The Weight-Bearing Function of the Fibula

A STRAIN GAUGE STUDY

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In lower animals, the fibula is considered one of the most important supporting structures of the leg. However, with man's conversion from digitigrade to plantigrade ambulation, anthropologists and anatomists have given a lesser, if not a vestigial, function to the fibula [10,12]. A structure may change in response to new tasks, or a change in shape may allow it to assume new functions. We assume that a definite function-form relationship obtains in our studies of the skeletal architecture of the body. Generally, in studies in which the biomechanical properties of a bone have been measured, there has been a fairly good correlation between the function predicted on the basis of shape and spatial orientation of a bone and the actual function of a bone [14].

Assumptions concerning the function of the fibula are based on an anatomical concept of the fibula as a lateral strut to the ankle, represented schematically in Figure 1. On the basis of this concept, the anatomist and the clinician have assigned to the fibula the role of being an outrigger for the origin and insertion of muscles, the distal extension of which serves as the lateral jaw of a caliper which, with the medial malleolus, holds the talus like a clevis during motion at the talocrural joint [5,10,20]. It has been generally accepted, with few exceptions [2,19], that all the weight applied to the lower extremities during plantigrade activity is transmitted across the tibial plafond to the dome of the talus, with the fibula serving as a lateral buttress but not participating in axial loading or weight-bearing [11].

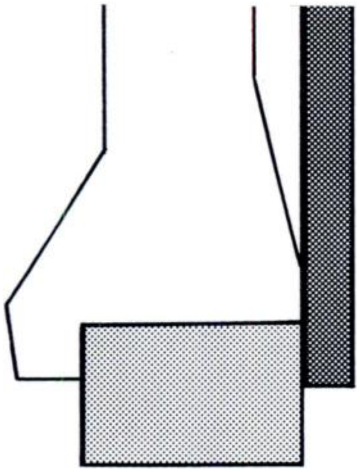

FIG. 1

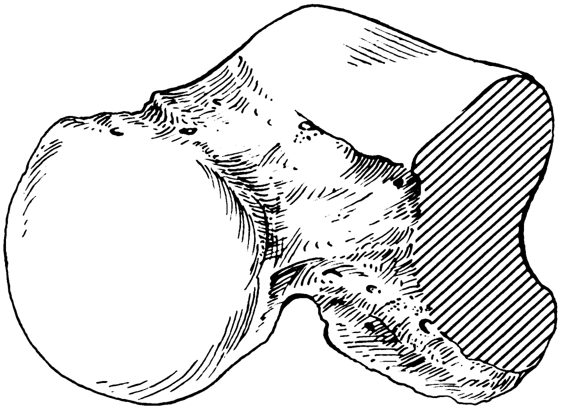

FIG. 2

Fig. 1: A schematic representation of the ankle with the traditional anatomical and functional concept of the fibula as a lateral buttress.

Fig. 2: A three-quarter view of the talus shows the oblique orientation of the lateral articular surface.

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However, certain clinical situations suggest that the fibula's function is not so simple or restricted. The tibia's response in congenital absence of the fibula and in cases in which the fibula has been removed surgically and the recent awareness of the importance of the lateral malleolus in ankle fractures [4,13,16,17,19,21,25] suggested participation of the fibula in weight-bearing and stimulated the present investigation.

The purpose of this paper is to show that the fibula is a weight-bearing bone through a closer examination of the anatomy of the ankle and by strain determinations on the fibula during simulated weight-bearing. By transmitting a portion of the body's weight during actual loading of the leg, the fibula would become an integral part of the static supporting architecture of the leg.

Anatomy

On examination of the lateral articular surface of the talus, it becomes apparent that this surface is not vertical but oblique in its attitude. The talus is wedge-shaped in coronal as well as horizontal section (Fig. 2). Although there is some individual variation in the orientation of the lateral facies, it is always oblique, usually with a concave surface laterally [3]. The distal part of the fibula articulates congruently and smoothly with it during all positions of plantar flexion and dorsiflexion. The motion of the talus is not about a simple transverse axis, but about an oblique and changing one which allows the fibula always to be snubbed against this geometrically complex structure [6]. On this basis, a truer schematic representation of the talofibular joint would be as shown in Figure 3. Roentgenograms show this relationship when the view is one that allows the beams to pass tangentially to the area of contact (Fig. 4). The proximal tibiofibular joint is also oriented obliquely; in fact, in 25 per cent of the specimens examined by Barnett and Napier, it was almost horizontal.

