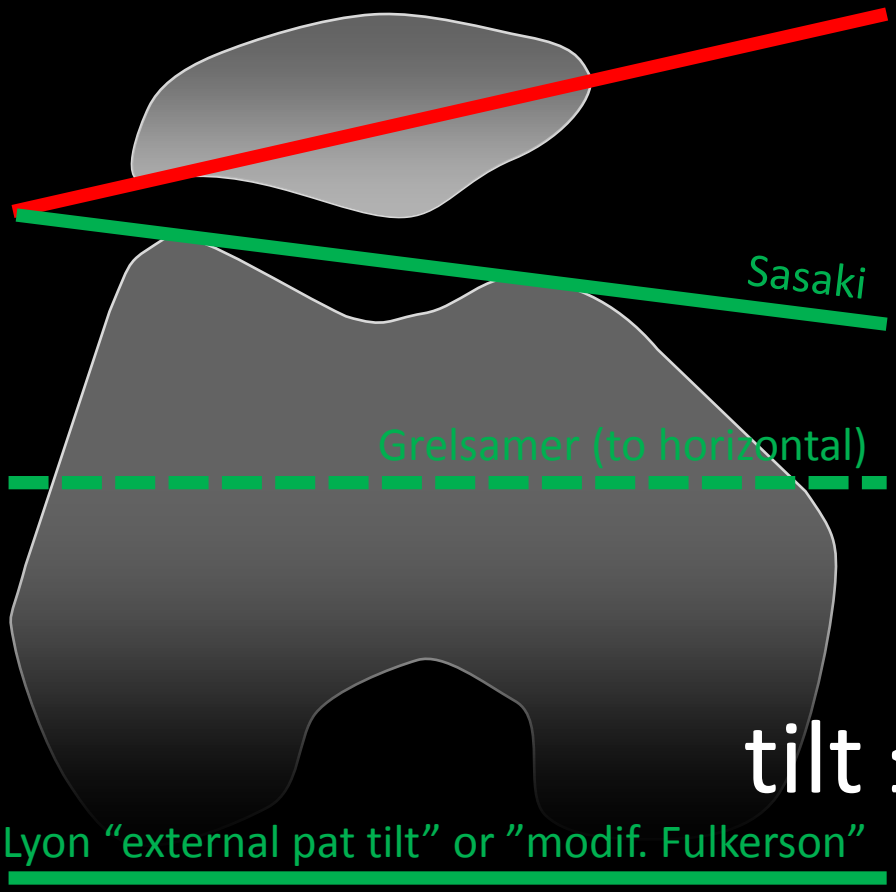
Fulkerson JP, Schutzer SF, Ramsby GR, Bernstein RA. Arthroscopy. 1987;3(1):19-24.

Patellar Tilt Angle (CT/MRI)

For Patellar Tilt



Other CT Tilt Angles



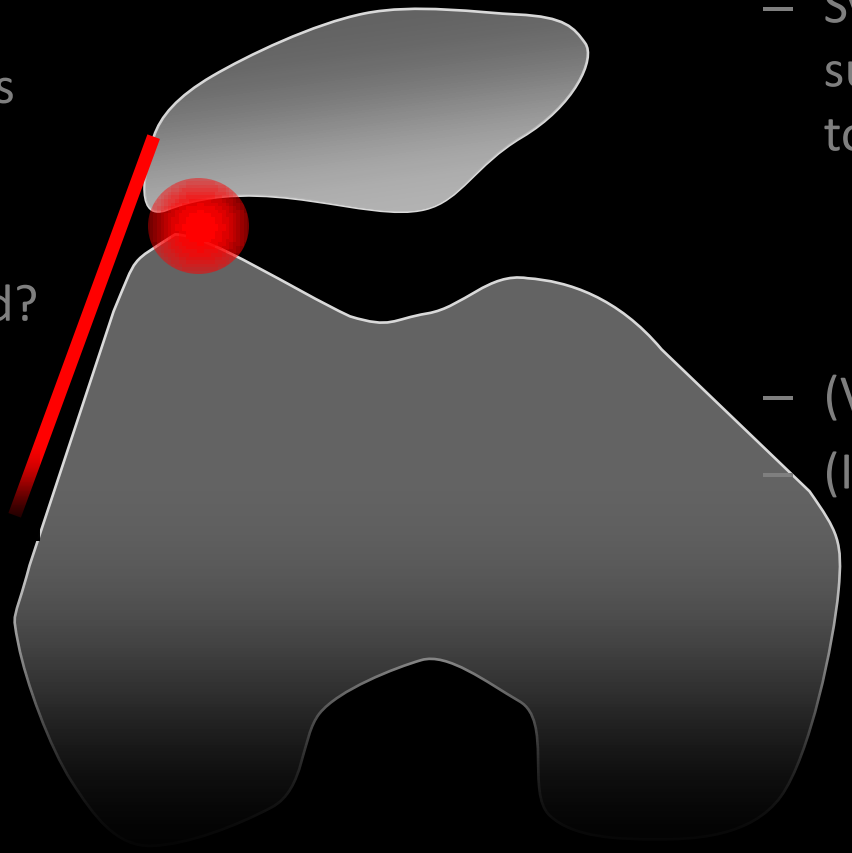
Dejour H et al. Knee Surg Sports Traumatol Arthrosc. 1994;2(1):19-26.
Grelsamer RP et al. JBJS Br. 1993 Sep;75(5):822-4. Sasaki T, Yagi T. Int Orthop. 1986;10(2):115-20.

Lateral Release

For Patellar Tilt

Excessive lateral pressure

- Cartilage damaged
- Soft tissue restraints adaptively tighten
- Trabeculae reorient
- Lat. joint malformed?
- Bipartite patella?



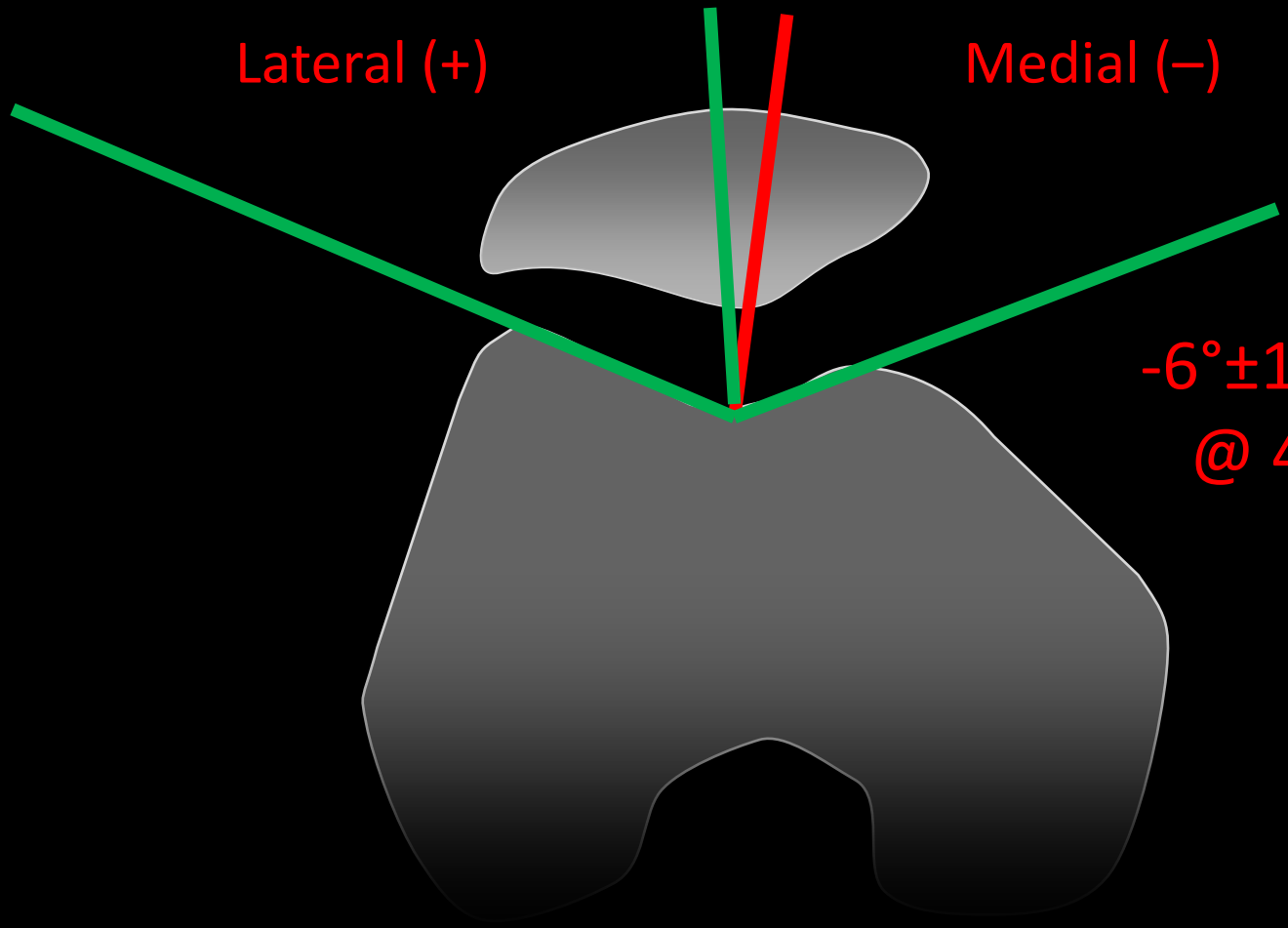
Released structures

- Synovium/retinaculum, superolateral patella to tibial tubercle
  - Epicondylopatellar band
  - Patellotibial band
  - Not overlying VL tendon!
- (VL obliquus tendon)
- (Infrapatellar fat pad)

Ficat C. La degenerescence du cartilage de la rotule. Semin Hosp Paris 1974;50:3210-3219.
Merchant AC, Mercer RL. Lateral release of the patella. Clin Orthop Relat Res. 1974;(103):40-5.
Shea KP, Fulkerson JP. Arthroscopy. 1992;8(3):327-34.

