The Joint as an Inclined Plane: The Slippery Slope

This is the companion article for the presentation on the DVD.

This article was rejected for publication by the online journal BMC Physiology with the following reviewers comments:

"Major Compulsory Revisions (that the author must respond to before a decision on publication can be reached)

1. The author's point that tools commonly used to analyze loads and forces across joints isolate parts of the body, as well as assume that the isolated portions of the body and structures outside of the part being analyzed are in equilibrium is very important and worthy of emphasis. However, the point that "in biologic bodies, the muscles and ligaments from within the falling body are useless in restraining the body from sliding down the slope" may be a hasty generalization or over-simplification. While the concrete view that individual muscles or ligaments can not provide this function is fair, it is quite possible that multi-component systems composed of muscles, tendons, ligaments, fascia and bones that span across larger regions of our bodies (e.g., the entirely abdominal cage) may be able to create stiffened sub-systems (e.g., like the tensegrity systems or trusses Dr. Levin and others have described in the past) that can effectively resist the downward slide of one bone across another at a single joint. This system level discussion is likely part of the answer to the problem, and discussion of this type of perspective should be added to the discussion.

2. A detailed description of the biomechanical function of a single critical joint (e.g., hip), how conventional models depict it is stabilized, how this can't be right, how a truss model would differ, and the physiologicaland biological implications of this alternative approach, also would greatly enhance the impact of the manuscript."

Keywords: biomechanics, joints, inclined plane

Background

The commonly used model for static support of terrestrial skeletal creatures assumes that the skeleton is the skyscraper-like frame on which the soft tissues are draped. In this model, all the supporting joints are compression loaded and would, of necessity, be stacked like a column of blocks with the center of gravity of each of the superior segments in a plumb line with the point of support beneath it. It is assumed that the muscles and ligaments surrounding the joint stabilize the joint and balance the superior segment over its center of rotation. If the center of gravity would lye outside the plumb line, the mass would fall, accelerating at 9.8 m x sec2, responding to the pull of gravity. Most synovial joints are close to frictionless with a coefficient of friction in the range of .0o5 [1]. When using a link-segment model commonly used in biomechanical modeling, the joints are assumed frictionless pin joints [2].

Method

Most diarthrodial joints have relatively flat surfaces and would have to be considered as inclined planes when their surface is tilted. Figure 1 depicts the forces on a body resting on an inclined plane.

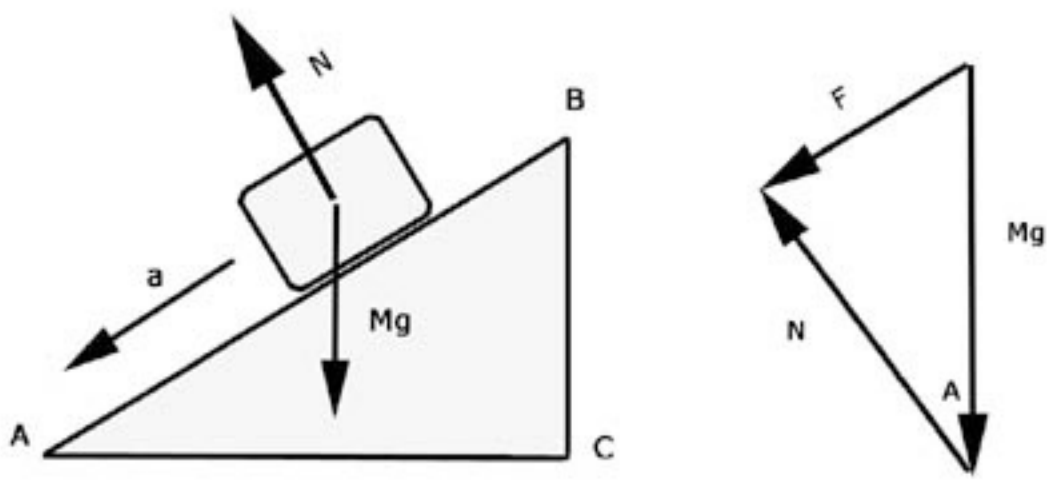

Figure 1.
Forces on a frictionless inclined plane.

When there is no friction, the only direction in which a plane surface can direct a force on a body placed on it is normal or perpendicular to the surface (N). The resultant (F) of the forces N (force at right angle to the surface of the plane) and Mg (mass x gravity) must be a force parallel to the plane. It can be seen that:

Sin A = F/Mg
F = Mg sin A.

