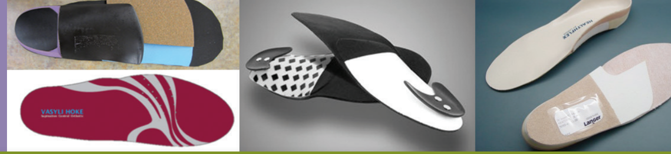
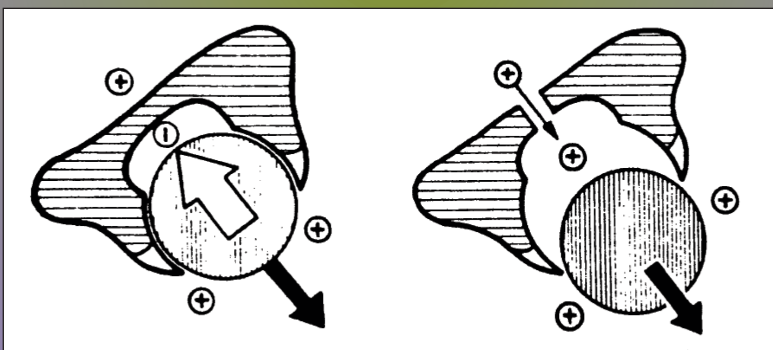


Mechanics of Joints and Muscle Actions

Here's a refresher on the basics of this science.

BY J. DAVID SKLIAR, DPM



Objectives

1) To appreciate the properties of the bones involved with stance and walking.

2) To appreciate the microscopic structure of joints and the factors necessary to prevent their disruption and eventual osteoarthritis.

3) To appreciate the effects of muscle forces on bones and joints.

4) To recognize the structural differences in flexors and extensors and the role they play in stance and in gait.

5) To be able to know what muscle limitations may be if a muscle transfer is required.

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*Following this article, an answer sheet and full set of instructions are provided (pg. 140).—**Editor***

Joint Structure and Function

Certain properties of joints are essential to normal function. Inadvertently destroying one of them, as in trauma or by surgery, can lead to degenerative joint disease (arthritis).

There are two smooth cartilaginous surfaces of a diarthrodial (movable) joint. Between the two surfaces is a film of viscous synovial fluid. Underneath the cartilage is a thin layer of subchondral bone which is joined to the cartilage by a layer of irregular calcified cartilage. The subchondral bone distributes the load gradually to the cortex of the bone. Ligaments help stabilize the joint,

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and a lax capsule enfolds in the plane of greatest motion. The capsule creates a closed joint cavity to maintain the synovial fluid (Figure 1).

Lubricant Film

It is a viscous film that lies between the two adjacent cartilaginous surfaces. It adheres to the cartilage chemically and permeates into it slightly. The ability of a joint to function normally is dependent upon keeping the integrity of the lubricant film. The synovial fluid is unique in that it has variable viscosity, being thinner for fast moving joints and thicker for slow moving joints.

Graduated Flexibility

From the cartilaginous surface to the midshaft of the bone there is a gradual change in the structure of the bone to one of increasing rigidity. This graduated flexibility is crucial to the joint function. A loss of this flexibility, as from pathology (e.g., Paget's disease) or by excessive bone callus from a healing local fracture, can be responsible for subsequent hypertrophic arthritis (Figure 2).

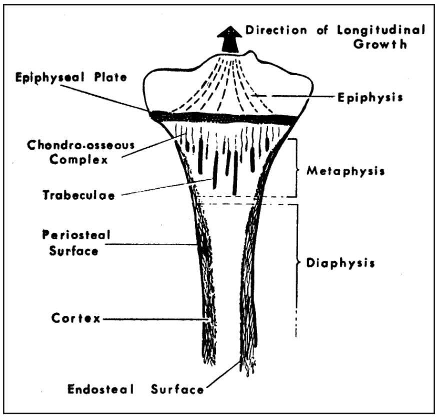

Figure 2: Graduated flexibility. The distal aspect is most flexible. The mid-portion of the bone is most rigid.

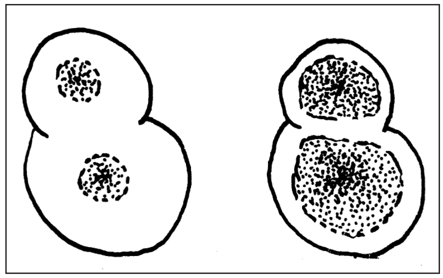

Figure 3: The tibial articulating surface of the knee, as seen from above. Left: The stippled area is the region of effective load transfer. Right: Under heavy load, the transfer area increases because the subchondral structures yield to allow this.