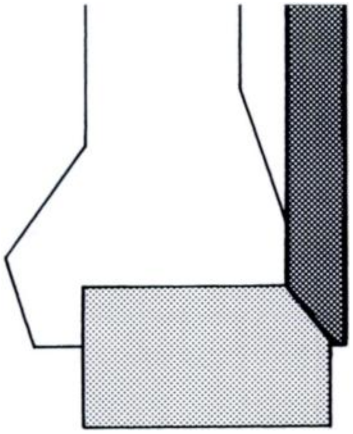


FIG. 3

FIG. 4

Fig. 3: A truer schematic representation of the ankle shows the oblique articulation of the fibula with the talus.

Fig. 4: A roentgenogram of the ankle showing the obliquity of the tibiofibular joint.

Biomechanics

For our purposes we may assume that each synovial-lined joint of the body forms an essentially frictionless articulation of gliding surfaces [22]. Two gliding, frictionless surfaces can exert a resultant force only in a direction which is perpendicular to the points of contact. In Figure 5, it can be seen that this force is actually a resultant vector with horizontal and vertical components. Therefore, any pressure which is exerted on the fibula by its articulation with the talus has to have some

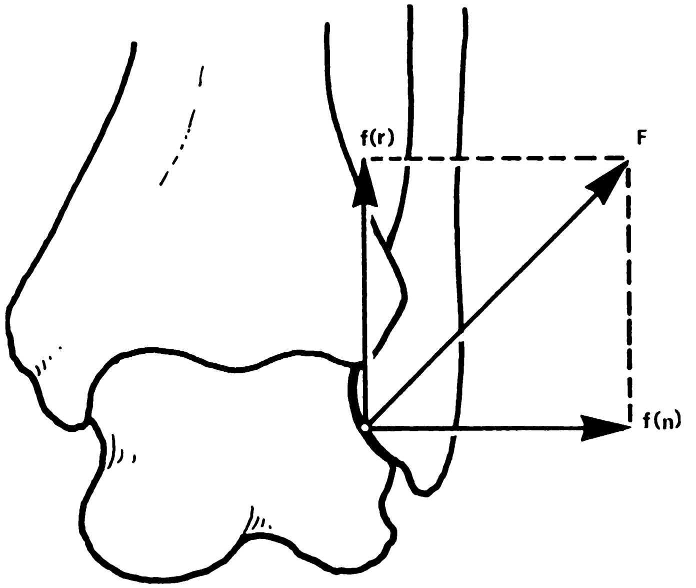


FIG. 5

The force *F* generated at the tibiofibular joint on weight-bearing is a resultant vector with a component vector (*v*) that transmits a vertical force.

force transmitted longitudinally through the fibula. The horizontal and vertical forces occur concurrently because of this wedging effect and suggest that, in standing and walking and particularly in some pathological states, the lateral stabilizing and axial loading functions of the fibula are occurring inseparably and simultaneously.

Method

Bonded strain gauges have been used to measure strain in other bones, especially the femur [14]. To my knowledge such a technique has not been used on the fibula. The strain gauge is a transducer whose electrical resistance changes when it is subjected to mechanical deformation [15]. Measurement of this change in resistance is accomplished by connecting the gauge as one limb of a Wheatstone bridge circuit. Changes in the resistance of the gauge are detected by a galvanometer. The degree of imbalance is measured and, if one knows the characteristics of each gauge as determined by the manufacturer, one can convert the measurements to a reading in micrometers of length change per millimeter of length. Elongation is given a positive sign and shortening a negative sign. By bonding the gauge directly to the specimen to be tested it will be deformed with the specimen and through the mechanical to electrical conversion the deformation of the specimen can be measured.

A load applied to a structure is transmitted as stress in the structure. The stress causes a deformation which when expressed as change per unit length is designated as strain. In the non-viscoelastic materials or in viscoelastic materials which are loaded relatively rapidly, there is a definite stress-strain relationship expressed as Young's modulus for the material [15]. The deformation or strain of a loaded beam is the algebraic sum of the axial and bending strains that occur at the particular site being measured. It is possible for a beam to have tensile strain in some areas depending upon the point of application of the load [9] (Figs. 6-A and 6-B). In studying the effect of weight-bearing forces, we have used a biostatic model because it is more valid to consider forces acting in a system which is in mechanical equilibrium [18].

