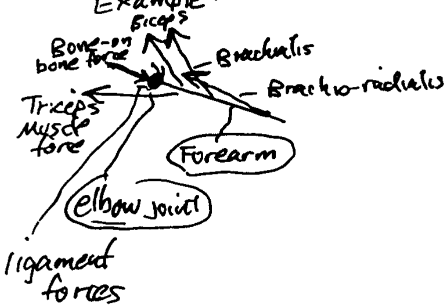
Kinetics of knee joint

Terms:

Resultant force at joint (   )
" moment " (   )

Example:



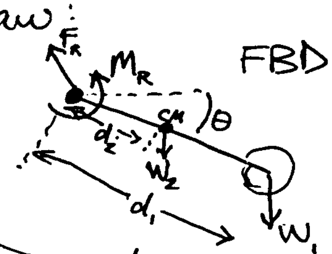
Note: There are many forces which arise in the upper arm that cross the elbow and influence forearm motion

These can be more simply represented by a single force (vector sum of all individual forces) and a single moment (vector sum of all individual moments)

F = " "
M = "

F_R & M_R can be computed knowing the mass & moment of inertia of the forearm & hand, linear & angular accelerations of the forearm & hand, the center of mass location of the forearm & hand, and any external forces e.g. weights applied to the forearm + hand

Use Newton's 2^{nd} Law: FBD:



Know m, a, I, α — Find ΣF, ΣM

(I estimated from cadaver data; α measured from film or video)

ΣF → Resultant force on forearm + hand

ΣM → Resultant moment on forearm + hand

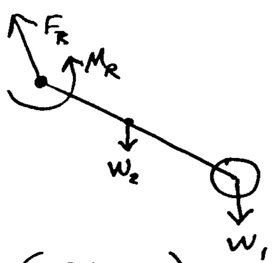
ΣF is the vector sum of F_R, W_2, W_1

ΣM_{CM} is the vector sum of the moments about CM of F_R, W_2, W_1 and M_R

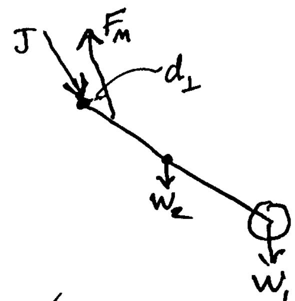
From this the only unknowns are F_R & M_R — Resultant force & moment at elbow joint

This process is called " "

["Forward dynamic analysis" involves knowing the forces & moments — compute the linear & angular accelerations.]



(FBD #1)



(FBD #2 very simple :)

Assumes only one elbow flexor (e.g.) is active and no extensor activity

If we equate these two diagrams then F_R is the

also M_R is the moment about the elbow joint produced by F_m ($M_R = F_m \cdot d_\perp$)

Note F_R and J are not the same

$\vec{\ } = \vec{\ } + \vec{\ }$

J is called various things by various authors

Nordin & Frankel ( ) textbook calls J "________"

Hinrichs (lecture notes) has called this "________"

Winter (1990) refers to J as "________"

Perhaps the best term is "________"?

Why not simply follow your textbook and call J "joint reaction force"?

Because Winter (1990) uses that term (joint reaction force) to mean the same thing as F_R (resultant joint force).

Therefore Hinrichs suggests avoiding the term joint reaction force altogether.

Hinrichs will refer to F_R & M_R as ________ & ________, respectively. J & F_M will be called the ____ force and ____ force, respectively.

Knee joint kinetics

Tibiofemoral joint

Example problems in Wiktorin & Nordin

Problems 8.8 and 8.6 on the following pages are from Wiktorin & Nordin (1986).

8.8. Loading of the Tibiofemoral Joint during Quadriceps Muscle Exercises with the Knee Extended and Flexed

Moment Equilibrium; Force Equilibrium

The quadriceps muscle is exercised isometrically with the knee flexed 30° and 90°. Because the purpose of the example is to show the effect of the knee joint angle on the internal forces on the tibiofemoral joint, the external force is kept constant.

The angles given for the line of application of the patellar tendon force are based on the average angles for 26 young men (Smidt, 1973).