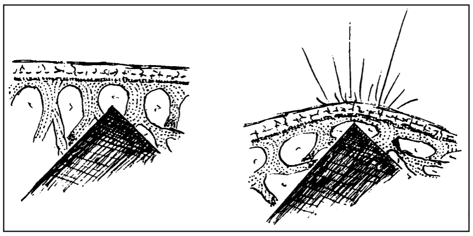

Figure 4: The dark mass represents a nail that is too close to the joint surface. Left: No load, no high spot. Right: Under heavy load, the rigidity of the nail causes a bump in the joint surface.

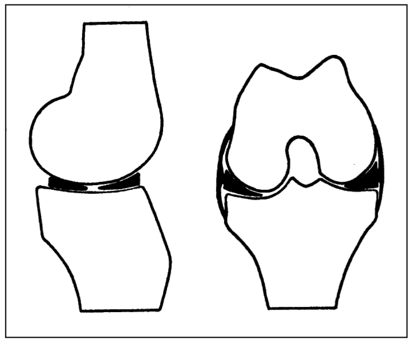

Figure 5: The knee as an example of an incongruent joint. This is adjusted by the menisci which increase the area of contact.

Joint Congruency

At rest, joint surfaces do not mate perfectly. As the load increases, the effective transfer area increases by virtue of the synovial fluid and the flexibility of the cartilaginous ends of the bones (Figure 3).

The shape of the contacting surfaces, and particularly the congruency, determines the function of the joint. The joint cartilage is subjected to a good deal of pressure from gravitational forces and muscular tension. Great demands are thus made on the elastic properties of cartilage.

The size of the contact area of cartilage is directly related to the amount of pressure in the joint. However, the amount of time a deforming force is applied to the cartilage affects its elasticity. It is in this aspect that most joint abuses occur via prolonged standing or prolonged maintenance of the joint in one position.

In addition, a smooth even distribution of the subsurface flexibility is essential. Local stiffening under cartilage can create a stress sufficient to break the lubricant film, resulting in cartilage breakdown (Figure 4).

Some joints have a large common area (e.g. ankle joint). Others are highly incongruent (e.g. knee joint, subtalar joint and midtarsal joint) (Figure 5).

The way in which a normal joint is loaded can change to produce a situation that exceeds the limits that

Continued on page 135

Joint cohesion is aided in general by ligaments, muscle tension, fascia, and atmospheric pressure.

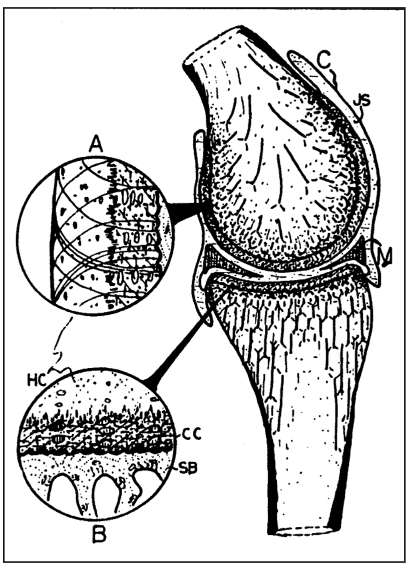

Figure 1: The knee as a joint prototype. C: capsule. JS: joint space. M: meniscus. HC: hyaline cartilage. CC: calcified cartilage. SB: subchondral bone.

Joints *(from page 134)*

can be compensated for by the normal flexibility. Genu valgum, for example, causes the lateral side of the knee to receive too much compression stress, and after some years, results in joint failure (Figure 6).

Joint Cohesion

In addition to the inherent stability joints possess, their cohesion is aided in general by ligaments, muscle tension, fascia, and atmospheric pressure. The latter is particularly true in the hip joint. When all muscles, ligaments, and capsule of the hip joint are severed, the head does not fall out of its socket; but when a hole is bored into the acetabulum from behind, the head is promptly released (Figure 7).

Moreover, x-rays taken under traction show a translucency between the joint ends, indicating a vacuum. In high altitudes, where atmospheric pressure is reduced, the loss of joint cohesion has to be accommodated for by increased muscular tension, which contributes to premature fatigue.

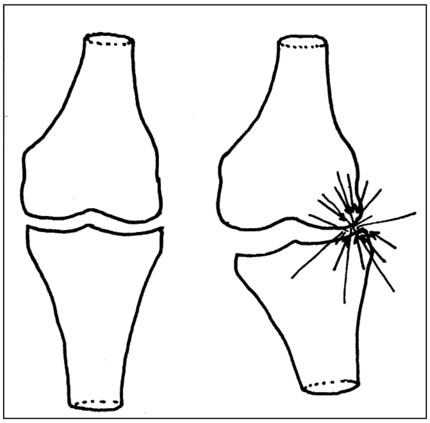

Figure 6: If a normal knee (left) is thrown out of alignment for a protracted time (right), the load concentration at the contact side will cause it to break down.