Following Newton’s second law F = Ma,

we get Mg sin A = Ma

from which a =g sin A.

The acceleration, a, is independent of the mass of the body and dependent on the angle of the slope. As the slope AB approaches vertical, sin A gets larger and approaches one (1) and a = g. That means that there will be no compression on the slope or joint reaction force.

To put it another way:
N, the force across the joint, is represented by the formula:

cos A = N/Mg
that gives us N = cos A x Mg.
As AB becomes vertical (900), cos A = 0 and N, the force on the plane = 0.

There is no equal and opposite force provided by the articular surface that keeps the superior body mass from falling. What keeps the body from sliding down the slope? As there is no friction, there must be a tension force (t) equal and opposite a [Figure 2].

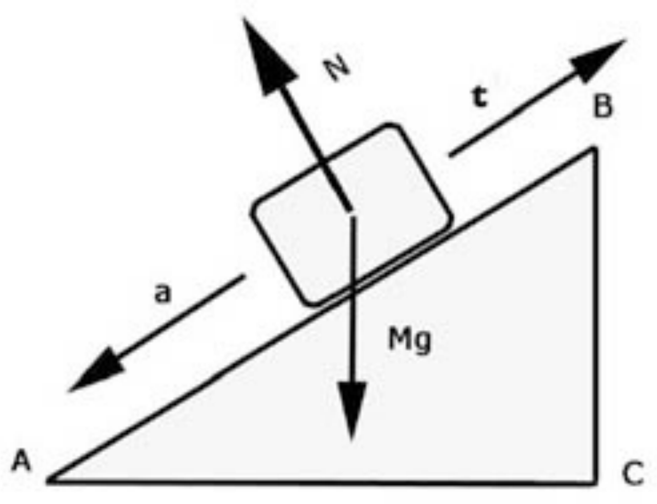

Figure 2. To keep the mass from sliding, t + a.

An analogy might be a rock climber hanging by his ropes against an ice face. Even if there is contact between the climber and the ice face, unless there is something gripping the ice face, the weight of the climber is born by the rope.

The rope is fixed to some external structure, the mountain, for when a mass is accelerating, only an external force can stop it.

Discussion

Most joints are tilted, sometimes to the vertical, during at least part of their function, and we should slide off these slippery slopes. Therein lies the problem. Free-body and link-segment analysis, the commonly used tools for analyzing loads and forces across joints, isolates parts of the body and assumes that the isolated portions of the body are in equilibrium and that the structures outside of the part being analyzed are also in equilibrium. All link-segment models assume that there is a stable column of bones supporting the anatomical structure and that the soft tissue drapes itself on a stable, stacked, compression loaded column of bones. However, in joints such as the glenohumeral[3] , scapulothoracic, carpal, metatcarpal, facet joints of the spine, the sacroiliac, mid foot and forefoot joints and, in fact, most joints at some time in their functioning, the opposing joint surfaces are near-vertical. The weight of the body mass, Mg, must be suspended by the ligaments and soft tissues and not by compressive loading of joints (Figure 3).

