MACH-1™ Micromechanical Systems

Automated Indentation Mapping

The Mach-1™ is a micromechanical testing system commercially available since 1999. Originally developed for cartilage testing, this multiple-axis tester is used in various configurations to evaluate the mechanical properties of tissues and soft materials. The Mach-1™ offers versatility in numerous biological, biomaterial, and material testing applications due to its modular design, small footprint, and customization features.

Mach-1 model v500css

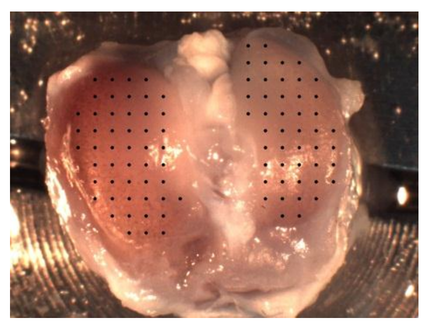
Advantages and Current Limitations of Indentation

Contrary to other testing configurations in which a sample of cartilage must be harvested from the articular surface, indentation is non-destructive and maintains the mechanical environment of the cartilage layer, in particular its interaction with the subchondral bone. This particularity of indentation thus allows the possibility to perform repeated tests at the same location and to test multiple sites with high spatial density, while leaving cartilage intact for subsequent characterizations. The present limitation of the indentation technique is due to the requirement that indentation be performed perpendicularly to the articular surface. Using a uniaxial mechanical tester for indentation, the researcher has to manually orient the sample surface perpendicular to the indentation axis at the location of interest. This visual alignment creates variation in the results and error in the localization of the test. Moreover, since mechanical tests on cartilage have to be performed in a chamber filled with saline solution, angular positioning of the chamber is limited due to the maintenance of the solution level inside the chamber and/or interference of the chamber wall with the indentation axis.

Ovine (sheep) condyles installed under a spherical indenter (d=1 mm) for normal indentation mapping

Automated Indentation Mapping

Taking advantage of the unique multiple-axis capabilities of the Mach-1 v500css tester, Biomomentum has developed novel functionalities which allow all the advantages of indentation testing, while overcoming traditional limitations. This technological advancement relies on the addition of two functions to the Mach-1 Motion software: "Scan XY" and "Normal Indentation". The "Scan XY" function moves the X and Y horizontal stages of the tester at predefined positions (contained in a list) prior to performing a series of functions at each of these positions. It should be mentioned that such a position list can be easily generated using a top view picture of the sample processed with Biomomentum's "Cartilage Mapping" software. The "Normal Indentation" function precisely detects the height and orientation of the surface at the XY position and records the load (multiaxial load cell) while simultaneously moving the three stages of the tester at different speeds in order to move a spherical indenter with a predefined displacement profile along a virtual axis normal to the surface of the sample.



Top view of a murine (rat) tibial plateau with a position grid superimposed

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Automated Thickness Mapping

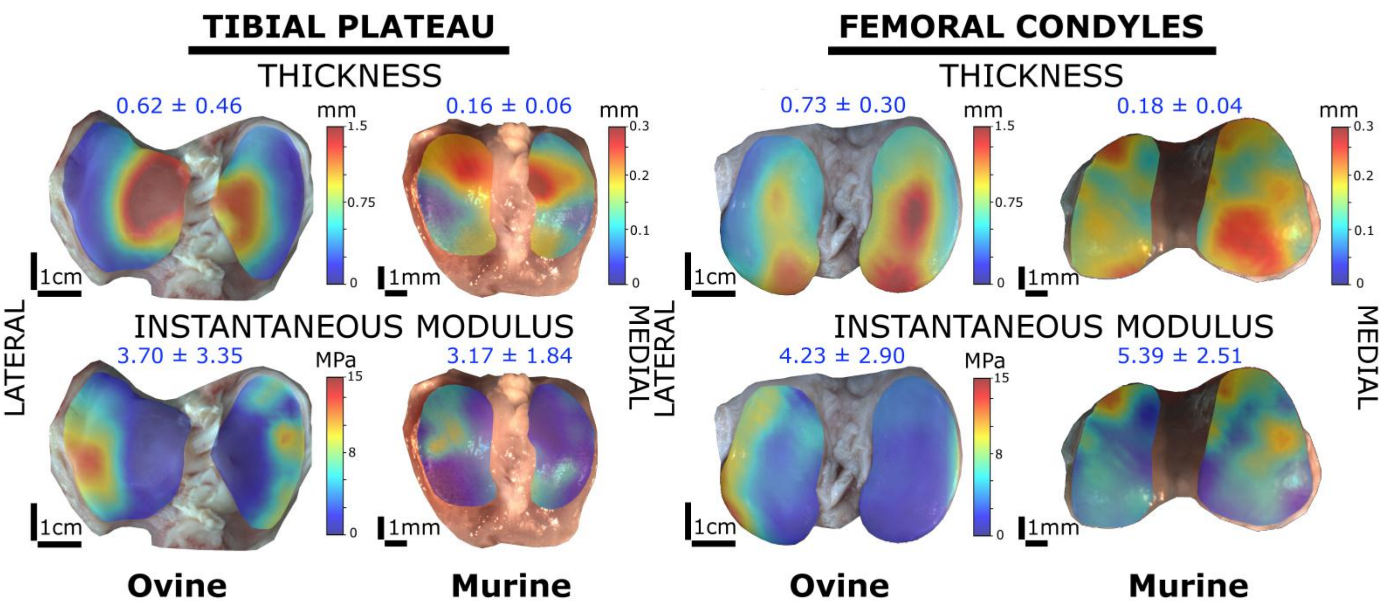
Replacing the spherical indenter with a needle probe, it is also possible to map cartilage thickness over the entire articular surface. This is done using the "Scan XY" (previously described) and the "Find Contact" functions. The "Find Contact" function moves the needle at a constant speed until it penetrates the cartilage surface and stops inside the bone. The difference between the vertical position of the surface (position where the load starts to increase) and the vertical position of the cartilage/bone interface (first inflection point in the displacement/force curve) provides the vertical thickness.[1] Cartilage thickness can be calculated using surface orientation previously obtained from the "Normal Indentation" function.

[1] Adapted from Jurvelin, J.S., Rasanen T., Kolmonen P. and Lyyra T. Comparison of optical, needle probe and ultrasonic techniques for the measurement of articular cartilage thickness. J. Biomechanics, Vol. 28, No. 2. pp. 231-235, 1995

Ovine (sheep) condyles installed for thickness mapping

Feasibility Study Results

Visually normal tibial plateau and femoral condyles were collected from a sheep and a rat. Using top view picture of each sample, 100-150 sites per surface tested using the automated indentation and thickness mapping protocol. Using corresponding thicknesses, the normal load vs. normal displacement curves obtained were analyzed in the Mach-1 Analysis software to extract mechanical properties. Results from the "Normal Indentation" function can also be used to create high resolution surface height maps.



Thickness and instantaneous modulus mappings obtained on ovine and murine articular surfaces

These results demonstrate the potential of this novel automated indentation mapping technique to characterize the mechanical properties of an entire articular surface with high spatial resolution, rapidity (~1 minute/site), precision, and reproducibility for joints as small as a rat joint.

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