Congruence Angle of Merchant

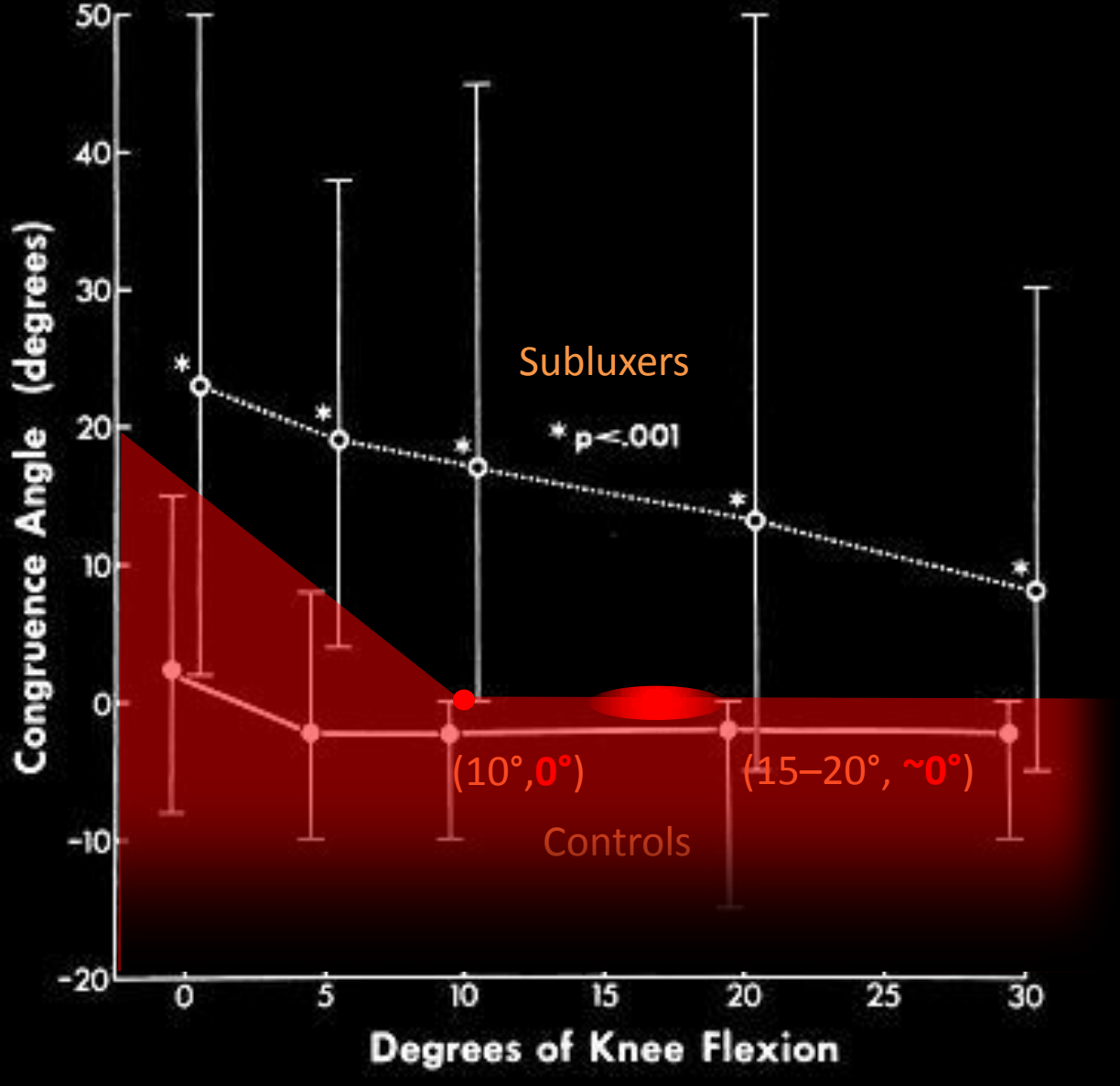
For Patellar Subluxation



Schutzer SF, Ramsby GR, Fulkerson JP. Orthop Clin North Am. 1986 Apr;17(2):235-48.
Merchant AC, Mercer RL, Jacobsen RH, Cool CR. J Bone Joint Surg Am. 1974 Oct;56(7):1391-6.

Congruence Angle (CT/MRI)

For Patellar Subluxation



Proximal Realignment

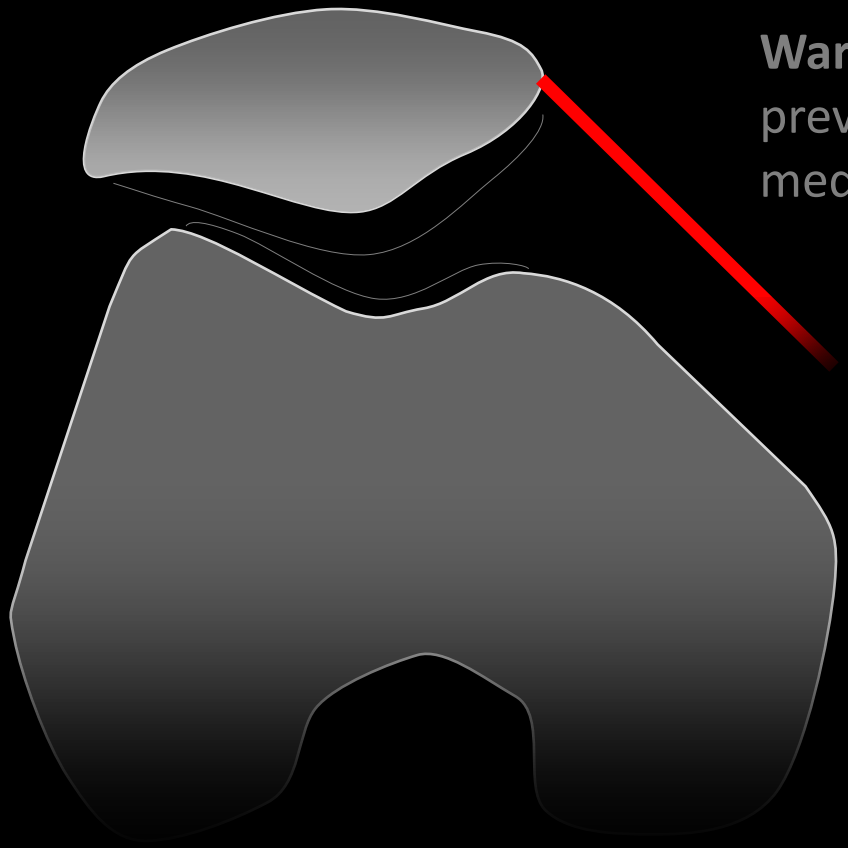
aka Reconstruction/Imbrication of MPFL

imbrex, imbricis, L.