Problems

8.8A. A patient is sitting and exercising the quadriceps muscle with the knee flexed 30°. At the ankle, 0.4 m from the center of motion of the knee, an external force of 150 N is applied perpendicular to the long axis of the tibia (Figure 8.8A). The moment arm of the quadriceps muscle force is 0.05 m. The force transmitted through the quadriceps tendon acts at an angle of 20° to the long axis of the tibia. The tibial plateau is perpendicular to this long axis. The weight of the lower leg may be disregarded.

How large a force (Q) must the quadriceps muscle exert for the lower leg to remain in 30° of flexion?

How large is the tibiofemoral joint reaction force (R)?

How large is the shear force (S) on the tibiofemoral joint?

In Figure 8.8A, draw in the force components acting on the lower leg parallel to the tibiofemoral joint surface.

8.8B. The same patient flexes the knee 90°. The patellar tendon then parallels the long axis of the tibia (Figure 8.8B). All other conditions are identical to those in problem 8.8A.

How large a force (Q) must the quadriceps muscle produce for the joint angle of 90° to be maintained?

How large is the tibiofemoral joint reaction force (R)?

How large is the shear force (S) on the tibiofemoral joint?

In Figure 8.8B, draw in the force components acting on the lower leg parallel to the tibiofemoral joint surface.

Discussion Questions

1. Is the magnitude of the tibiofemoral joint reaction force (R) affected by the knee joint angle?

2. Which cruciate ligament transmits loads during the quadriceps muscle exercise against resistance with the knee flexed 30°? With the knee flexed 90°? Assume that the anterior cruciate ligament absorbs ventrally directed shear forces and that the posterior cruciate ligament absorbs dorsally directed shear forces.

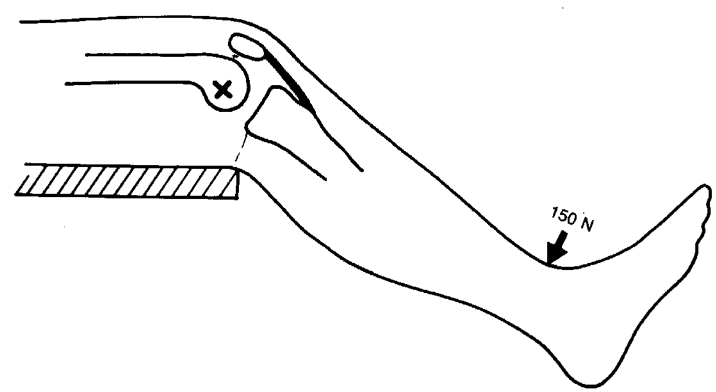


Figure 8.8A. Quadriceps muscle exercise with the patient in a sitting position and the knee flexed 30°. An external force of 150 N is applied to the ankle perpendicular to the long axis of the tibia. The alignment of the patellar tendon is shown.

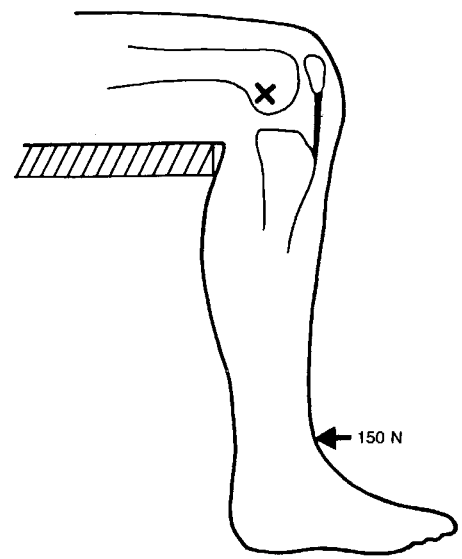
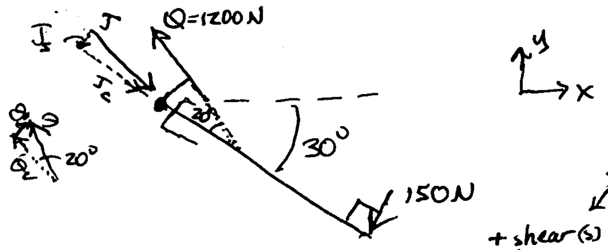
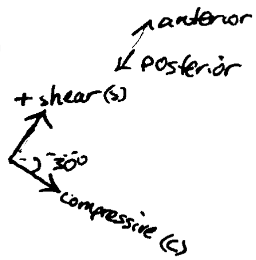