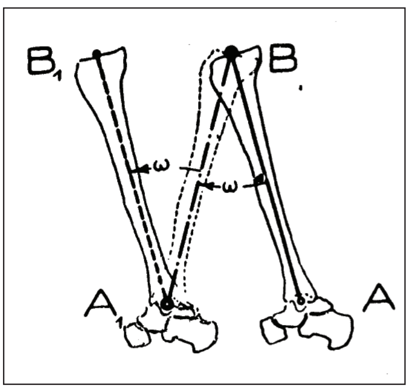

Figure 8: Transformation of two rotations, about the ankle and knee, into a translatory forward motion of the leg.

in the stance phase of gait).

The question arises, why is a kinetic chain necessary at all? The hip joint is capable of motion in all body planes (abduction and adduction, flexion and extension, and internal and external rotation). These motions are sufficient to change the position of the entire limb without involving any changes in other members of the link. Indeed, if we walked on a globular surface and only required one certain step length, i.e., the length of the closed kinetic chain, there would be no need for other joints of the lower extremity; however, more often than not, we are required to plant the foot within the radius of the limb and it is the action of the knee joint specifically which alters the length of the extremity.

The pressure and tension of bone becomes diminished by the effect of muscular function.

A Kinetic Chain

According to Steindler, "A kinetic chain is a combination of several successively arranged joints constituting a complex motor unit." Where the terminal end is free, it is known as an open kinetic chain, (e.g., the waving of a hand). When a terminal joint is restricted from moving, partially or completely, it is known as closed kinetic chain, (e.g., fixation of the foot

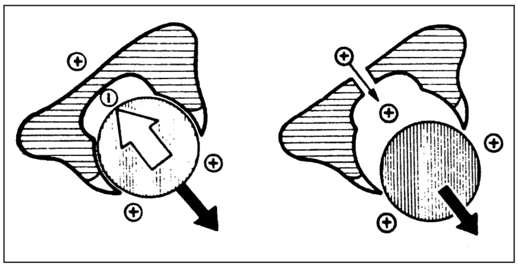

Figure 7: Atmospheric pressure and joint cohesion. (See text).

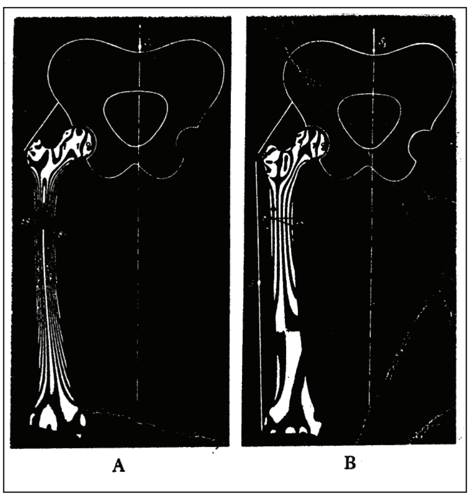

Figure 9: Tension optical picture: A. Under weight-bearing alone. B. Under pressure plus counter tension of the tensor fascia, showing pressure and tension of the bone diminished.

The ankle joint and subtalar joint together perform definite alterations in the column to allow it to adapt to various irregularities of the contact surface. The midtarsal joint, in turn, allows for irregularities between the forefoot and rearfoot in relation to the supporting surface. The metatarsal-phalangeal and interphalangeal joints allow for maximum balance and base of support at the push-off phases of gait.

Translatory Motion in a Kinetic Chain

All movements in the joints are rotatory motions, which must be converted into linear movement for locomotion. Imagine a rod rotating around one end. If the rod is now made to rotate around the other end the same amount, but in the opposite direction, the end effect is that the rod is now in a parallel position.

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By replacing the rod with the lower extremity, (the tibia, ankle joint, and foot) we have developed a crude gait model. The tibia has advanced forward in a parallel or translatory direction (Figure 8).

Effect of Muscular Tension on Gravitational Stresses in Bone

The pressure and tension of bone becomes diminished by the effect of muscular function. This is particularly important in long bones of the lower extremities, where gravity tends to produce bending stresses. These changes of stress on bone were demonstrated in tension optical pictures. The pull of the muscles can be compared to that of "guy" wires, which neutralize the pressure and tension stresses produced by bending. In the femur, when in unilateral stance, the "guy" wire function is provided by the ilio-tibial tract (Figure 9).