Proximal Realignment

aka Reconstruction/Imbrication of MPFL

Alternative/adjunct:
VMO advancement



Warning: may load previously damaged medial facet cartilage

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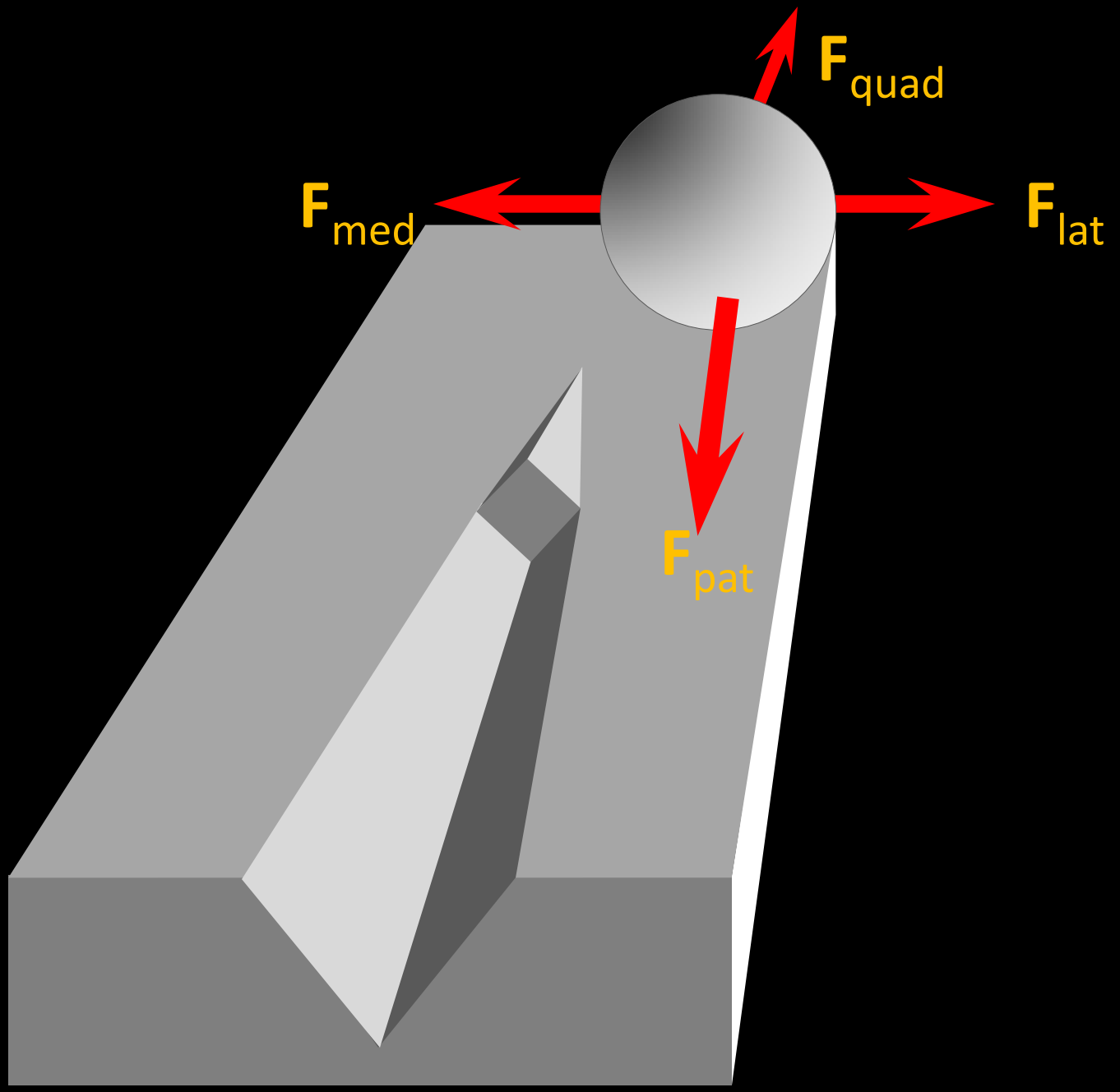
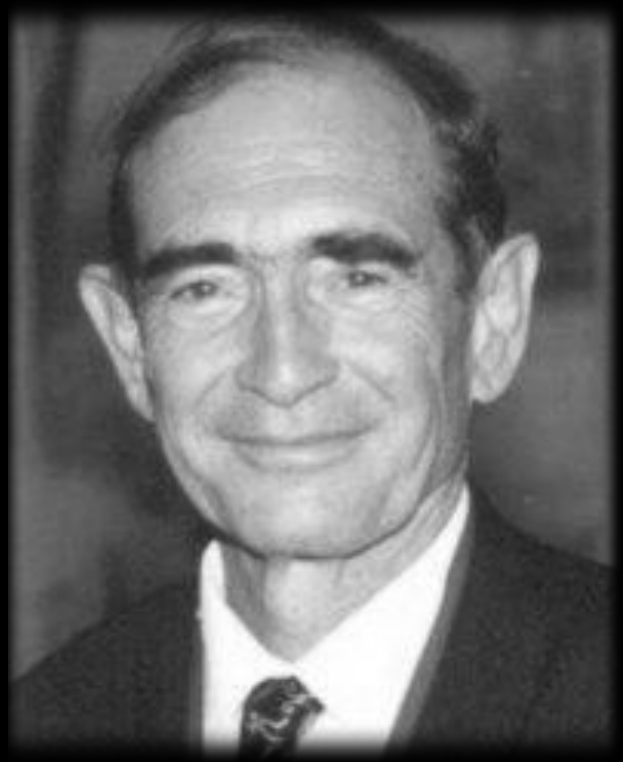

F quad
F med
F lat
F pat

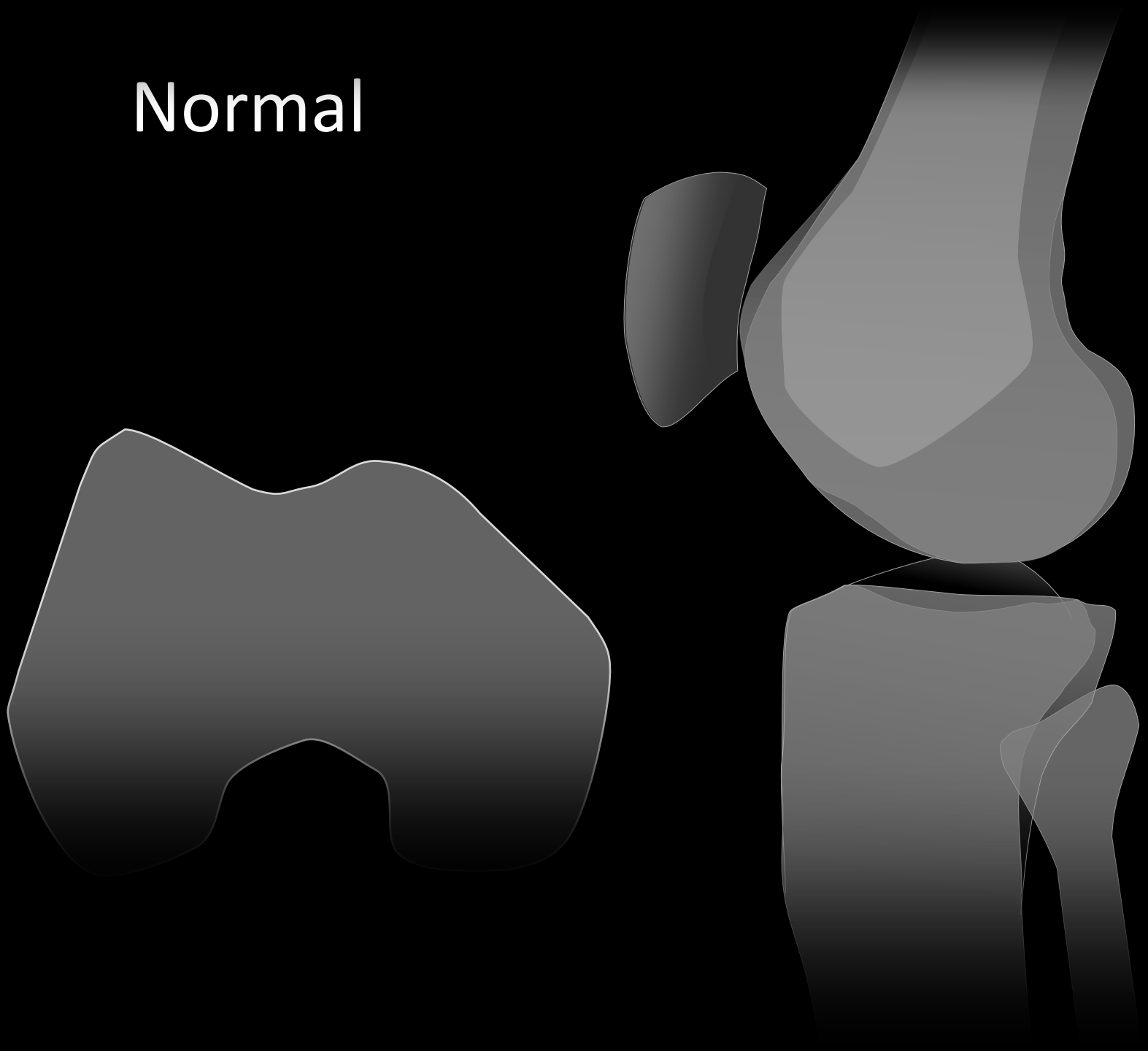
Les Dejour



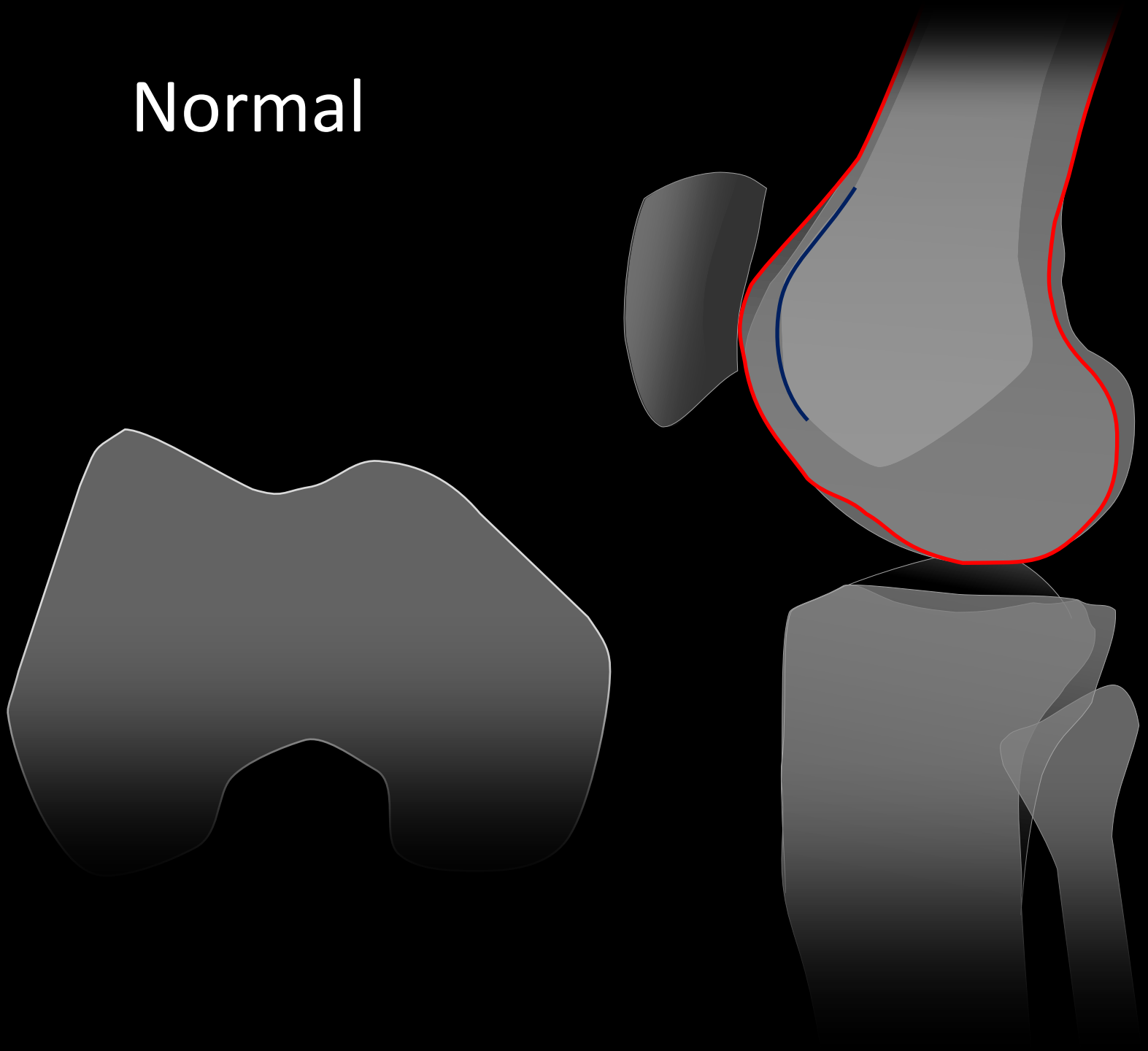
Henri, *père*
(1930–1998)