Figure 8.8B. Quadriceps muscle exercise with the patient in a sitting position and the knee flexed 90°. An external force of 150 N is applied to the ankle perpendicular to the long axis of the tibia. The alignment of the patellar tendon is shown.





$\Sigma F_c = 0$

$J_c - Q_c = 0$

$J_c = Q_c = Q\cos 20^\circ$

$=$ ______ N

$\Sigma F_s = 0$

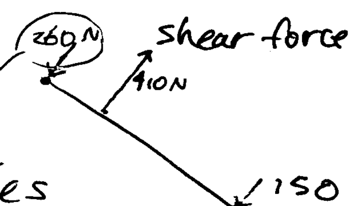
$-J_s + Q_s - 150N = 0$

$J_s = Q_s - 150 = Q\sin 20^\circ - 150 = 1200\sin 20^\circ - 150N$

$J_s =$ ______ N $=$ [   ] (shear force at joint)

$J = \sqrt{J_c^2 + J_s^2} =$ ______ N $=$ [N]

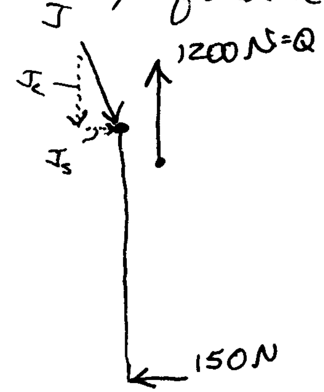
shear force comparison:



ACL provides this shear force (provides posteriorly directed shear force) to counteract the net anteriorly directed force

primarily provided by quadriceps muscle force.

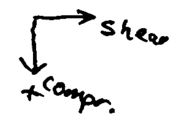
90° knee angle



$\Sigma F_c = 0$

$J_c - Q = 0$

$J_c = Q =$ ______ N



$\Sigma F_s = 0$

$J_s - 150 = 0$

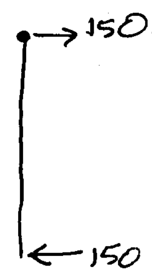
[$J_s =$ N]

shear force

$J = \sqrt{J_c^2 + J_s^2} = \sqrt{1200^2 + 150^2}$

$=$

$=$ [N]



directed anteriorly to counteract the posteriorly directed shear force from the weight machine

Knee joint kinetics (cont'd)

Functions of Patella:

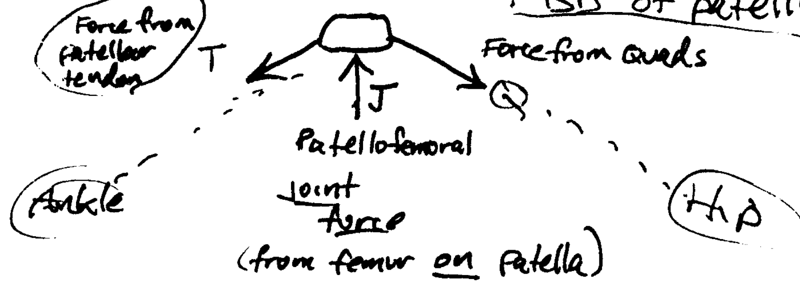
1.

2.

the front of the knee from acute forces from impacts (e.g. w/ ground) It spreads these forces over a larger area on front of the distal femur.

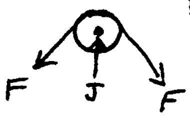
3. It acts somewhat like a "sliding see saw" as it moves into the groove between femoral condyles. In the process it modulates the forces above it (from quadriceps) and below it (from the tibia pulling back)

FBD of patella



Your textbook does not discuss this function #3. By assuming patella to be a "frictionless pulley" then T = Q by definition. However, this is not the case. $T \neq Q$ generally and the patella acts to modulate the ratio of T/Q as needed to best serve the needs of the knee joint.

