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Multiphase elastic homogenization, and the mechanics of tendon-to-bone attachment

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ABSTRACT

Estimates of the effective stiffness of a composite containing multiple types of inclusions are needed for the design and study of functionally graded systems in engineering and biologic materials. One important stiffening mechanism in biologic systems is the accumulation of a high volume fraction of mineral inclusions within and upon collagen fibers. Modeling of this mechanism is critical for understanding how stresses are transmitted from tendon to bone and for designing improvements to surgical procedures for reattaching tendon to bone. The latter is a critical need because failure rates following surgical reattachment are as high as 94% in some populations. Modeling of such material remains difficult Because of a number of physiological and mathematical challenges. A range of methods have been described in the literature for estimating the effective elastic properties of composites containing low volume fractions of different inclusion types. Here, we provide an estimate of the effective elastic responses of composites containing high volume fractions of different, ellipsoidal and anisotropic inclusion types. The homogenization estimate compared well against numerical simulation and available experimental data. The method out-performed all methods of which we are aware for modeling of numerical simulations of the mechanical response of the graded attachment of tendon to bone. The method is a good candidate for the characterization of composites with multiple types of anisotropic inclusions, even if these inclusions have moderate volume fractions and a variety of aspect ratios.