David Henri, *fils*
(1963–)

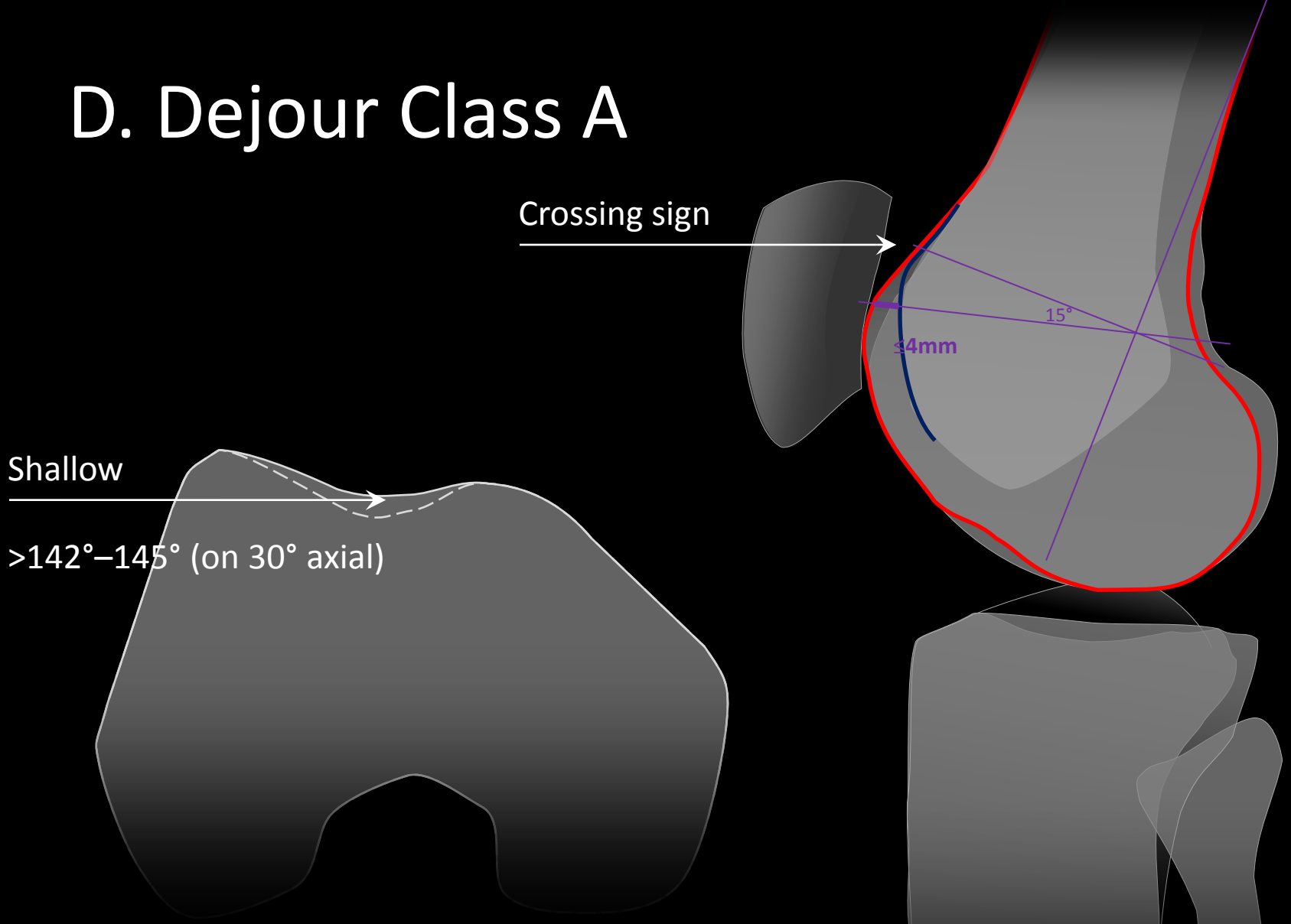
Normal



Normal

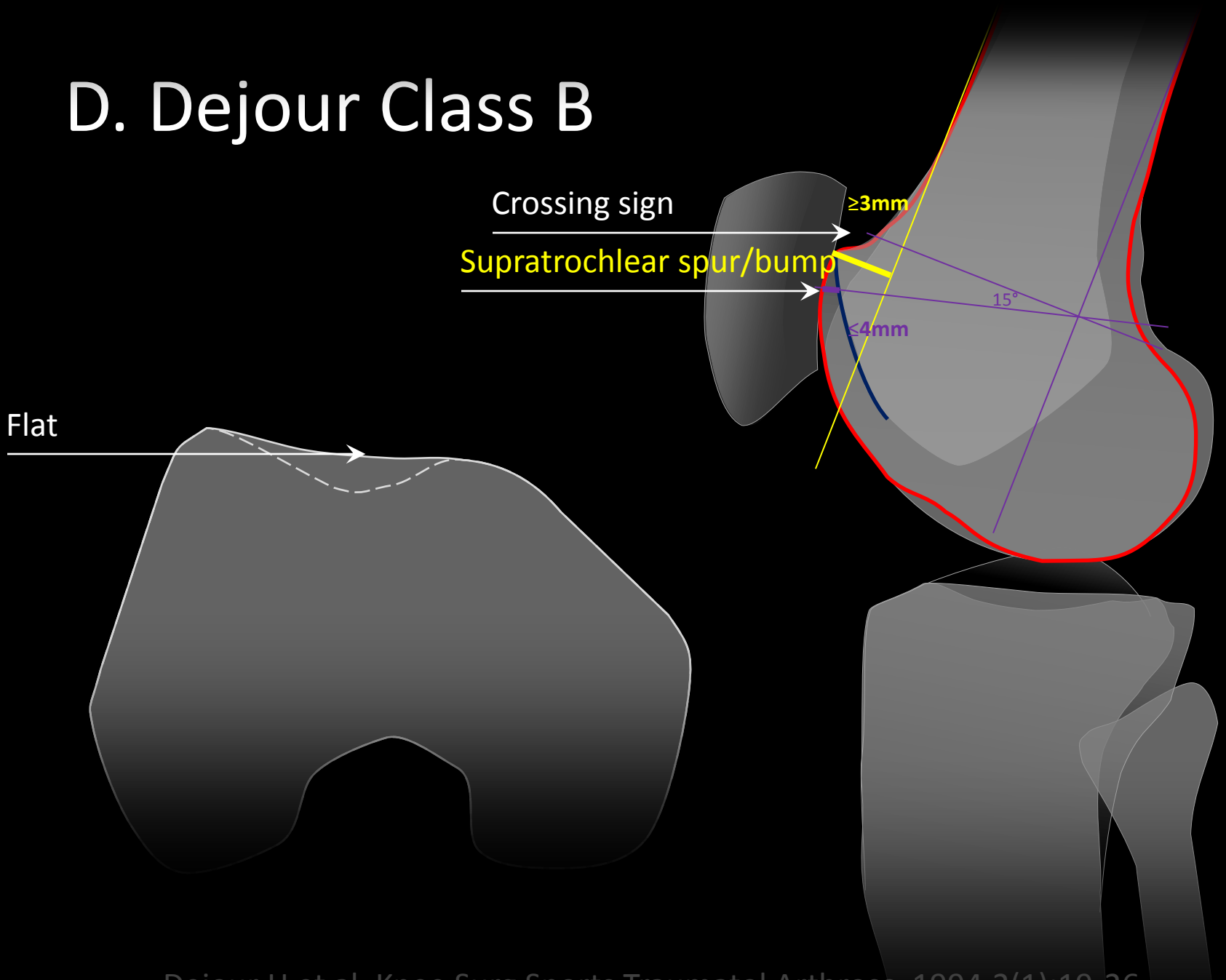


D. Dejour Class A



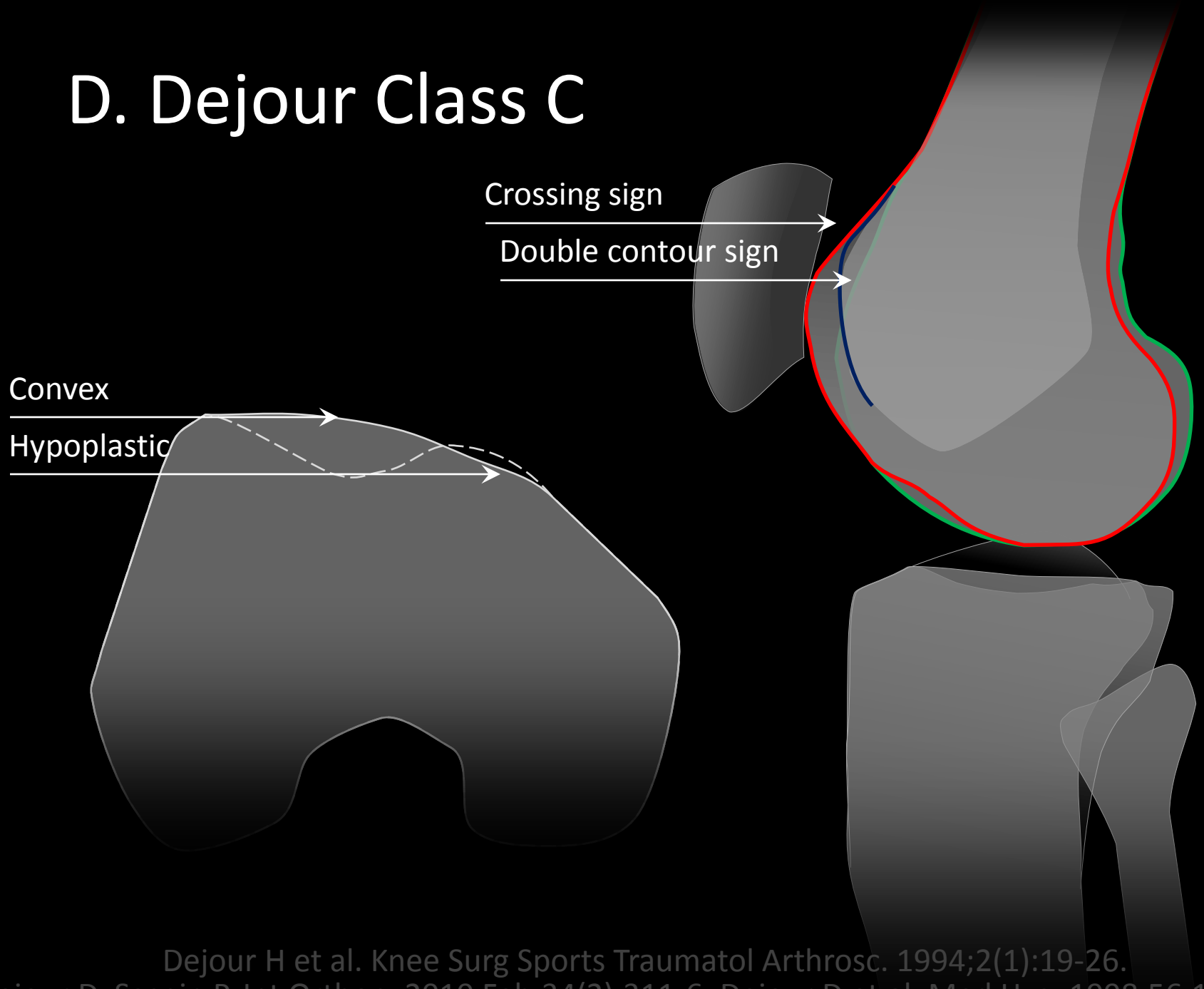
Rémy F et al. Rev Chir Orthop Reparatrice Appar Mot. 1998 Nov;84(8):728-33.
Rémy F et al. Surg Radiol Anat. 1998;20(4):285-9. Rémy F et al. JBJS Br. 2002;84B:43.

D. Dejour Class B