Frictionless pulley model
F = F on both sides



see saw model $T \neq Q$ necessarily

if system is in equilibrium
Then $\Sigma M_A = 0$

— = 0

=

Q = Quad muscle force
= Patellar tendon force (ligament)

if $d_Q > d$
then T > Q

see studies by Huberti et al (1984) & Eijden et al (1986) which showed when knee is fully extended $T \approx Q$ (or perhaps may be slightly more than Q). When knee is flexed up to about 30-40°, then T > Q [Huberti et al T/Q maxes at 1.25 at 30° then drops]. When knee is flexed beyond 50° or so, then T/Q < 1 (P<Q). Huberti et al reported T/Q minimum to be ~ 0.75 at 90-120° angle.

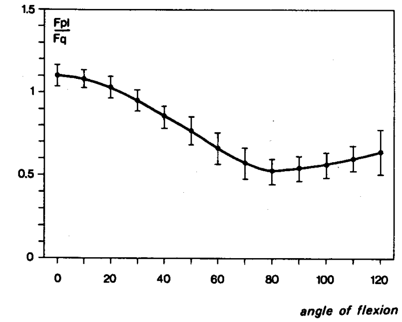


Fig. 10. Ratio F_{pl}/F_q between patellar ligament force and quadriceps force vs flexion angle.

from Eijden et al. (1986). *J. Biomech.*, 19, 219-29.

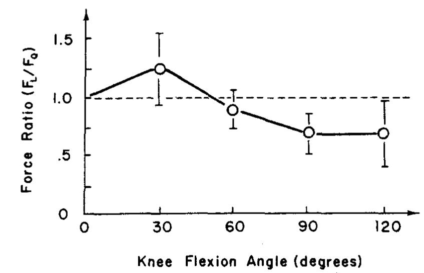


FIG. 3. Force ratio (F_L/F_Q) of ligamentum patellae force (F_L) to quadriceps tendon force (F_Q) as function of flexion angle. At 30° F_L is approximately 30% greater than F_Q. At 90 and 120° F_L is approximately 30% less than F_Q.

from Huberti, et al. (1984). *J. Orthop. Res.* 2: 49-54.

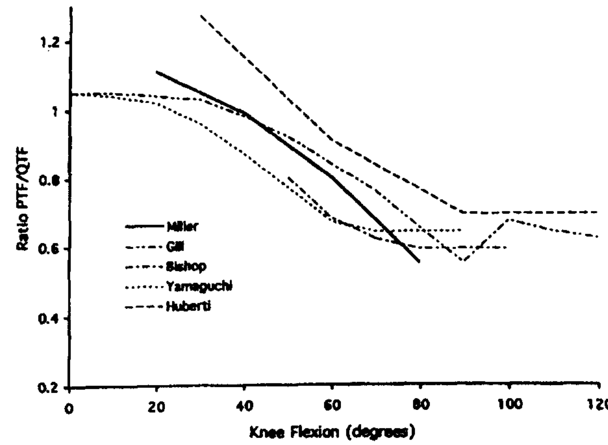


Figure 7. The ratio of the patellar tendon force (PTF) and the quadriceps tendon force (QTF) plotted against knee flexion (mean and SD). The current study is compared with previous *in vitro*[3,8] and theoretical studies[13,15].

from Miller et al. (1997). *Clinical Biomechanics*, **12**, 1-7.

8.6. The Patellofemoral Joint Reaction Force during Quadriceps Muscle Exercises with the Knee Extended and Flexed

Composition of Forces

This example shows the effect of the knee joint angle on the patellofemoral joint reaction force during quadriceps muscle exercises. It can be used in planning and discussing exercise programs for patients with chondromalacia patellae, in whom the magnitude of the patellofemoral joint reaction force must be taken into consideration.

