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Bone mass distribution in the lower leg

A quantitative computed tomographic study of 36 individuals

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We measured bone density and volume at different levels of the normal lower leg by computed tomography. The fibular mass at each transverse level was 18–20 percent of the total bone mass. Tibial masses at all the levels correlated with distal femoral and proximal tibial masses. Summing the fibular and tibial masses augmented the correlations. The mass values varied substantially at different levels of the lower leg, being highest in the midshaft.

We hypothesize that the lower extremity is a biomechanical continuum where the distribution of the bone mass corresponds to the functional demands, indicating that the fibula is not "dispensable."

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In previous cadaver studies (Alho et al. 1985, Alho et al. 1988), we found a correlation between bone density and mass at different levels of the femur, and the two values were correlated with bending and torsional strength of the bone as a structure (Alho et al. 1989, Husby et al. 1989).

In the present study, we made density and mass estimations in the femoral condyles and in the lower leg bones of voluntary subjects. Values at different levels were compared and related to the values of the femoral and tibial condyles.

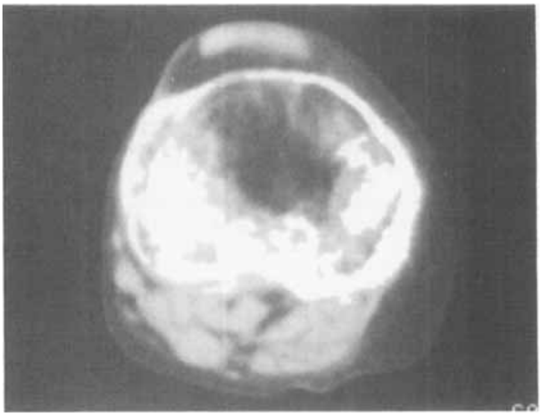

Figure 1. CT slice through the tibial condyle. The pixels used in the computation are highlighted.

Material and methods

Thirty-six healthy volunteers, median age 63 (42–88) years, participated in the study.

Computed tomograms were made on a GE 8800 equipment (General Electric, Milwaukee, WI, U.S.A.) using standard abdominal scanning parameters. Mean density and volume were measured for all the pixels with a density of more than 100 CT units (Figure 1). Ten-millimeter tomographic slices were cut in the femoral condyles and in standardized locations in the lower leg: viz., in the tibial condyle immediately above the proximal end of the fibula, in the proximal fibula and tibia (Figure 2), in the midshaft, and proximal to the malleoli. As an approximation of the relative bone masses in a CT slice, we calculated the product CT density × pixel volume.

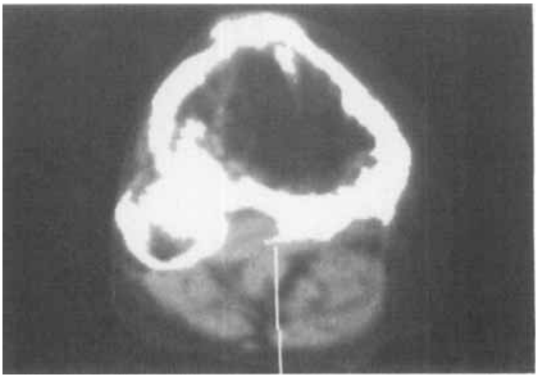

Figure 2. CT slice through the proximal tibia and fibula, with the computed pixels highlighted.

The Pearson correlation coefficients were calculated for the relationship between values in different

Table 1. Measured mean density and standard deviation (*SD*) of the density values (CT units) and mass values (CT units × volume [cm^3] × 10^{-2}). Mean *SD*

Location	Density		Mass	
Femoral condyle	195	*57*	49	*20*
Tibial condyle	186	*43*	41	*22*
Proximal tibia	267	*68*	32	*15*
Proximal fibula	201	*77*	7.2	*9.1*
Sum, mass			39	*20*
Midshaft tibia	1,059	*172*	50	*15*
Midshaft fibula	834	*200*	12	*5.4*
Sum, mass			62	*19*
Distal tibia	246	*65*	32	*16*
Distal fibula	394	*147*	7.6	*4.1*
Sum, mass			40	*20*

Table 2. Correlation (*r*) and significance (*P*) between the mass-related values of the femoral and tibial condyles, and the different mass values of the lower leg