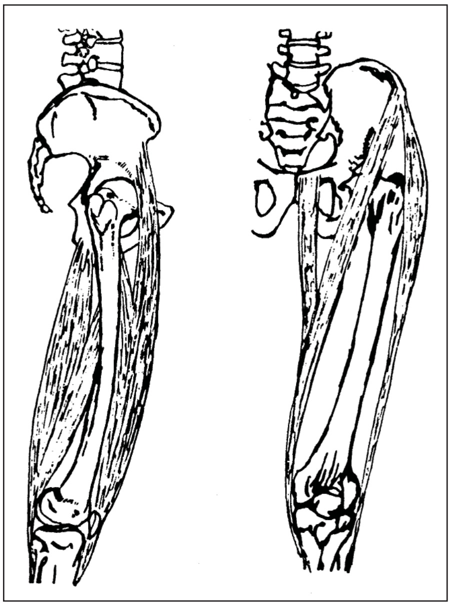

Figure 10: Muscular tension, reducing the stresses on the knee insertions.

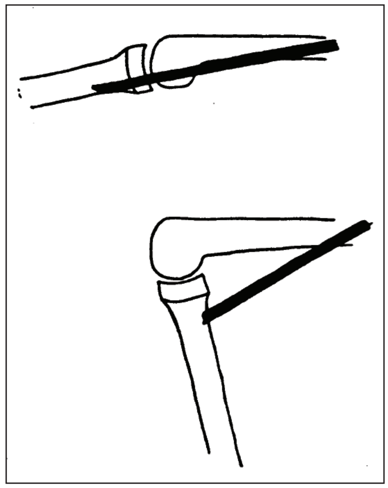

Figure 11: The angular relationship between the line of force and the bone alters with the movement of the joint.

The tension of muscles reduces the possibility of fracture in bones from gravitational and dynamic stresses.

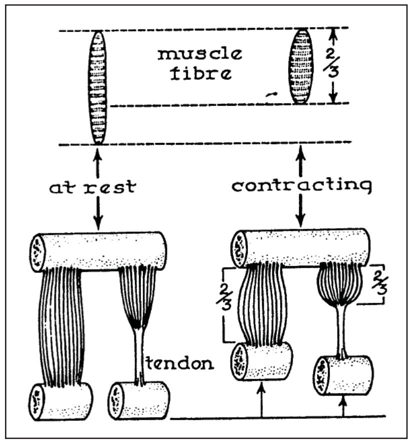

Figure 12: The greatest amount a whole muscle can actively shorten is dependent on the maximum contraction of its contractile units.

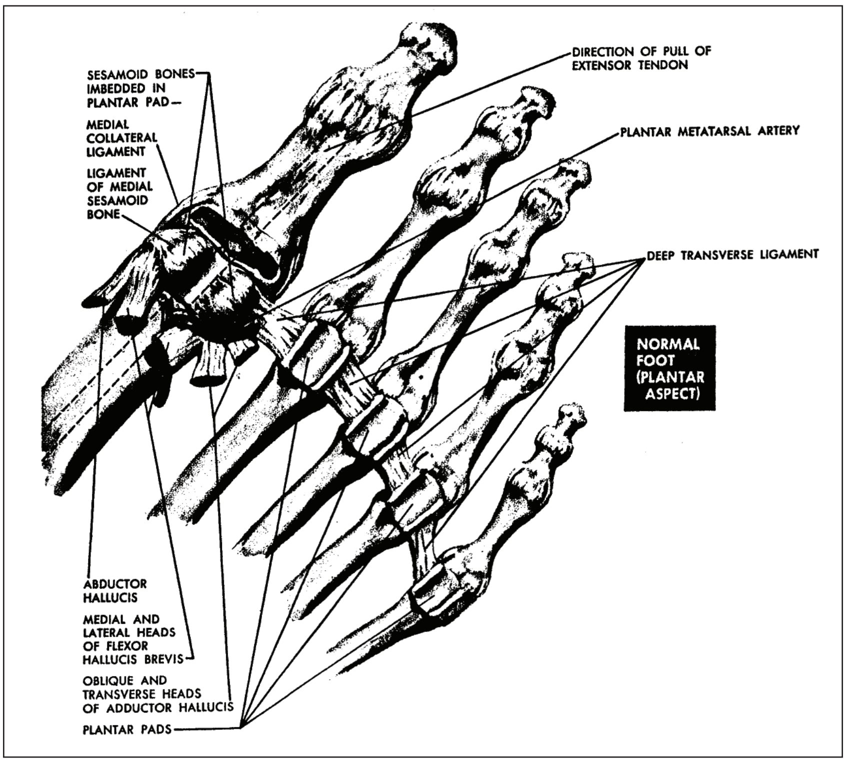

Figure 13: Deflection of the flexor brevis in the sagittal plane by the sesamoids.