The angle between the patellar tendon and the quadriceps tendon (Figure 8.6) varies with the knee joint angle. In the example, the values for this angle are taken from a study by Matthews et al. (1977), who determined the angle radiographically after placing two metal wires along each of these tendons.

Problems

8.6A. A patient is exercising the quadriceps muscle isometrically from a sitting position with the knee flexed 5°. The quadriceps muscle force (Q) is 1000 N. The angle between the patellar tendon and the quadriceps tendon is 35° (Figure 8.6, top). How great is the patellofemoral joint reaction force (P) at equilibrium? The patella can be considered as a frictionless pulley. The force transmitted through the patellar tendon is designated as T.

8.6B. The patient exercises the quadriceps muscle with the knee flexed 45°, and then 90°. The quadriceps muscle force in both cases is 1000 N.

How large is the patellofemoral joint reaction force (P) at the two joint angles if the angle between the patellar tendon and the quadriceps tendon is 55° at 45° of knee flexion (Figure 8.6, middle) and 80° at 90° of knee flexion (Figure 8.6, bottom)? Consider the patella as a frictionless pulley.

Plot the values for forces Q and P for each of the three joint angles in a coordinate system in which the horizontal axis represents the knee joint angle and the vertical axis represents the magnitude of the forces.

Discussion Question

Cite some factors that influence the magnitude of the patellofemoral joint reaction force.

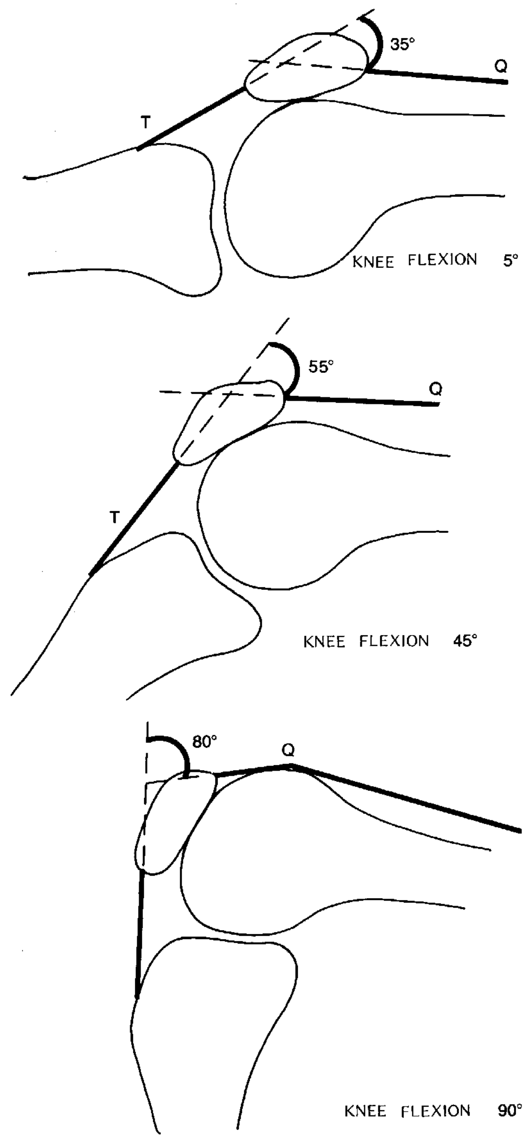
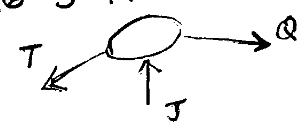


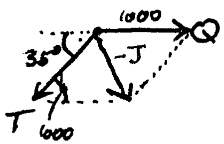
Figure 8.6. The angle between the patellar tendon (T) and the quadriceps tendon (Q) is 35° at 5° of knee flexion (top), 55° at 45° of knee flexion (middle), and 80° with the knee flexed 90° (bottom).