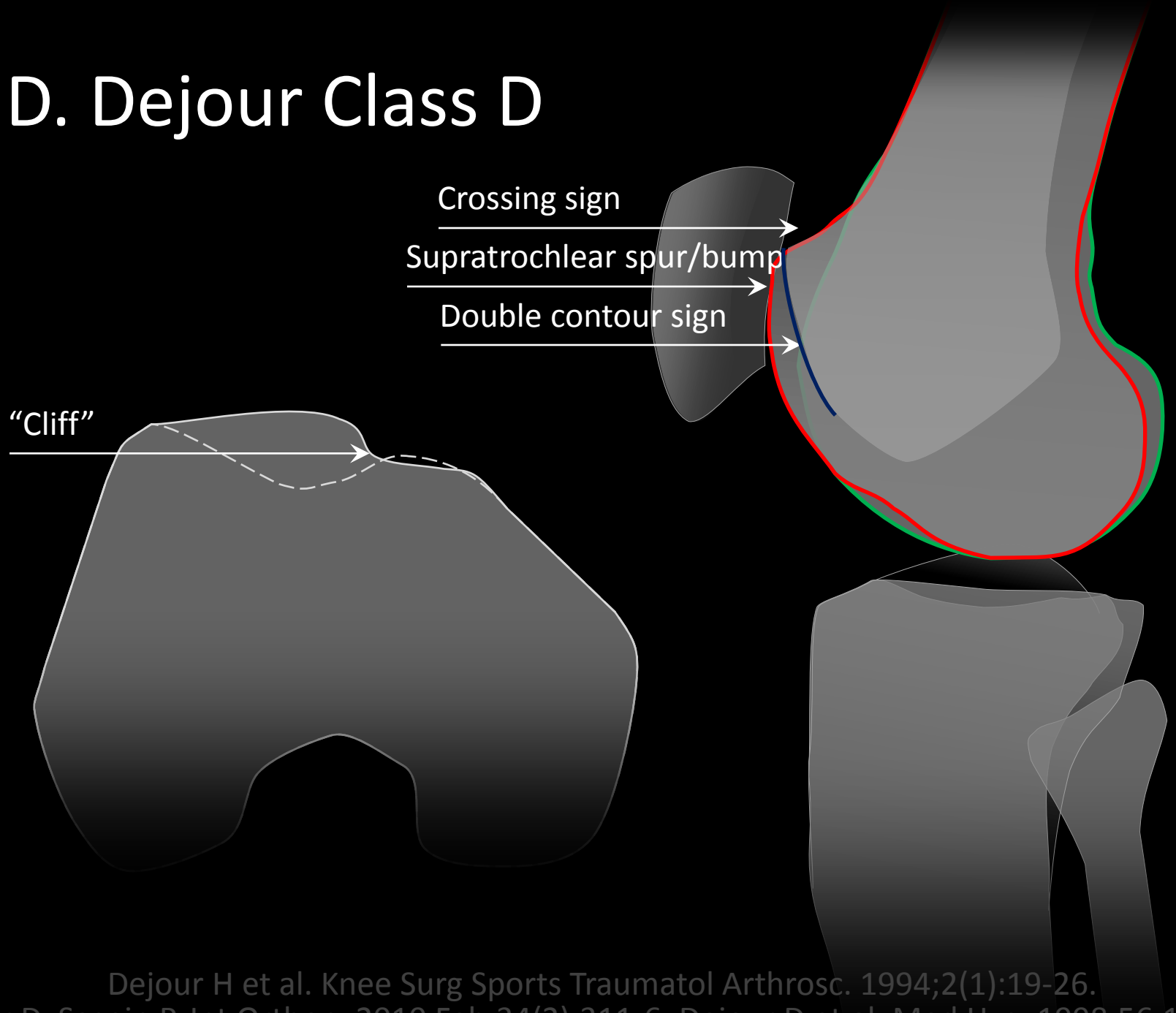
Dejour H et al. Knee Surg Sports Traumatol Arthrosc. 1994;2(1):19-26.
Dejour D, Saggin P. Int Orthop. 2010 Feb;34(2):311-6. Dejour D et al. Med Hyg. 1998;56:1466-71.

D. Dejour Class C



Dejour H et al. Knee Surg Sports Traumatol Arthrosc. 1994;2(1):19-26.
Dejour D, Saggin P. Int Orthop. 2010 Feb;34(2):311-6. Dejour D et al. Med Hyg. 1998;56:1466-71.