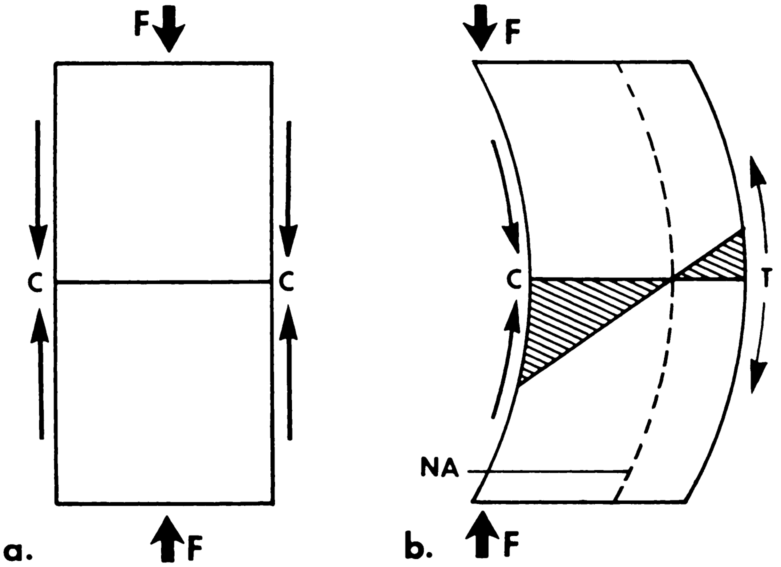


FIG. 6-A FIG. 6-B

Fig. 6-A: Axial loading of the beam causes compression (*C*) of its surface.

Fig. 6-B: If the load is applied eccentric to the neutral axis (*N.A.*), there is compression (*C*) generated on the concave surface and tension (*T*) on the convex surface.

Because Young's modulus varies from area to area in a bone, it is appropriate that our determination be in strain without trying to convert this mathematically to stress[14].

Materials

Strain gauges: The strain gauges were single element linear type which measure the average strain over the active gauge area in a single longitudinal direction. The types used were BCHC9-121H linear gauges (Automation Industries) with resistance of 120 ± 0.2 ohms with a gauge factor of 2.6 and an active length of 3.8 millimeters.

Strain indicator: The Wheatstone bridge circuitry was provided by a model P-350 Portable Digital Strain Indicator (Automation Industries, Inc.). A model SB-1 10-channel Switch Balance Unit (Automation Industries, Inc.) was used to allow multichannel sequential reading from one strain indicator.

Specimens: The lower extremities from five above-the-knee amputations were used for the experiment. All limbs had been amputated for peripheral vascular disease, and there was no known history of other disease or injury to the leg. The specimens were stored frozen and then allowed to thaw at room temperature for at least twenty-four hours prior to their use.

Loader: Loading of the specimens was performed using a sliding dead weight loader attached by a threaded coupling to a rod which was cemented into the condylar region of the femur. The rod was oriented in the mechanical axis of the femur.

Technique

Wide resection of muscle was performed to allow good exposure for the application of the gauges. The periosteum at the site of gauge application was removed and the strain gauges were bonded directly to the moist cortical bone of the tibia and fibula with a monomer adhesive. The gauges and leads were then waterproofed with nitrile rubber. The strain gauges were placed on the anterior, posterior, and lateral surfaces of the mid-shaft of the fibula in all specimens. In the last three specimens, gauges were also placed at the mid-shaft of the tibia on its anterior, medial and posterior surfaces. The specimens were placed beneath the loader in an attitude that allowed the weight line to fall just anterior to the knee and ankle joints in the sagittal plane and through the knee and ankle joint in the frontal plane. This configuration most closely resembles relaxed standing on one foot [24]. Each bridge was balanced in the loaded position under zero load condition.

A load of sixty-eight kilograms was applied rapidly and readings were made within one minute. On returning to zero load conditions the strain also approached zero. It required approximately two minutes to reach zero strain which is probably a manifestation of the viscoelastic property of bone. It was essential to observe the response to unloading to eliminate drift and possible temperature induced effects on the gauges. The specimens were then reloaded as before and the interosseous membranes were incised in order to determine what effect the membrane might have on the transmission of load.

TABLE I

STRAIN READINGS FROM FIBULA WITH SIXTY-EIGHT-KILOGRAM LOAD

Surface	1	2	3	4	5
Anterior	−47/−30*	−60/−54	−39/−32	−20/−24	−18/−18
Lateral	−31/−30	−30/−3	−28/−22	−10/−10	+5/0
Posterior	+40/+30	−3/−4	+20/+18	+3/−5	−12/−9

* Intact specimen with membrane excised. − = compression; + = tension.