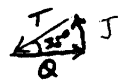
8.6 5° Flexion



$Q = T = 1000\,N$

$\Sigma F = 0$





$J^2 = T^2 + Q^2 - 2TQ\cos 35°$

Law of cosines

$J = \sqrt{T^2 + Q^2 - 2TQ\cos 35°}$

$= \sqrt{\quad}$

$=$ ______

$\Sigma F_x = 0 \Rightarrow J_x$

$\Sigma F_y = 0 \Rightarrow J_y$

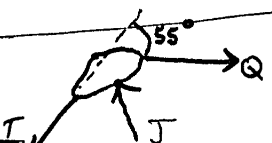
$J = \sqrt{J_x^2 + J_y^2}$

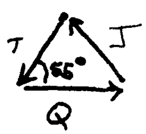
45° Flexion

$J = \sqrt{T^2 + Q^2 - 2TQ\cos 55°}$

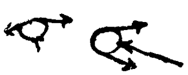
$J = \sqrt{1000^2 + 1000^2 - 2(1000)^2\cos 55°}$

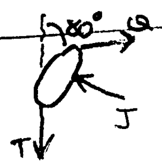
$=$ ______ N

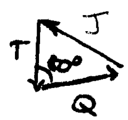




90° Flexion







$J = \sqrt{1000^2 + 1000^2 + 2(1000)^2\cos 80°}$

$=$ ______

8.6 w/ $T =$ Q

$J_x = \Sigma F_x = 1000 - \quad \cos\phi$ (35°)

$J_y = \Sigma F_y = 0 - \quad \sin\phi$

$J = \sqrt{x^2 + y^2}$

$=$ ______ N $\qquad \theta = \tan^{-1}(\text{—})$ $=$ ______

Law of cosines: (magnitude)

$J = \sqrt{1000^2 + \quad^2 + 2(1000)(\quad)\cos 145°}$

$=$ ______

Law of sines:

$\frac{\sin\theta}{\quad} = \frac{\sin 35°}{J}$

$\sin\theta = \frac{\sin 35°}{J}$

$= \frac{\sin 35°}{\quad} =$

$\theta = \sin^{-1}(\quad) =$

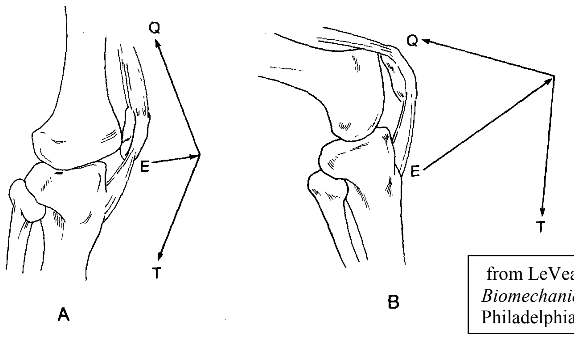


FIGURE 5–34

Concurrent force system at the patellofemoral joint. Q = quadriceps muscle force; T = patellar tendon force; E = equilibrant of the two forces that occurs at the patellofemoral joint. Note that the magnitude of E changes as the knee angle and muscle force change.

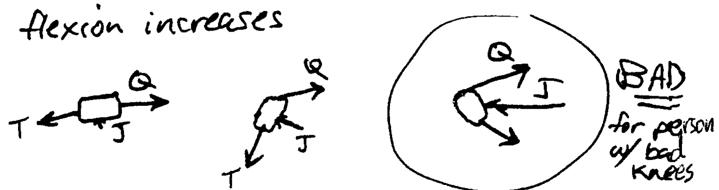
from LeVeau, B. (1992). *Williams and Lisner's Biomechanics of Human Motion.* W.B. Saunders, Philadelphia.

How do these forces T & Q affect the patellofemoral joint force (J)?