The tension of muscles reduces the possibility of fracture in bones from gravitational and dynamic stresses. Evidence of this fact is realized in pathological conditions affecting musculature, wherein bending fractures of long bones occur more readily due to loss of tension, reducing stresses of muscles. Thus, a muscularly developed athlete is much less prone to bone injury than one who is not an athlete.

The lower the muscular insertion on the bone, the greater its effect on lowering tension stresses. Muscles

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with broad insertions release more tension than those with narrow insertions (Figure 10).

Leverage and Equilibrium

Muscles are capable of both rotatory force and stabilization. The angle of application of the insertion to the bone determines its relative actions. Muscle applied to the bone at 90° would develop a pure rotatory force; applied parallel to the bone, it would function purely in stabilization.

Since most muscles insert at only slight angulations, their prime purpose appears to be stabilization, rather than rotatory motion (Figure 11).

Although a single muscle may develop a large stabilizing component, it cannot stabilize a joint by itself. It must also have its rotatory component checked by the action of an antagonist.

The angle of application of a muscle is not constant. The angle of insertion becomes progressively greater in a flexor as the bone is progressively flexed. We would expect, then, the rotatory effect to increase at the expense of stabilization.

The structural unit of contraction is the muscle cell (fiber). The greatest amount a whole muscle can shorten actively is dependent upon maximum contraction of all its units (cells) (Figure 12).

The maximum a muscle cell can contract is less than 2/3 of its resting length (57%). A muscle with a long tendon in relation to its muscle length will shorten (or contract) less than one with a longer muscle mass. This can be related to the prime function of a particular muscle. For example, the peroneus longus has a small muscle belly and a long tendon. It's functionally a stabilizer.

The gastrocnemius has a large belly and a short tendon. Its prime function is one of movement rather than stabilization. Thus, in contraction, the muscle loses its ability to develop tension in direct relationship to the amount of contraction, and this loss of tension production overrides any mechanical advantage gained by the angle of application. The angle of application may be increased without decreasing muscle length by the following means:

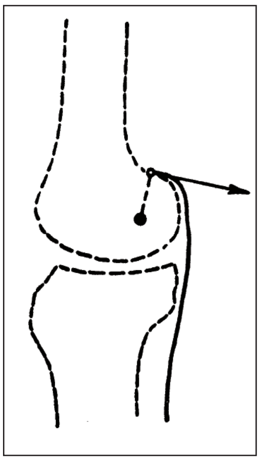

Figure 15: Deflection of tendon by bony prominences.

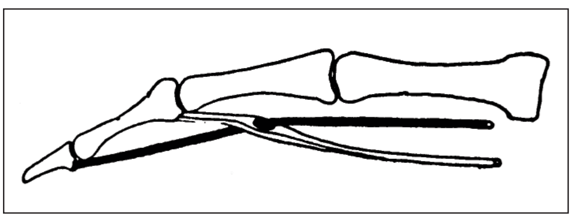

Figure 14: Increase of the angle of application by the short digital flexor.

Accessory Bone Deflection

The patella changes the obliquity of the quadraceps tendon, increasing its mechanical advantage. The sesamoids increase the plantar flexion of the flexor hallucis brevis (Figure 13).

The deflection is of advantage only if the plane of pull is not altered, otherwise the deflection could be a mechanical disadvantage (e.g., the accessory navicular bone decreases the supinatory effect of the posterior tibial tendon).

Muscle Pull

Muscles may pull a tendon from the underlying bone, such as is the case with the flexor digitorum longus as it pierces the flexor digitorum brevis. When the brevis contracts, it pulls the longus down, thus increasing its angle of application (Figure 14).

Another example is the action of the vastus lateralis in the thigh, which pulls the iliotibial band away from the bone, thus increasing its rotatory effect against gravitation force when standing on one leg.

Muscles may pull a tendon from the underlying bone, such as is the case with the flexor digitorum longus as it pierces the flexor digitorum brevis.

Deflection of Tendons by Bony Projections

At these locations, there are usually strong fibrocartilaginous sheaths, such as with the peroneal tendons around the lateral malleolus. A good deal of the muscle pull is absorbed in pressure against the retaining tissue. At times, this restraint is so great that the tendons dislocate over the lateral malleolus. The posterior condyles of the femur deflect the tendons of the gastrocnemius and the hamstrings, thereby augmenting their angle of application (Figure 15).