	Correlation with			
	Femoral condyle		Tibial condyle	
Location	*r*	*P*	*r*	*P*
Tibial condyle	0.73	0.000	–	–
Proximal tibia	0.56	0.004	0.70	0.000
Proximal fibula	0.45	0.02	0.31	0.04
Sum, proximal lower leg	0.66	0.001	0.69	0.000
Midshaft tibia	0.87	0.000	0.70	0.000
Midshaft fibula	0.75	0.000	0.67	0.000
Sum, mid-lower leg	0.87	0.000	0.72	0.000
Distal tibia	0.83	0.000	0.85	0.000
Distal fibula	0.77	0.000	0.80	0.000
Sum, distal lower leg	0.83	0.000	0.87	0.000

locations. Because of the large number of observations, the significance level was set at $P < 0.01$.

Results

Table 1 shows the mean CT density- and mass-related values in the different locations. The sum of the mass-related values of the tibial and fibular midshafts was about 50 percent higher than the respective values proximally and distally in the lower leg. The mass value in the femoral condyles was greater than in the proximal or distal lower leg but smaller than in the mid-diaphyseal lower leg.

The correlation analysis (Table 2) showed a good correlation between the mass-related values at all the levels for both the tibia and the fibula with exception of the proximal fibula. The sum of tibial and fibular mass values correlated better with the tibial and femoral condylar values than with the mass of tibia or fibula alone.

The mass values of the fibula were 18–20 percent of the total mass values at all the levels.

Discussion

The long bones of the lower extremity form a continuum where the distribution of the mass and strength seem to reflect the functional demands (Alho et al. 1989). In the mid-lower leg the fibular values alone correlated with the femoral and tibial condylar values, which suggests that the fibula has a definite weight-bearing role.

The fibula is usually considered to be dispensable. It is not presumed to participate in weight bearing, being important only for muscular attachments and for the ankle joint (Schaeffer 1942). Hence, the fibula is used in bone grafting. It is removed in tumor surgery without replacement and apparently without consequences for the function of the lower leg.

The combined weight-bearing function of the tibia, interosseous membrane, and fibula is complex. Anatomic studies have shown that the proximal tibiofibular joint is obliquely to horizontally oriented, and in 25 percent of the cases it is almost horizontal (Barnett and Napier 1952), whereas the distal fibulotalar joint is oblique to vertical. In strain-gauge studies of autopsy specimens, Lambert (1971) concluded that the fibula shares one sixth of the total load on the lower leg, whereas Takabe et al. (1984) found mean values between 6 and 10 percent depending on the position of the ankle. The former observation accords with our mass determinations.

In a finite element model, Reuben et al. (1989) found the fibula and interosseous membrane to alter the stresses in the tibia. The interosseous membrane exhibited stresses in the direction of its fibers, transferring forces to the proximal tibia. Our observations cannot be compared directly with the latter study. However, the weak correlation between the proximal fibular and the proximal tibial values suggests unloading of the proximal fibula but significant loading of the fibular shaft and distal fibula.

The direction of the fibers of the interosseous membrane indicates that the fibula has a weight-bearing function, as if the foot-ankle-tibia were suspended upon it. This seems to agree with the findings of Reuben et al. (1989), indicating the stress transfer from the fibula through the interosseous membrane to the proximal tibia.

In a previous study on the femur (Alho et al. 1988), we found a slight proximal-to-distal increase in the mass. In the present study of leg bones, the mass was greatest in the midshaft. The forces acting on the bones are obviously more complex than what may be deducted from a mere body weight bearing function.

As noted before, our mass values are relative. Further, they are not linearly related to strength. Complex calculations of moments of inertia would be needed based on absolute mass unit measurements for fully valid comparisons. It seems, for instance, that less mass is needed in the ends than in the shaft part of the lower leg because of larger bone areas in the ends, and thus more favorable moments of inertia.

We conclude that the long bones of the lower extremity form a mechanical continuum where the masses are distributed in relation to a load-bearing function, which is common to the whole extremity. Our results do not exclude mass distribution due to local needs, e.g., in juxtaarticular areas of bone. The role of the fibula in the mechanics of the lower leg is subsidiary but not dispensable.

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