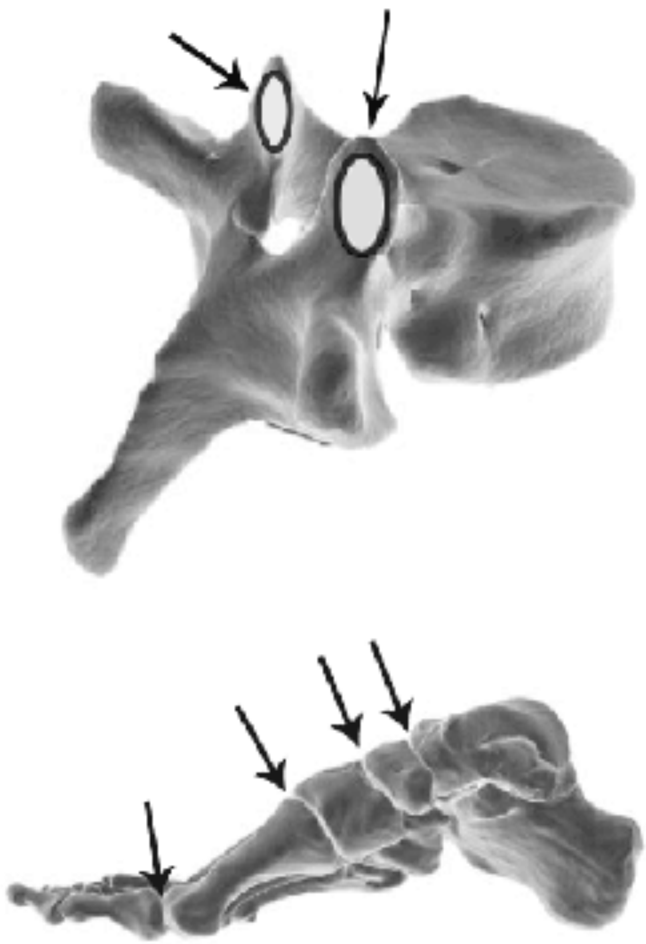

Figure 3. Some joints that are near-vertical during normal function. a: scapulothoracic b: carpal bones c: facet joints of spine d: sacroiliac joints e: foot joints

Even with the slightest tilt of the joint, the mass of the body, which is accelerating to the earth at a rate of 9.8 m x sec2, will start slipping off the joint surface and head toward the center of the earth. When walking, the knee is almost never straight, and, in normal stair climbing, flexes to 60 degrees. What should be the most stable platform in human weight bearing is a tilted slippery plane, and the tibia-talo joint is equally precarious [4]. If, as in real-life, the 'free-body' is actually part and parcel of the external mass that is supposedly stabilizing it, then there is no external force anchoring the free-body that is sliding down the slippery slope of a joint. Once the body starts down the slope, there is no way for the body to bring itself it back to a higher level as that would be lifting one self by ones own bootstraps. An external force is necessary. Since the force cannot come from within, in biologic bodies the muscles and ligaments from within the falling body are useless in restraining the body from sliding down the slope. For example, the lumbodorsal fascia cannot support the sacrum and keep it from falling out of the pelvis nor can the hamstring muscles keep the femur from sliding off the tibia and neither can the calf muscles keep the tibia from sliding off the talus.

Conclusions

From this simple model it becomes obvious that the actual compression loads across joints must be much less than that that has been previously calculated when using free-body diagrams in which the free-body is assumed to be stabilized by the underlying bony column. Nor can we assume that the muscles above act as tension restrainers. The slippery slope of synovial joints becomes a fatal flaw in the rigid link-segment skeletal model. Even if the soft tissues above restrained the structure from sliding, there still would not be full body weight resting on the tilted joint surface. With slippery slopes as joints, and no internal forces capable of keeping the superior body parts from sliding off the inferior parts, skeletal bodies should collapse in a heap. Since real-life skeletal bodies are stable with little apparent effort, there must be a different model other than the free-body diagram, lever based models currently in vogue. The lever/post and lintel/ stack-of-blocks/link-segment model that has been in use since Borelli [5] proposed it in the sixteen hundreds, cannot hold itself up with near-frictionless joints. It is illogical to continue to use models that are inconsistent with physical laws.

It is not the purpose of this paper to answer the question of how the skeletal body is stabilized but rather to alert us to the paradox of a construct that by physical laws should be unstable, but maintains its integrity with minimal effort. Certainly, biologic structures conform to physical laws. To quote Thompson, "Cell and tissue, shell and bone, leaf and flower, are so many portions of matter, and it is in obedience to the laws of physics that their particles have been moved, molded and conformed" [6]. Other systems could work. Truss systems are stable with frictionless joints. The angle and slipperiness of the slope of the joint is irrelevant in truss systems (Figure 4).

Figure 4. a: Square frame model with rigid joints and torque b: Triangular, truss model with pin joints and no torque

Frictionless or ‘pin’ joints are the hallmark of trusses. In his classic book, On Growth and Form, first published in 1917, D’Arcy Thompson [6] hypostatized that musculoskeletal frameworks might be constructed as trusses. Since then Pearce [7], Gordon [8, 9], Ingber and colleagues, [10-13], Levin [3, 14-17], Wendling [18, 19], Moreno [20], Maina [21] and others have used truss systems to model biologic structures.

Finite element modeling using tetrahedral building blocks do use a truss system. However, the differences in the mechanics of trusses as opposed to hexahedral models seem to be ignored. Those using tetrahedral modeling should be aware that what they have created mathematically has the mechanical properties of a truss, not a cube, and take advantage of it. In a truss, there are no bending moments, just tension and compression, and there is no torque generated at the joints.

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