Cartilage Streaming Potentials Measured with an Arthroscopic Medical Device Correlate with Site-specific Biochemical and Biomechanical Properties of Equine Articular Cartilage

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Arthro-BST Intended Use

Quantitative Assessment of Cartilage Electromechanical Properties

Clinical Arthroscopy
R&D experiments with an open joint

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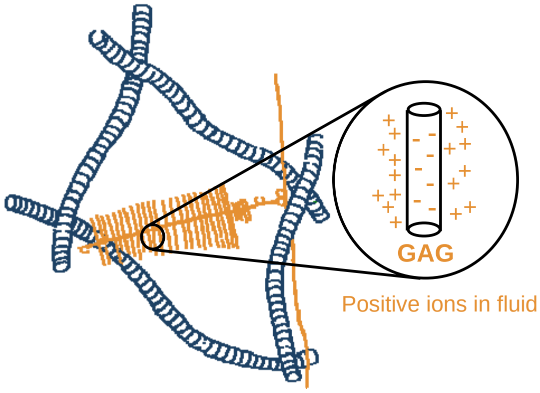
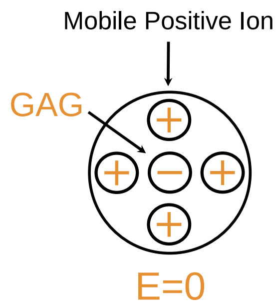
Our group has developed a new device named Arthro-BST that measures streaming potentials. Its intended use is the quantitative assessment of cartilage electromechanical properties. For example, during clinical arthroscopy or R&D experiments with an open joint.

What are Streaming Potentials ?





Glycosaminoglycan (GAG) entrapped in a collagen fibril network

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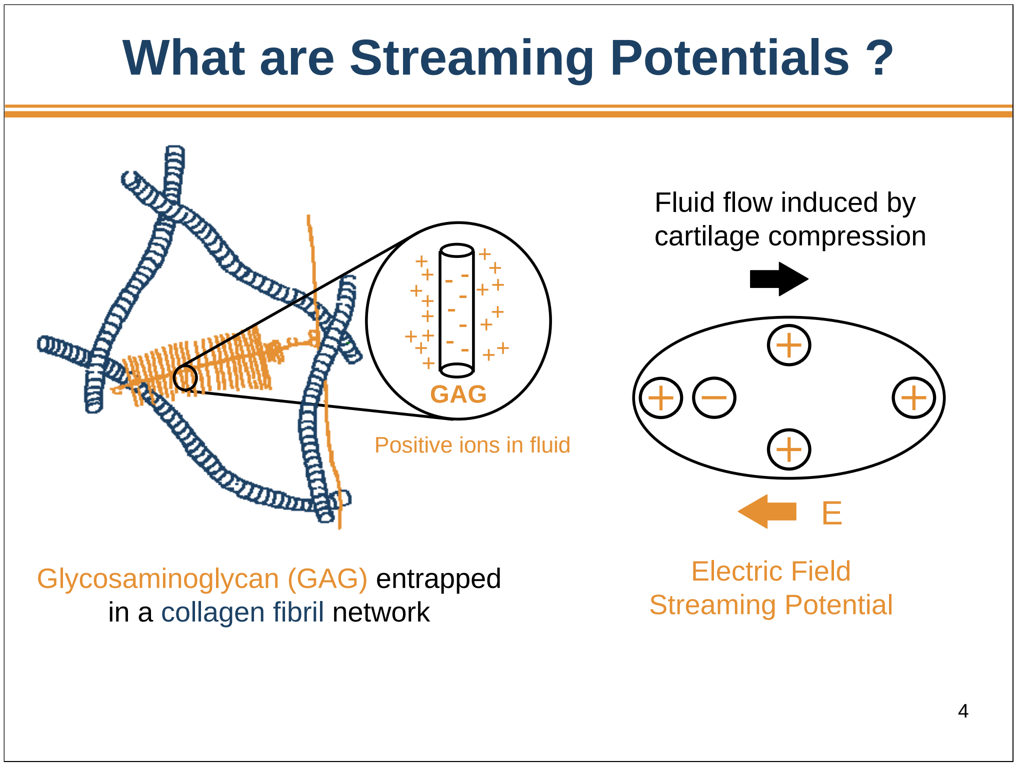
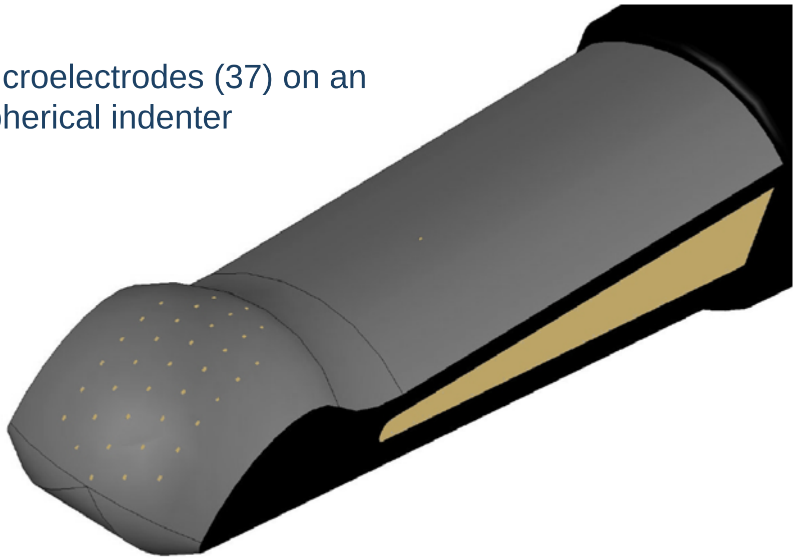
So, what are streaming potentials? In cartilage, glycosaminoglycan is entrapped in a collagen fibril network. Due to the negative charge of GAG, there is an excess of mobile, non-fixed, positive ions in the fluid. Under equilibrium conditions, with no load or fluid flow, these positive charges are symmetrically arranged so that no net macroscopic electric field exists.