Deflection of a Tendon by Anatomic Grooves

The peroneal groove in the cuboid acts as a pulley. It serves to change the angle of the tendon to a perpendicular relationship with the axis of the first ray, thus enhancing its efficiency.

Morphological Adaptation of Muscle

Types of Muscle:

Muscles are anatomically designed for either power or speed, usually not both. For speed, the fibers are long, less numerous, and they are arranged in a parallel fashion. These are termed *unipennate* or *strap* or *spurt* muscles, and are

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typical of all swing phase muscles of gait. Their lifting height (range of motion) is greater, but power is less. Hip flexors, for instance, have greater range than extensors, but the extensors are more powerful.

For power, the fibers are short, more numerous, and the fibers are arranged in a pennate fashion. Their range of motion is less, as well as their speed of action. They are typical of the stance phase muscles of gait. These muscles are termed bipennate, or multi-pennate muscles (Figure 16). The work factor of both types of muscles are the same (if volume is equal) since, Work = Force x Distance.

Effect of Insertion Site on Function

Everything being equal, the muscle which is attached closer to the center of a joint would require a greater power to lift a given load a certain distance. This is analogous to pushing a door open from the hinged side compared to pushing it at the opposite side, a longer distance but with little force.

Thus, for power, the muscle is attached at a greater distance from the center of the joint, yielding a longer lever arm (shunt, or pennate muscles). For speed, the muscle is attached closer to the center of motion, yielding a shorter lever arm (spurt, or unipennate muscles) (Figure 17).

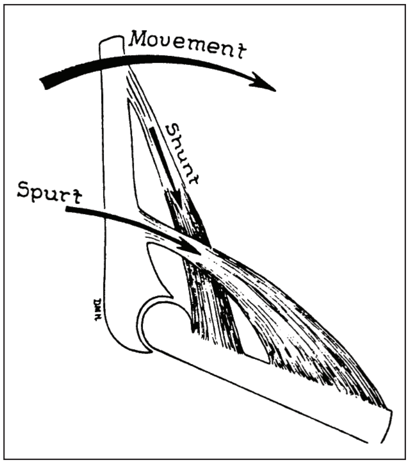

Figure 17: Shunt muscles attach further from the joint and develop more power. Spurt muscles attach closer to the joint.

In large weight-bearing joints, both types of action are required, and therefore they are supplied with both types of muscles. For example, the knee joint has attached to it the biceps femoris (power) and the hamstrings (speed).

Since most muscles' axes align themselves at an angle to the three body planes, they have a primary action and secondary actions.

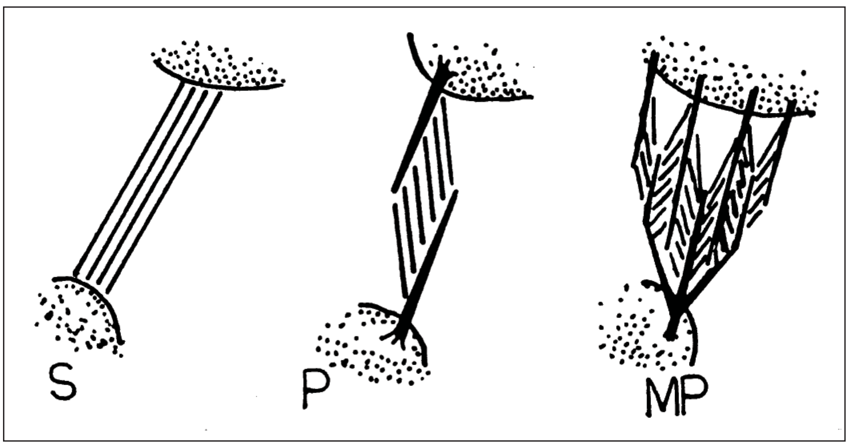

Figure 16: Some arrangements of fibers in muscles. S: strap muscle; P: pennate muscle; MP: multipennate muscle.

Coordination of Muscle Action; Inversion of Actions

Since most muscles' axes align themselves at an angle to the three body planes, they have a primary action and secondary actions. These secondary actions often change with the position of the joint. The adductor brevis, for example, in normal stance is a secondary flexor of the hip joint, but it changes to an extensor at 50 degrees of hip flexion. The quadratus femoris sits on the sagittal axis and, as such, it is a flexor when the hip is extended and an extensor when the hip is flexed.

Remote Effects of Muscles in Kinetic Chains

When the body is in static stance, the lower extremities are in a closed kinetic chain. The external resistance is their reactive force of gravity to the body weight. In this situation, the muscular action is different than when the limb is free. In a closed kinetic chain, the muscle often develops a rotatory effect upon a remote joint. Biarticular muscles may even reverse their motor effect on a particular joint. **PM**

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Dr. Skliar was Associate Professor in Biomechanics at N.Y. College of Podiatry and Barry University. He is the author of the textbook "Biomechanics and Podiatric Orthopedics" and is past president of the American College of Foot Orthopedists.

