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Summary

Hylonome

Structural heterogeneity in bone: good or bad?

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A characteristic feature of bone (shared with most mineralised biomaterials) is its hierarchy, and its mass of interfaces. There are the 'solid' interfaces: across flaws in the mineral, between mineral and collagen and other organics, between mineralised fibrils, between lamellae, between lamellar and woven bone, between Haversian lamellae and the interstitial lamellae (including the enigmatic cement sheath), between the layers in fibrolamellar bone, and between compact bone and trabecular bone (particularly in compact-coarse cancellous bone). Then there are the 'gappy' interfaces: between canaliculi and the surrounding bone, between osteocyte lacunae and the surrounding bone, and between blood vessels and surrounding bone. Then there are the 'damage' interfaces, which may develop over time: within diffuse damage, across microcracks, and across macrocracks. Apart from interfaces, there are more gradual changes of properties, such as differences in mineralization and orientation, that may have noticeable mechanical effects.

One could ask, simplistically: 'Are interfaces and heterogeneity a good or a bad thing for bone's mechanical integrity?' The answer, simplistically, is 'Both.'

The process of fracture involves the formation and development of flaws. These probably develop overwhelmingly at interfaces. Therefore it might seem adaptive to have the bone as uniform as possible. But this is not the case. Inevitably, a structure must have some interfaces and flaws, due to the rough-and-tumble of everyday life. If one of these is large enough, relative to the local stress, then it will spread catastrophically if there is nothing to stop it. However, if the crack runs into flaws, either those that have developed as a result of the crack's travel, or that have developed as a result of the stress field producing the crack, or which were pre-existing, then *according to their orientation* they may hinder the crack, or promote its travel. The question of determining how the disposition and orientation of microcracks/damage is a matter of intense interest to materials scientists, but the answer is still inchoate.

If pre-existing microcracks in bone are disposed in such a way as to hinder crack growth, would it be adaptive to have them in place *before* crack growth started? Probably not, because another feature of cracks is that they increase the compliance (reduce the stiffness) of the bone compared to that in the uncracked state. But it is surely the primary function of bones to be stiff. A reduction of stiffness, even if it reduces the ability of cracks to travel once the bone had entered the post-yield region, is not likely to be adaptive. Most bones spend most of their 'lives' being resilient, and not entering the post-yield region.

The ideal situation would seem to be to have bone filled with coherent, reasonably strong interfaces, which will behave elastically, but which open up if a dangerous crack nears them, and which lie in such an orientation that the crack growth is impeded. One can attempt to answer the question of whether bone is in this ideal situation in a number of ways; for instance:

- By comparing the mechanical properties of bones of different histologies, with varying amounts and orientations of interfaces;
- By comparing the mechanical properties of bone before and after damage has been induced;
- Theoretically, by using FEA and similar methods.

In all these studies, it must be remembered that what is sauce for the traumatic goose may not be sauce for the fatiguing gander.

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