Scott Tashman, Ph.D.

Joint injury and joint disease are leading causes for disability and decreased quality of life. Understanding structure-function relationships of bones, cartilage, ligaments and other joint structures is critical for preventing disease/injury, as well as developing and evaluating effective treatments. Joint tissues are responsive not only to joint mechanics but also to their biochemical environment, both of which contribute to the balance between catabolic and anabolic processes critical to long-term joint health. Thus, it is essential to assess joint function in the most “natural” conditions possible, under loads commonly encountered in every-day life.

Since the advent of modern computerized video-motion analysis systems in the 1980’s, in vivo dynamic assessment of functional limb movement has steadily become more readily available, easier to use and more accurate. A great deal of knowledge has been gained from these systems, and they continue to be an important tool for the study of human movement. However, the fundamental limitation of these systems, their reliance upon external skin markers, cannot be completely overcome. This limitation renders these systems incapable of assessing dynamic function down to the level of critical joint tissues such as ligaments and cartilage.

Over the past decade, new tools have emerged for assessing joint function, primarily using radiography or MRI to directly observe the structures of interest. Dynamic or cine MRI can provide unique insights into the interactions between soft tissues during quasi-static or slow movements, though it remains limited to low frame rates and activities than can be performed within the space constraints of the MRI magnets. Systems using commercially available single or dual fluoroscopic systems (“C-arms”) offer higher accuracy and greater freedom of movement, but have inherent limitations that limit studies to relatively slow activities. Biplane radiographic systems designed specifically for dynamic joint function studies offer greater movement freedom, larger fields of view and dynamic imaging capabilities (high frame rates, short exposure times) adequate for studying nearly any human motion. These systems, pioneered at Henry Ford Hospital (Detroit, MI), are gaining rapid acceptance as the “gold standard” for high-accuracy joint kinematics, and are available or in development at a number of orthopaedic research centers across the country. This presentation will describe the basic concepts of this instrumentation and present some applications to ligament injury and osteoarthritis research.

With the motion analysis “toolkit” expanded to include dynamic MRI and radiographic techniques, new opportunities have arisen for understanding the mechanisms that regulate joint response and developing new strategies for preventing or treating joint injury/disease. By providing high-accuracy data for developing, validating and driving subject-specific musculoskeletal models, these technologies should also lead to breakthroughs that may finally enable computer modeling to achieve its long-promised objectives for improving prevention and treatment of musculoskeletal disorders.

Despite their wide potential, several important challenges remain in the development and utilization of these technologies. Tissue segmentation from 3D imaging (CT, MRI) remains an imprecise and largely manual process, impeded by the absence of readily available software tools (either commercial or open-source) designed for quantitative biomechanics applications. The tracking processes for determining 3D kinematics from image sequences also remain highly labor intensive (requiring 10-30 hours of labor for every hour spent collecting data), dramatically increasing the costs for studies. Lack of standards for system validation and data reporting impede our understanding of the relative capabilities of different systems (and their applicability to different joints/movements) and prevent combining data from multiple centers (a prerequisite for large-scale clinical trials).

Finally, studies incorporating these technologies (especially if ionizing radiation is used) must be designed to intelligently address significant clinical questions, rather than just reporting mounds of kinematic data of uncertain application. The most meaningful studies may need to be multidisciplinary, incorporating expertise from engineers, molecular/cellular biologists, surgeons, rehabilitation experts and epidemiologists as needed to assess biomechanics in a more holistic context. Well-designed studies are essential to overcome the all too common impression that motion analysis studies often generate a great deal of data with only limited contribution to improving relevant scientific knowledge and ultimately clinical care.