SEE ANSWER SHEET ON PAGE 141.

1) The viscosity of synovial fluid is:
   A) thinner for fast moving joints.
   B) dependent on surrounding tissue temperatures.
   C) always constant.
   D) none of the above.

2) The inherent flexibility of a long bone is:
   A) least at its mid-portion.
   B) greatest at the joint area.
   C) uniform throughout the shaft.
   D) dependent upon the calcium intake of the individual.

3) The size of the contact area of cartilage is directly related to:
   A) the amount of pressure in the joint.
   B) bone density.
   C) ligament length.
   D) none of the above.

4) Factors for normal joint function include:
   A) hyaline cartilage.
   B) graduated flexibility.
   C) lubricant film.
   D) all of the above.

5) Joint cohesion is aided in general by:
   A) ligaments
   B) muscle tension
   C) fascia
   D) all of the above

6) Osteoarthritis can occur from
   A) loss of graduated flexibility.
   B) loss of joint cartilage.
   C) loss of synovial fluid.
   D) all of the above

7) Stresses on bones are reduced by:
   A) muscles.
   B) joint capsule.
   C) gravitational forces.
   D) atmospheric pressure.

8) Genu valgum, over time, could cause excessive compression stress to result in pathology at the:
   A) lateral aspect of the knee joint.
   B) medial aspect of the knee joint.
   C) posterior patella surface.
   D) all of the above.

9) Pressure and tension of bone is diminished by the effect of muscular tension, thus:
   A) muscularly developed athletes are less prone to bone injuries.
   B) the lower the muscular insertion on a bone, the greater its effect on lowering tension stress.
   C) the pull of muscles on long bones is comparative to that of a guy wire.
   D) all of the above.

10) Since most muscles insert at only slight angulations, their prime purpose appears to be:
   A) rotary motion
   B) locomotion.
   C) stabilization, rather than rotatory motion.
   D) none of the above.

11) Regarding muscle activity:
   A) The greatest amount a whole muscle can actively shorten is dependent upon maximal contraction of all of its cells.
   B) The maximum a muscle cell can contract is 30 percent of its resting length.
   C) A muscle with a long tendon relative to its muscle length will contract more than more than a muscle with a longer mass.
   D) None of the above.

12) Regarding muscle activity:
   A) The angle of application of a muscle is constant.
   B) The angle of application of a flexor muscle becomes progressively greater as the bone is progressively flexed.
   C) In contraction, muscles lose their ability to develop tension in direct relationship to the amount of contraction.
   D) Answers b and c

13) The angle of application of tendon to a bone may be increased without decreasing muscle length by:
   A) action of accessory bone deflection, only if the plane of pull is not changed.
   B) another muscle pull on a muscle tendon.
   C) deflection of the tendon by bony projections.
   D) all of the above

14) Muscles anatomically designed for speed all:
   A) have fibers that are long
   B) have fibers arranged parallel
   C) insert close to the joint end of a bone
   D) all of the above

Continued on page 140

15) Swing phase muscles are:
A) strap muscles.
B) have high lifting ability.
C) designed for speed.
D) all of the above.

16) A combination of several joints united so that the end segments are fixed is called:
A) open kinetic chain.
B) closed kinetic chain.
C) rigidity.
D) hypermobility.

17) Extensor muscles of the hip:
A) are pennate muscles.
B) have fast reaction compared to the hip flexors.
C) are less powerful than the flexors.
D) none of the above.

18) Muscles designed primarily for speed:
A) are usually attached away from the center of rotation.
B) have long, parallel fibers.
C) have short range of motion.
D) are typical of stance phase muscles.

19) An increase in mechanical advantage by the presence of an accessory bone in its tendon occurs in all of the following, except the:
A) os perineum and peroneus longus tendon.
B) sesamoids in the flexor hallucis brevis tendons.
C) patella in quadraceps tendon.
D) all of the above.

20) The effect of the insertion site on muscle function is as follows:
A) For power, the muscle is attached at a short distance to the joint.
B) For speed, the muscle is attached close to the joint.
C) Some joints require insertions both close and distant to the joint on the same bone.
D) answer b and c.

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Note: If you are mailing your answer sheet, you must complete all info. on the front and back of this page and mail with your credit card information to: ***Podiatry Management*, P.O. Box 490, East Islip, NY 11730.**

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(1) Each participant achieving a passing grade of 70% or higher on any examination will receive an official computer form stating the number of CE credits earned. This form should be safeguarded and may be used as documentation of credits earned.