Results

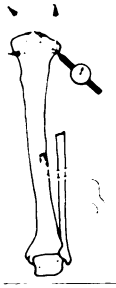
With loading there was marked deformation of the fibula as shown in Table I. The negative numbers represent compression of the underlying bone and the positive numbers represent tension. The geometry and position of the fibula and its deformations with loading suggests that it reacts like an eccentrically loaded beam with strong bending moments as well as axial stress. The compressive strains are due to axial compression load or bending load or both. These negative strains causing positive readings probably represent the surface tending to bend in a concave direction. Tensile strain readings probably represent the side tending to bend in a convex direction. An attempt was made to determine what actual stress could cause such deformation. The fibula was removed from the specimen with its gauges intact and known loads were applied to the fibula in controlled directions in order to duplicate the readings which were registered during the loading of the intact specimen. This, however, was impossible to accomplish.

Since we could not reliably determine the actual force that was applied to the fibula, we modified our technique to allow us to determine the fibula's contribution to weight-bearing by placing strain gauges on the shaft of the tibia. The gauges were placed on the medial, lateral, and posterior surfaces of the tibia. Since the tibia is triangular in cross section, the gauges on these surfaces would respond to bending strain on the surfaces beneath the gauges. The limbs were loaded and the strains on the tibia and fibula were recorded. The proximal one-half of the fibula was then resected. All readings on the tibia were significantly changed in the absence of the fibula (Table II). While the specimen was still loaded I then applied force at varying angles to the proximal tibiofibular articular surface with a spring-loaded sliding rod which was calibrated in kilograms. With this external force we could bring the

TABLE II

STRAIN READINGS FROM TIBIA WITH SIXTY-EIGHT-KILOGRAM LOAD

Surface	1	2	3
Medial	+71/+76/+88*	+20/+20/+46	−4/−12/+38
Lateral	−340/−359/−487	−58/−64/−112	+82/+54/−92
Posterior	+218/+223/+186	+80/+88/−120	−175/−178/−268



External Force to Substitute the Fibula's Effect on Strain on the Tibia

1	2	3
12.7 kilograms	11.3 kilograms	9.9 kilograms
15 degrees lateral	12 degrees lateral	15 degrees lateral
3 degrees posterior	10 degrees posterior	15 degrees posterior

* Intact specimen with membrane excised and fibula resected.

readings of the tibial gauge to the original figures on the intact specimen. In each case the direction of the rod at this point was nearly perpendicular to the tibiofibular articular surface. As shown in Table II the force required was between nine and fourteen kilograms and was always from a posterolateral direction. A resolution of the vertical components of this vector at the proximal tibiofibular joint would be the actual weight-bearing force on the fibula with loading.

Discussion

Strain determinations of the fibula by using strain gauges show that the weight transmitted from the femur to the tibia and the foot causes a reaction in the fibula. This implies a weight-bearing function of the fibula, but little can be concluded about the actual pattern of stress that is applied or its magnitude. Strain determinations on the tibia were made with an intact fibula and then repeated with the fibula's function substituted for by the application of an external force at the normal point of application of the fibular head to the tibia. The results would seem to show that this external force is the total resultant of the force that the head of the fibula applies beneath the lateral tibial plateau during weight-bearing.

The presence of an intact interosseous membrane had little effect on the measurements. This refutes the theory that the oblique fibers of the membrane may serve as the mode of transmission of stress to the fibula during weight-bearing. The membrane may serve to prevent bowing of the fibula and it, therefore, may allow the fibula to serve better as a beam to shore up the posterolateral surface of the tibia. The question might be raised as to the validity and applicability of this biostatic model. It is realized that this spatial orientation and weight transmission do not exactly simulate any dynamic or probably static attitude during normal weight-bearing; however, a more physiological model would bring into the study non-quantitative variables so that we would be measuring factors other than those we have defined [18].

Under physiologic and dynamic conditions, the stresses would probably be magnified because of the increased forces caused by acceleration and also because of the contraction of the muscles which originate on the fibula and pass across the ankle joint [7]. We attempted to simulate muscle contraction on our specimens; however, due to autolysis of the muscles we were unable to approach physiologic tensions. Yet, at tensions less than physiologic ones, we were able to generate up to threefold increases in deformation of the fibula with tension on the tendo calcaneus. This could not be quantitated at this time and a separate investigation is in progress to determine the reactions caused by muscle forces.

Conclusion

In a biostatic model one-sixth of the static load of the leg was carried by the fibula. This force was generated by the fibula's articulation with the talus and possibly also by the inferior tibiofibular ligaments and was applied to the proximal tibiofibular joint. Little of the load was transmitted by the interosseous membrane.

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