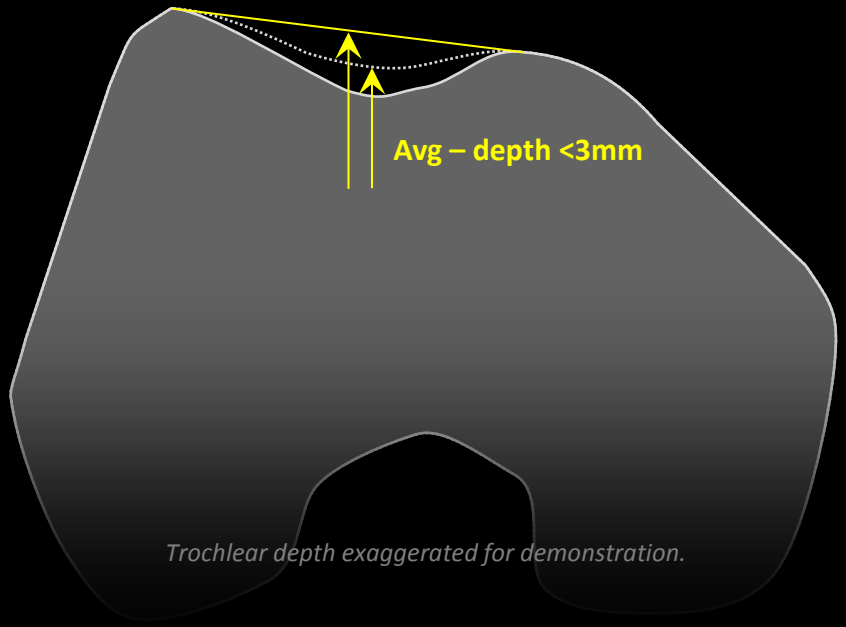
D. Dejour Class D

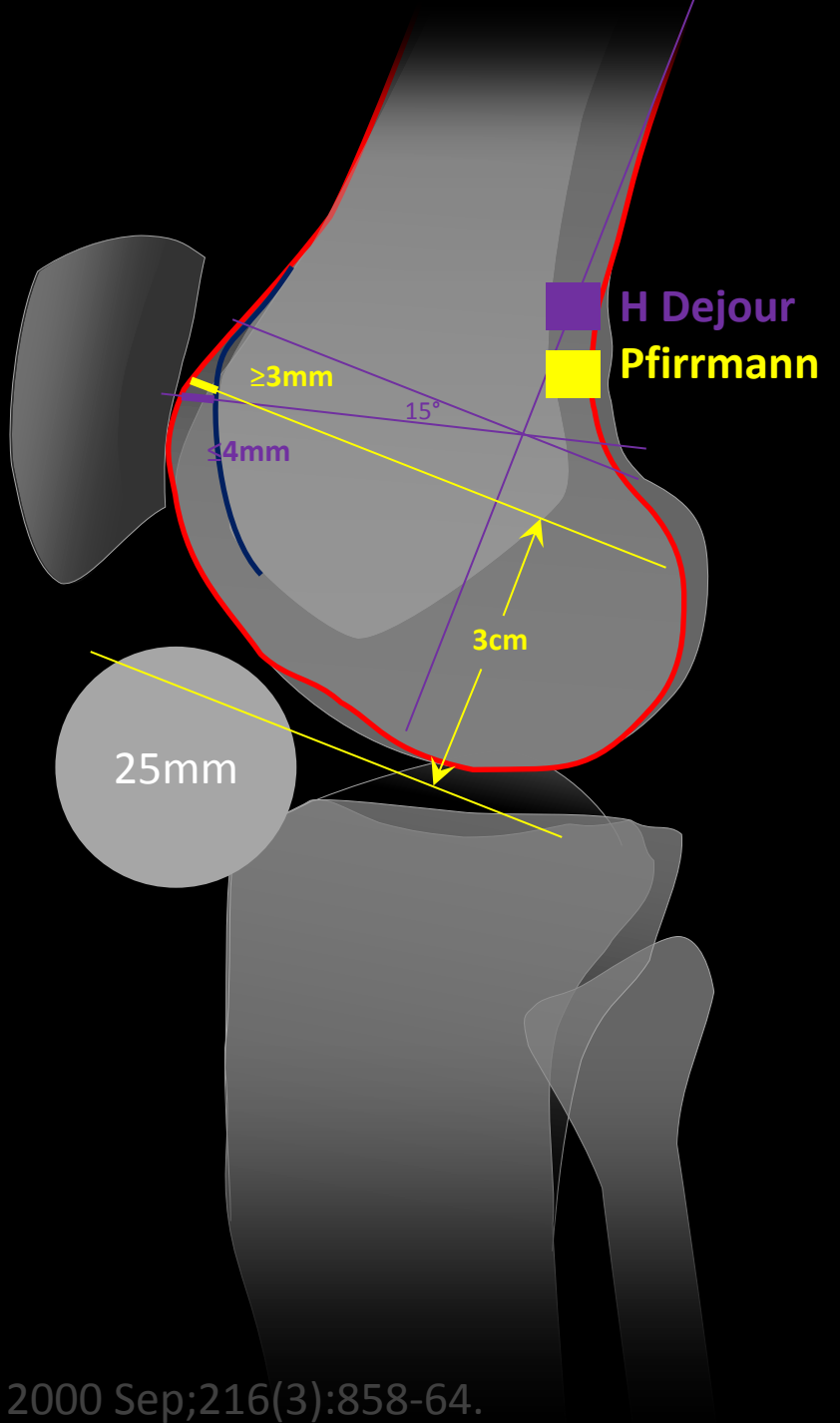


Dejour H et al. Knee Surg Sports Traumatol Arthrosc. 1994;2(1):19-26.
Dejour D, Saggin P. Int Orthop. 2010 Feb;34(2):311-6. Dejour D et al. Med Hyg. 1998;56:1466-71.

Pfirrmann (MRI)

- Knee in extension
- Includes cartilage
- Sensitivity 100%, specificity 96%

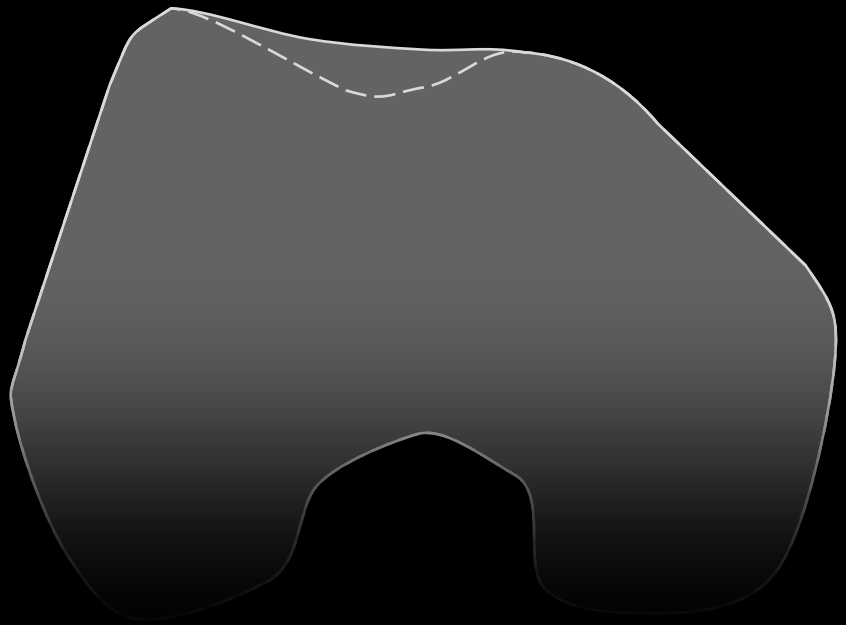


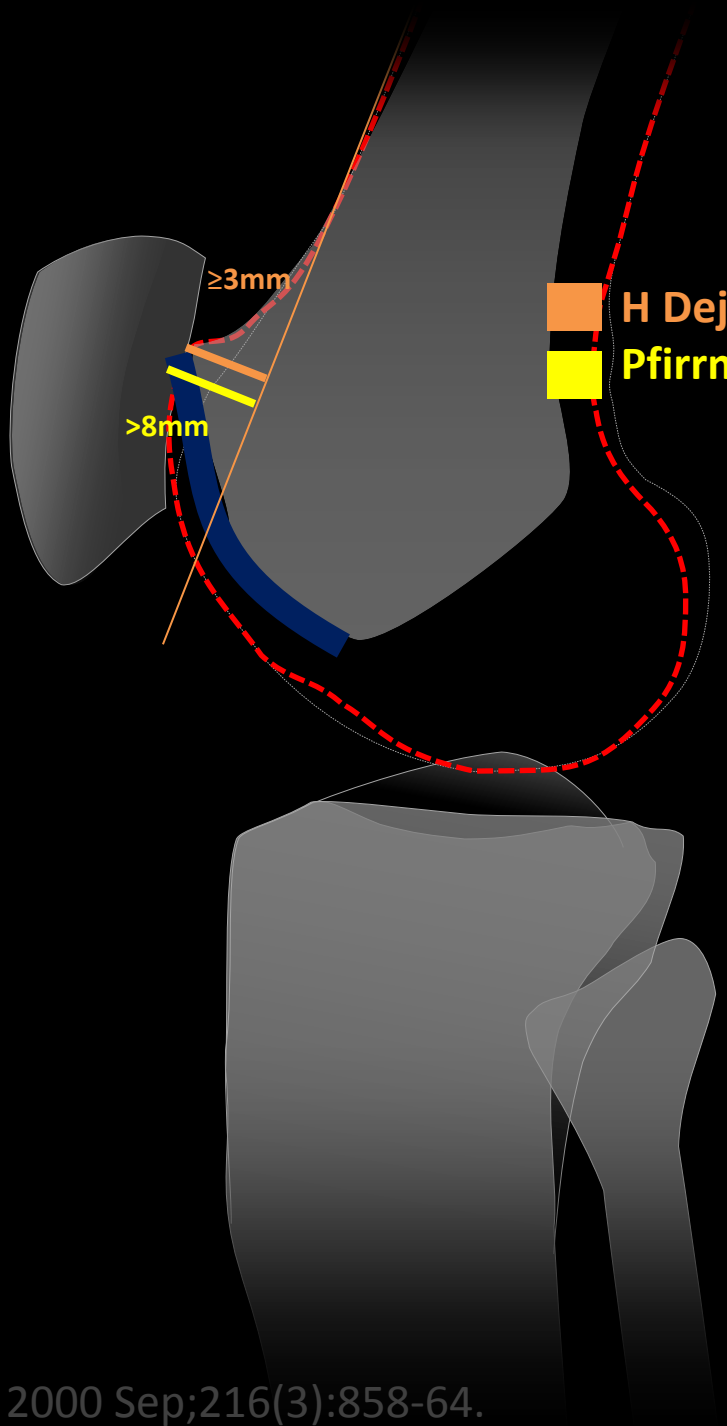


Pfirrmann CW et al. Radiology. 2000 Sep;216(3):858-64.