(2) Participants receiving a failing grade on any exam will be notified and permitted to take one re-examination at no extra cost.

(3) All answers should be recorded on the answer form below. For each question, decide which choice is the best answer, and circle the letter representing your choice.

(4) Complete all other information on the front and back of this page.

(5) Choose one out of the 3 options for testgrading: mail-in, fax, or phone. To select the type of service that best suits your needs, please read the following section, "Test Grading Options".

TEST GRADING OPTIONS

Mail-In Grading

To receive your CME certificate, complete all information and mail with your credit card information to:

Podiatry Management
P.O. Box 490, East Islip, NY 11730

PLEASE DO NOT SEND WITH SIGNATURE REQUIRED, AS THESE WILL NOT BE ACCEPTED.

There is **no charge** for the mail-in service if you have already enrolled in the annual exam CME program, and we receive this exam during your current enrollment period. If you are not enrolled, please send $23.00 per exam, or $179 to cover all 10 exams (thus saving $51 over the cost of 10 individual exam fees).

Facsimile Grading

To receive your CME certificate, complete all information and fax 24 hours a day to 1-631-563-1907. Your CME certificate will be dated and mailed within 48 hours. This service is available for $2.50 per exam if you are currently enrolled in the annual 10-exam CME program (and this exam falls within your enrollment period), and can be charged to your Visa, MasterCard, or American Express.

If you are *not* enrolled in the annual 10-exam CME program, the fee is $23 per exam.

Phone-In Grading

You may also complete your exam by using the toll-free service. Call 1-800-232-4422 from 10 a.m. to 5 p.m. EST, Monday through Friday. Your CME certificate will be dated the same day you call and mailed within 48 hours. There is a $2.50 charge for this service if you are currently enrolled in the annual 10-exam CME program (and this exam falls within your enrollment period), and this fee can be charged to your Visa, Mastercard, American Express, or Discover. If you are not currently enrolled, the fee is $23 per exam. When you call, please have ready:

1. Program number (Month and Year)
2. The answers to the test
3. Your social security number
4. Credit card information

In the event you require additional CME information, please contact PMS, Inc., at **1-631-563-1604**.

ENROLLMENT FORM & ANSWER SHEET

Please print clearly...Certificate will be issued from information below.

Name ____ Soc. Sec. #__________________________
Please Print: FIRST MI LAST

Address____

City_________________________________ State_______________ Zip_____________________

Charge to: _____Visa _____ MasterCard _____ American Express

Card #_________________________________Exp. Date_____________

Note: Credit card is the only method of payment. Checks are no longer accepted.

Signature________________________ Soc. Sec.#______________ Daytime Phone____________________

State License(s)___________________ Is this a new address? Yes_______ No_______

Check one: _____ I am currently enrolled. (If faxing or phoning in your answer form please note that $2.50 will be charged to your credit card.)

_____ I am not enrolled. Enclosed is my credit card information. Please charge my credit card $23.00 for each exam submitted. (plus $2.50 for each exam if submitting by fax or phone).

_____ I am not enrolled and I wish to enroll for 10 courses at $179.00 (thus saving me $51 over the cost of 10 individual exam fees). I understand there will be an additional fee of $2.50 for any exam I wish to submit via fax or phone.

Over, please

ENROLLMENT FORM & ANSWER SHEET *(continued)*

EXAM #6/14
Mechanics of Joints and Muscle Actions
(Skliar)

Circle:

1.	A	B	C	D	11.	A	B	C	D
2.	A	B	C	D	12.	A	B	C	D
3.	A	B	C	D	13.	A	B	C	D
4.	A	B	C	D	14.	A	B	C	D
5.	A	B	C	D	15.	A	B	C	D
6.	A	B	C	D	16.	A	B	C	D
7.	A	B	C	D	17.	A	B	C	D
8.	A	B	C	D	18.	A	B	C	D
9.	A	B	C	D	19.	A	B	C	D
10.	A	B	C	D	20.	A	B	C	D

Medical Education Lesson Evaluation

Strongly agree [5]	Agree [4]	Neutral [3]	Disagree [2]	Strongly disagree [1]

1) This CME lesson was helpful to my practice ____

2) The educational objectives were accomplished ____

3) I will apply the knowledge I learned from this lesson ____

4) I will makes changes in my practice behavior based on this lesson ____

5) This lesson presented quality information with adequate current references ____

6) What overall grade would you assign this lesson?
A B C D

How long did it take you to complete this lesson?

______hour ______minutes

What topics would you like to see in future CME lessons ?
Please list :

____

____

____

____

____