Accurate constitutive modeling of soft tissue is crucial for creating and restoring conditions of health. For example, the surgical treatment of coronary arteries obstructed by an atherosclerotic plaque, to which a majority of heart attacks are attributed, involves a method called angioplasty, which is nothing but a controlled injury applied mechanically to stretch the media beyond normal physiological states so as to permanently enlarge the cross section of the blocked artery, restoring its original blood flow characteristics [1]. The critical questions in angioplasty, like the optimum extent to which the vessel cross section could be stretched can be answered through a finite element analysis where an accurate constitutive law is employed. Likewise, it is vitally important to know the conditions under which the rupture of aneurysms is likely (e.g. [2]), which could only be calculated to the accuracy of the constitutive law employed in the calculations. Yet another example is the design of tissue engineered arteries, which requires a good understanding of arterial remodeling and growth behavior that becomes critical once implanted [3, 4]. Even the particular procedure to be used in implanting these artificial soft tissue needs to be constructed, in addition to associated medical requirements, using finite element calculations where the constitutive model used is sufficiently accurate [5]. Much of the work on the constitutive modeling of blood vessel tissue in the literature is in the form of phenomenological models using tensorial invariants that treat the arterial wall as a single layer and account for the passive mechanical response of the arterial wall. A detailed review of such constitutive models as well as others available in the literature can be found in [6], [7] and [8]. These reviews will not be repeated here to save space. However, for completeness of the work, some of the most important early work with approaches that account for histology of the material sufficiently, which is rather recent, need to be mentioned. The work of von Maltzahn et. al. [9] is not only structural but also anisotropic. Tözeren [10] accounts for some arterial histology although far from being complete. Wuyts et. al. [11] also approach the problem from a structural point of view. Some of the important models that are both structural and anisotropic are those by Demiray [12] and Rachev [13]. Rachev’s model also attempts to account for remodeling in the tissue. Finally, Holzapfel’s model is noteworthy as one of the recently developed models [6]. Although the phenomenological approaches using tensorial invariants in material modeling of biological soft tissue has been successful to some extent, they can hardly reproduce important material behavior (such as Bauschinger and vertex effects occurring in many engineering materials and probably in biological soft tissue as well) under multiaxial loading. For example, to be able to simulate so called vertex effects, it is well established that a multi-surface plasticity approach resembling physical phenomena closely is necessary. Microplane models constitute a class of models that apply such phenomenological models in a more refined way and at a lower scale than the conventional macro scale so as to reflect the physics of the material more accurately. For example, in microplane models, the elastic behavior is represented in vectorial form on planes of various orientations selected for optimal integration of material response, which is then integrated to yield the second order tensorial form for numerical analysis using finite element method. This structure, in a way, resembles the true physics of materials more closely considering the different orientation of actual grains (or building blocks) of various types of materials resulting in a directional dependence of material response. Similarly, plastic material behavior is calculated on these planes and integrated to yield the macroscopic tensorial form for finite element analysis. Although the true mechanism of plastic flow based on dislocation motion is not addressed explicitly, and thus the approach is phenomenological, the construction of the model as described reflects the structure of the material (e.g. directional dependence of material behavior) at meso-scale [14]. As a result, the model enables a multi-surface plasticity type plasticity formulation naturally, creating advantages both in terms of material behavior simulation and numerical smoothness of response.
despite the complexity of the problem handled [15]. In short, microplane models can account for not only the same types of phenomenological behavior as the classical tensorial models, but also more complex material behavior which normally falls beyond the reach of classical tensorial ones [16, 17, 18]. As a result, microplane models have been developed for a variety of engineering materials with superior modeling properties compared to their tensorial counterparts. For example, a complex engineering material, concrete, is modeled arguably much more successfully by microplane model M4 than the most advanced tensorial models for concrete available in literature at that time [17, 19, 20]. Microplane models have been developed also for rocks [21], stiff foams [22] and shape memory alloys [23]. Later, a thermodynamically consistent study of the microplane theory was performed further justifying the validity of the approach [24].

References