Pfirrmann (MRI)

- Knee in extension, midsagittal
- Includes cartilage
- Sensitivity 75%, specificity 83%



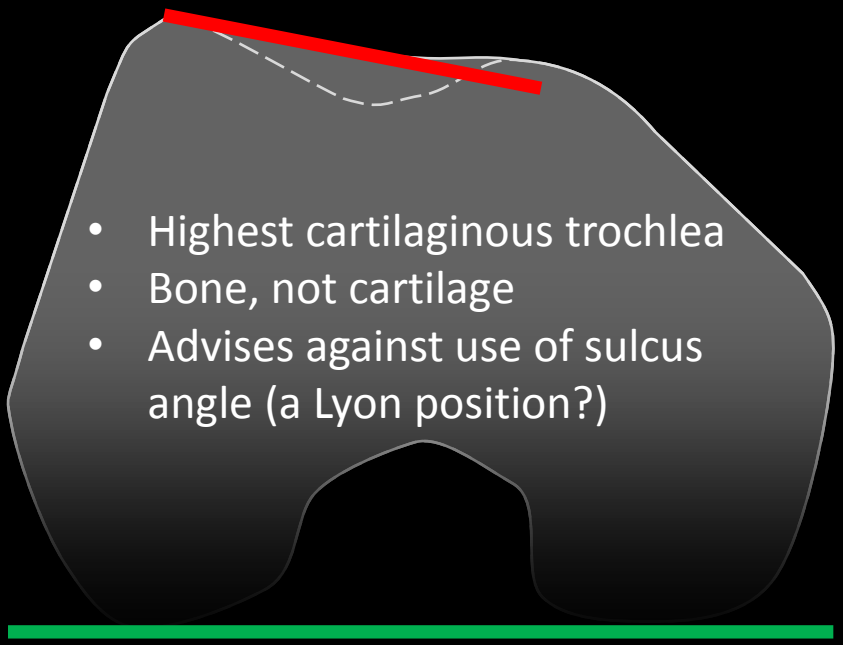


Pfirrmann CW et al. Radiology. 2000 Sep;216(3):858-64.

Miscellaneous Measures of Dysplasia

Lateral Trochlear Inclination

tilt ≥ 11°

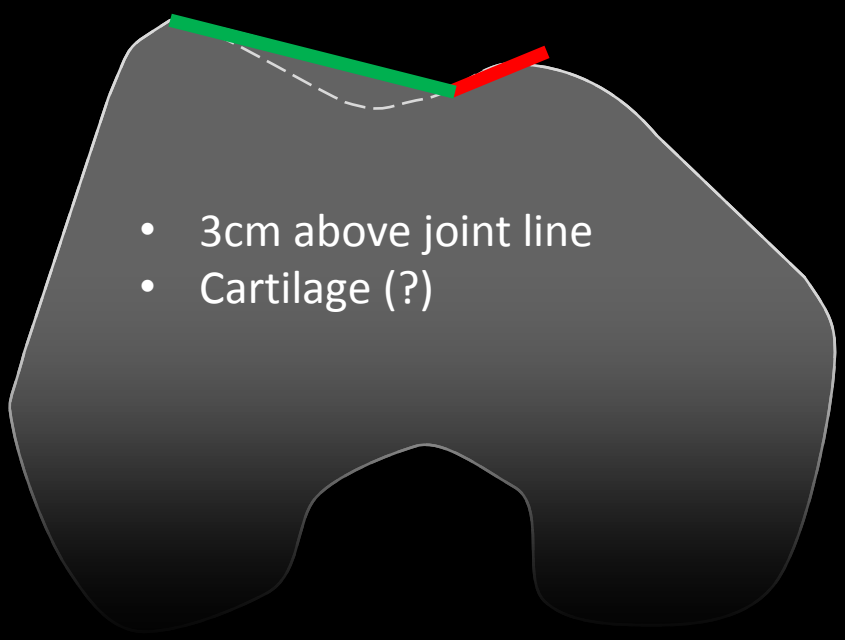


- Highest cartilaginous trochlea
- Bone, not cartilage
- Advises against use of sulcus angle (a Lyon position?)

Carrillon Y et al.
Radiology. 2000 Aug;216(2):582-5.

Facet Asymmetry

A/B ≥ 0.40



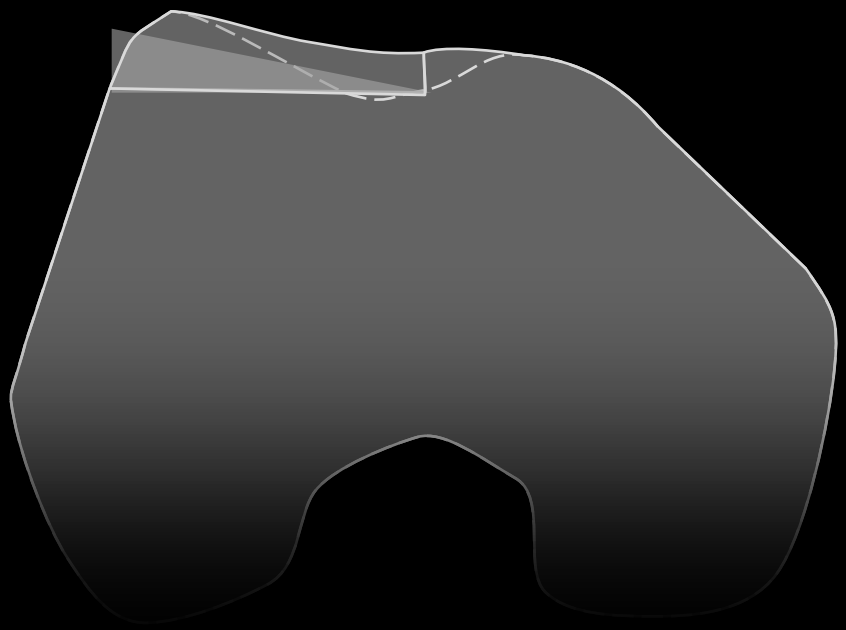
- 3cm above joint line
- Cartilage (?)

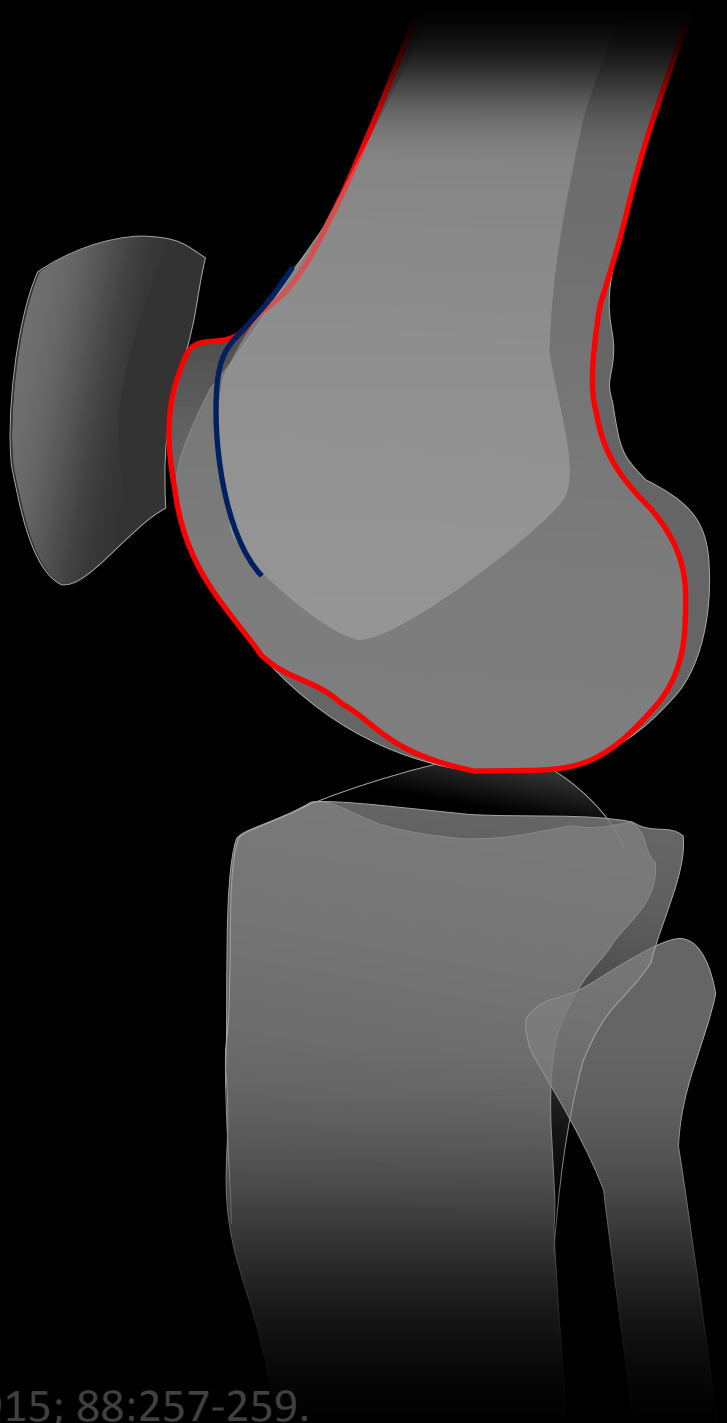
Pfirrmann CW et al.
Radiology. 2000 Sep;216(3):858-64.