General relationships:

1. J ______ with increases in Q &

2. J ______ as the degree of knee flexion increases



J gets very large when knee is fully flexed

Data from Reilly & Martens (1972) Peak values

level walking	J ≈	BW
stair climbing & descending	J ≈	BW
Knee bends	J ≈	BW

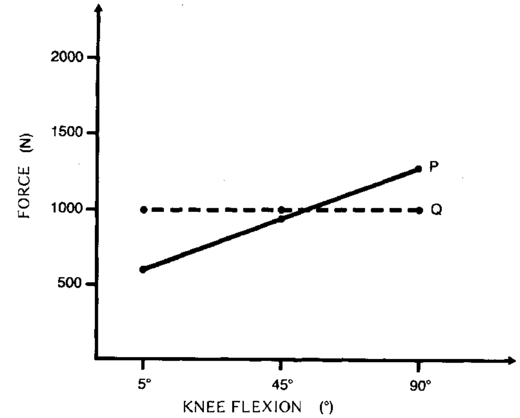


Figure 8.10.7. The patellofemoral joint reaction force (P) at three knee joint angles (5°, 45°, and 90°) with the quadriceps muscle force held constant (Q = 1000 N).

from Wiktorin & Nordin (1986).

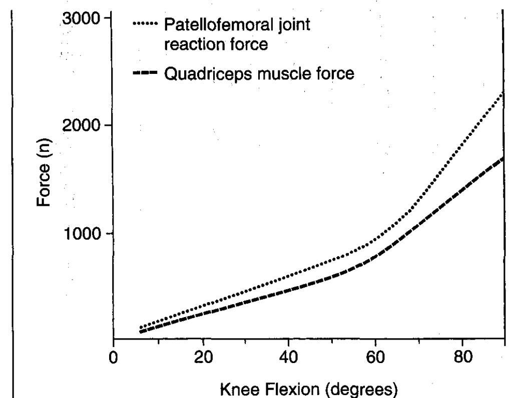


FIG. 7-21

Patellofemoral joint reaction force and quadriceps muscle force during knee bend to 90° (three subjects). *Adapted from Reilly, D.T. & Martens, M. (1972). Experimental analysis of the quadriceps muscle force and patellofemoral joint reaction force for various activities.* Acta Orthop Scand, 43, *126*

from Nordin & Frankel (2001).

Assigned article to read but <u>no</u> <u>critique</u> <u>necessary</u>.

Grabiner et al. (1994) Neuromechanics of the patellofemoral joint <u>Med. Science Sports Ex.</u> <u>26</u>, 10-21.

Patellar mistracking is generally believed to be associated with weakness in the ______ ______ muscle ( ) compared to the ______ ______ ( ). There is a controversy, however, as to whether or not one can selectively activate and strengthen the VMO without also activating & strengthening the VL. Grabiner et al review many recent studies — one possible conclusion is that a general ______________________ as a whole may bring the VMO strength up above a ______ ______ and perhaps VMO strength (even with VL strength gains) is crucial to proper patella tracking and reduction of pain. (Read the article for further information.)

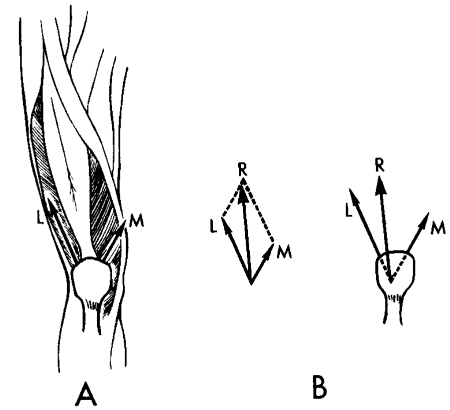


FIGURE 4–21

In locating the single resultant vector (R) of the combined vastus lateralis (L) and medialis (M) muscle forces on the patella, their action lines are extended to the point of intersection.