Albee

1915

- First, but wrong, approach
  - Raising edge vs lowering center
- Elevates contact pressures



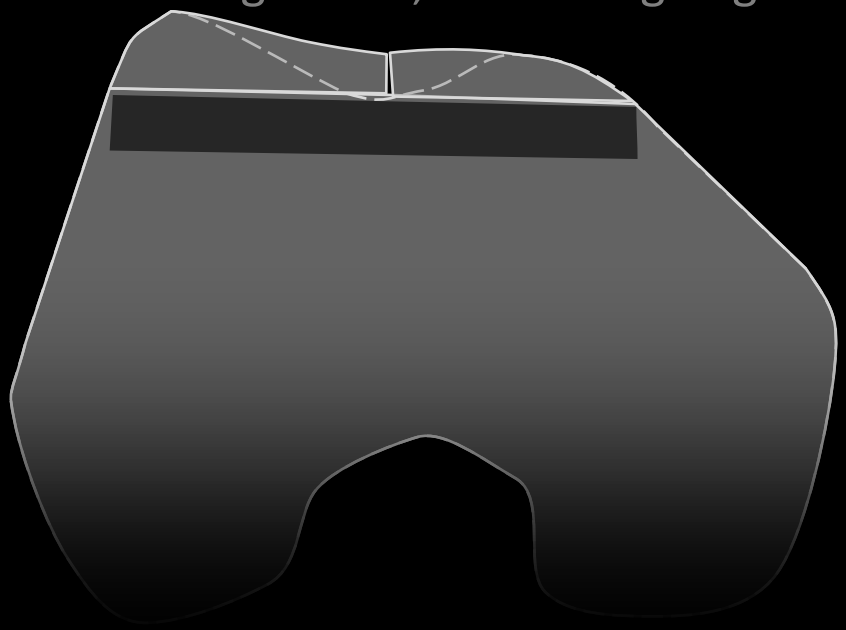


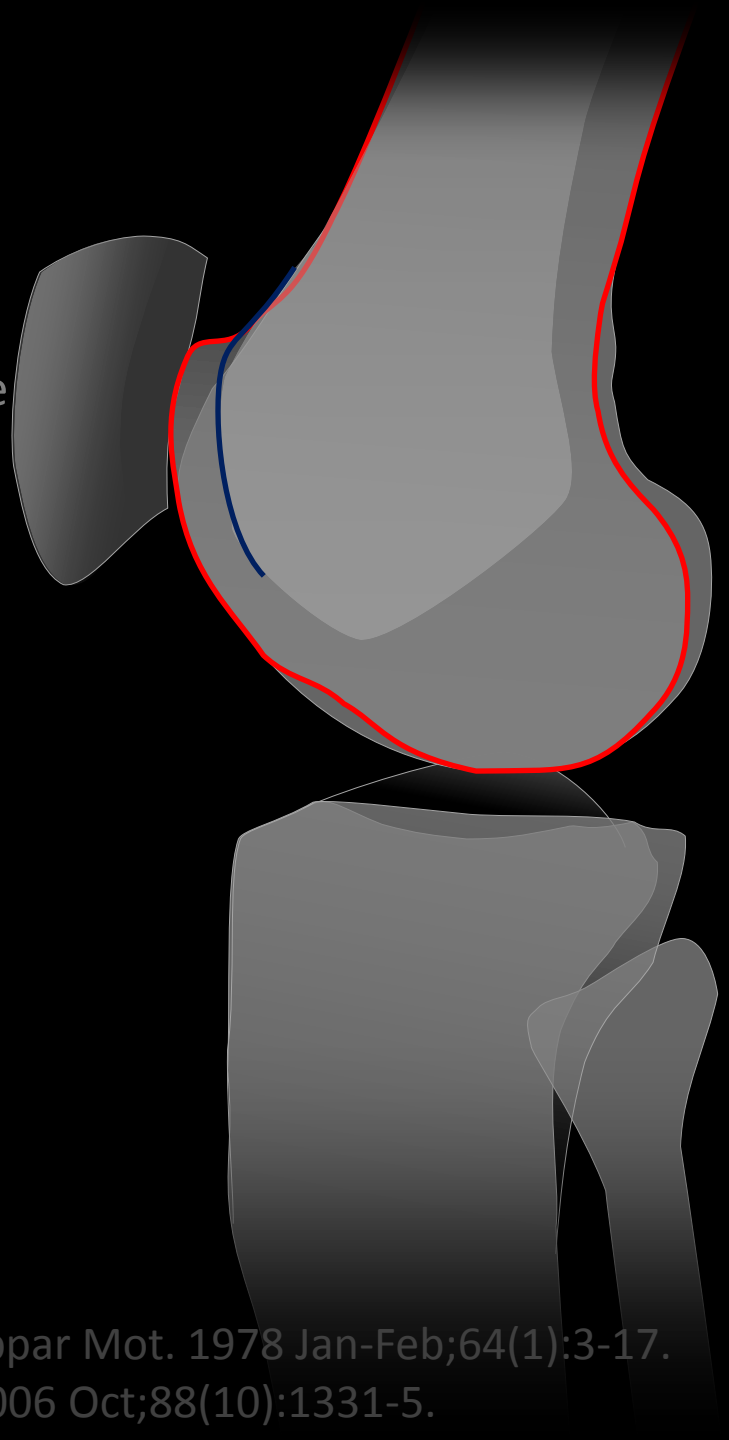
Albee FH. Med Rec 1915; 88:257-259.

Masse(–Dejour)

1978

- "Deepening trochleoplasty"
  - Variant: Bereiter thin-flap technique
- Corrected approach
  - Lowering center, not raising edge



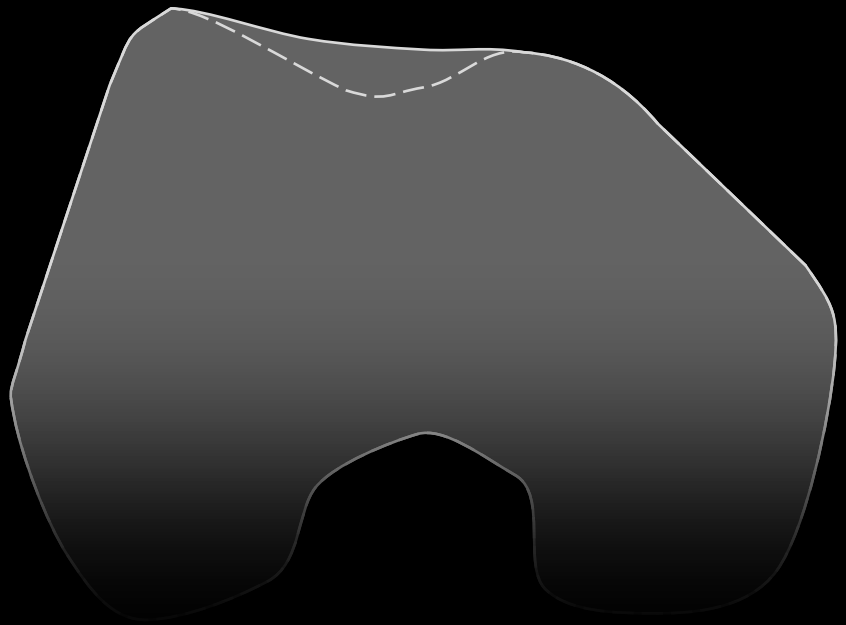


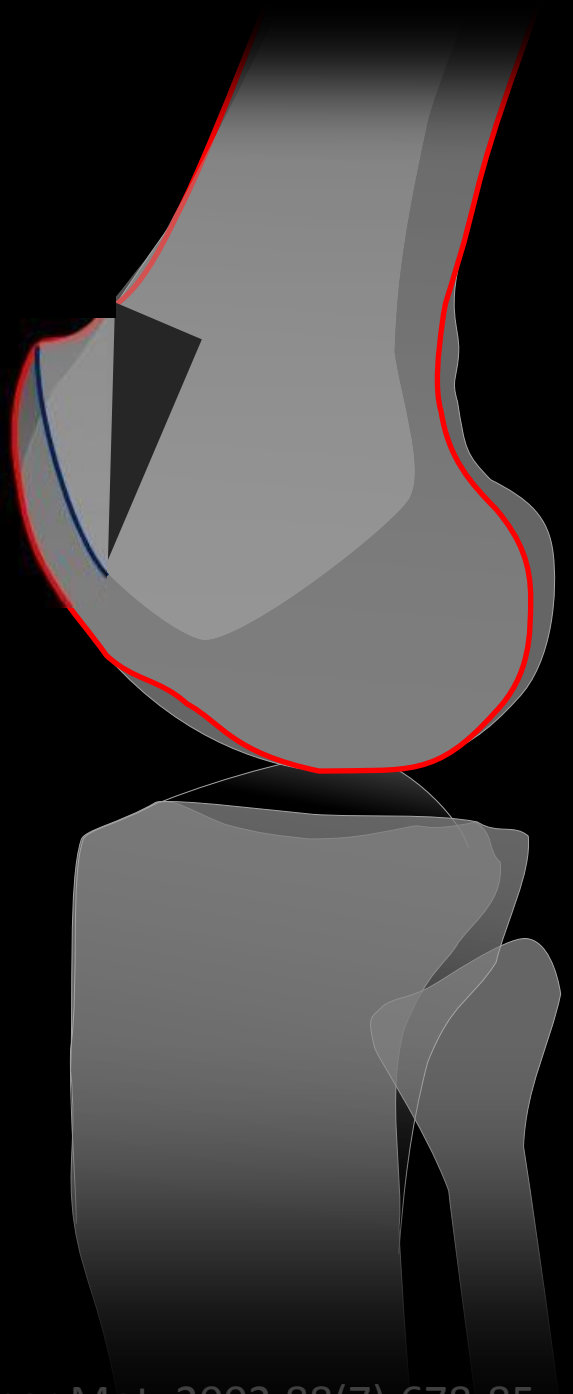
Masse Y. Rev Chir Orthop Reparatrice Appar Mot. 1978 Jan-Feb;64(1):3-17.
von Knoch F et al. JBJS Br. 2006 Oct;88(10):1331-5.

Goutallier

2002

- “Wedge recession trochleoplasty”
- Aims to correct supratrochlear bump
- Trochlea itself unchanged





Goutallier D et al. Rev Chir Orthop Reparatrice Appar Mot. 2002;88(7):678-85.

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Dejour H et al. Knee Surg Sports Traumatol Arthrosc. 1994;2(1):19-26.

Takeaway Points

- Appreciate patellar biomechanics, normal and abnormal
- Understand factors predisposing to maltracking:
  - Patella alta
  - Excessive TT–TG (Q angle)
  - Patellar tilt/subluxation
  - Trochlear dysplasia
- Observe and measure under validated conditions.

merci