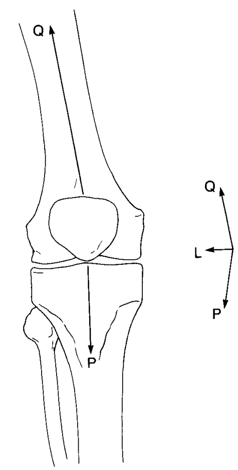
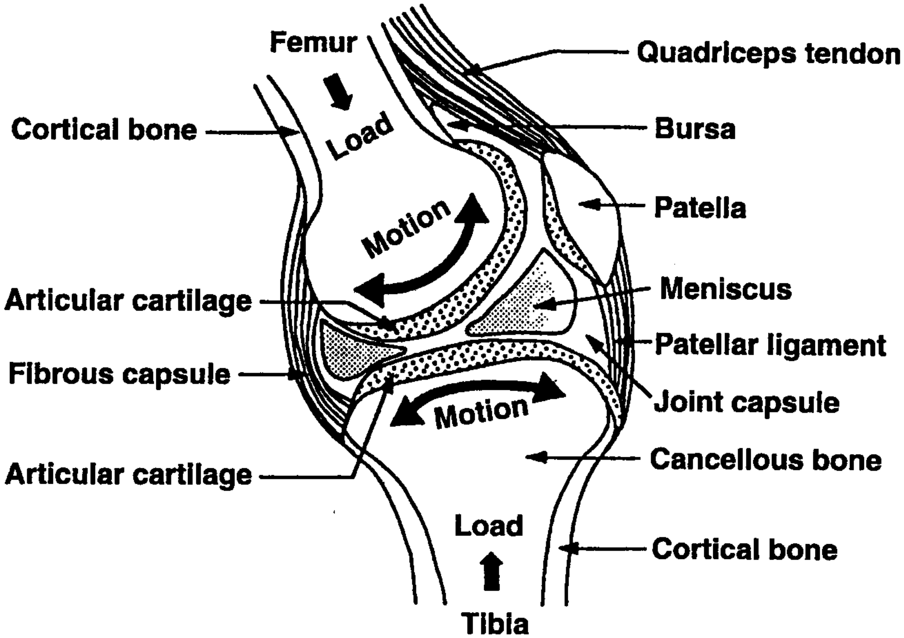


FIGURE 4–22

Force vectors of quadriceps muscles resultant and patellar tendon can give lateral resultant to produce subluxation or dislocation.

Figures on this page from LeVeau, B. (1992). *Williams and Lisner's Biomechanics of Human Motion*. W.B. Saunders, Philadelphia.

Meniscus



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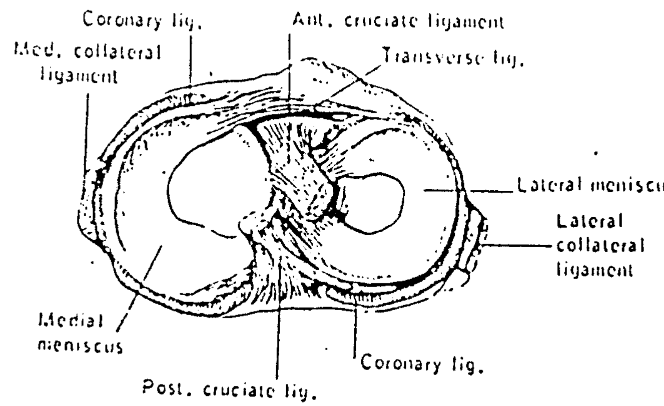

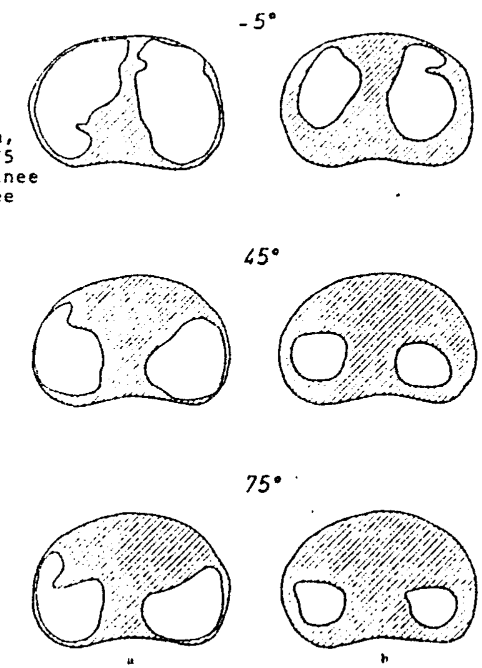

Figure 2[13]-Tracings of weight-bearing areas at 5 degrees hyperextention, 45 degrees flexion and 75 degrees flexion. Left: knee with menisci. Right: knee without menisci