During fluid flow induced by cartilage compression there is a displacement of positives ions relative to the fixed charge of GAG resulting in an electrical field named streaming potentials. You can imagine how streaming potentials would be sensitive to GAG content and collagen organization. For example, a loss of GAG removes the fixed charge and cleavage of collagen network allows GAG to move with the fluid, both reducing streaming potentials.

Arthro-BST Sensor

Microelectrodes (37) on an
spherical indenter



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The sensor of this device has 37 microelectrodes evenly distributed over the surface of a spherical indenter. Streaming potentials are recorded by every microelectrode when the spherical indenter is manually compressed against the articular cartilage surface.

Measurement Principle

Streaming Potentials → 37 microelectrodes (Sterile Tip) → Handle

↓

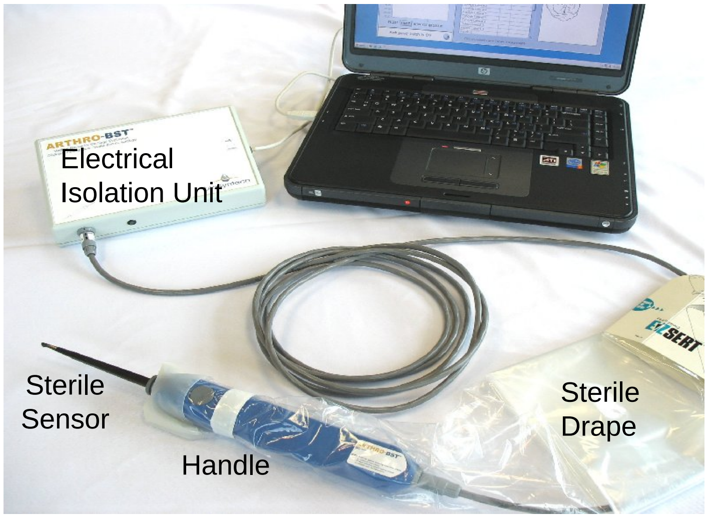
Electrical Isolation Unit

↓

Computer

↓

Electromechanical Properties



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This is the complete system. The streaming potential signals are recorded by 37 microelectrodes, then digitized in the handle of the device, sent to an electrical isolation unit and finally transferred to a computer for signal analysis. The 37 streaming potential signals are then analysed with a mathematical algorithm to extract a parameter that is representative of the electromechanical properties of the cartilage.

Why a Spherical Indenter ?

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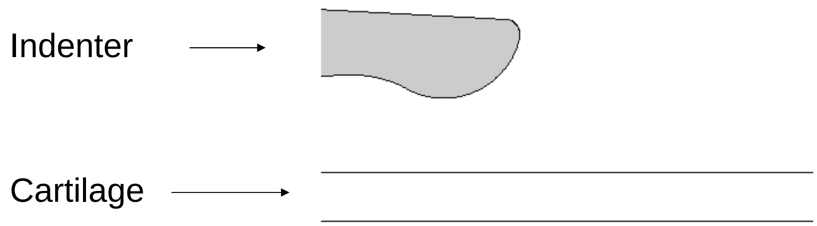
You may ask why a spherical indenter and so many microelectrodes? During a manual indentation it is difficult to perfectly align an indenter relative to the cartilage surface.

Why a Spherical Indenter ?



Streaming Potentials Inside Cartilage

Calculated electromechanical properties are independent of the orientation

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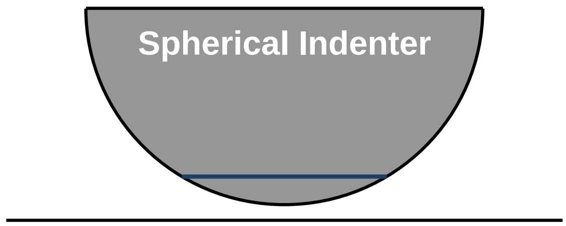
We overcome this lack of control in the orientation by using a spherical indenter. As long as you are in the spherical region of the indenter, the induced streaming potentials are the same within the cartilage. Consequently, the calculated electromechanical properties will be independent of the orientation.

Why a Spherical Indenter ?



Articular Cartilage Surface

Calculate electromechanical properties when a predefined compression amplitude of 150um is reached

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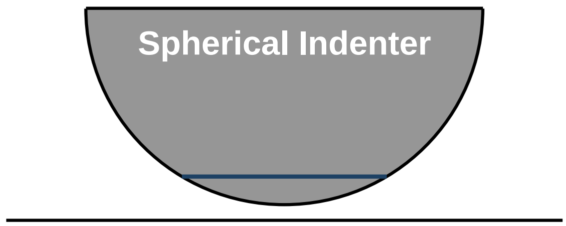
By knowing how many electrodes are touching the cartilage you can follow the amplitude of the compression. With this device the streaming potentials are used to calculate electromechanical properties when a predefined compression amplitude of 150um is reached.

Why a Spherical Indenter ?



Articular Cartilage Surface

Calculate electromechanical properties when a predefined compression amplitude of 150um is reached

Calculated electromechanical properties are independent of the force applied.

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As a result, if a very light force is applied versus a larger force the calculated electromechanical properties will be the similar since they are both calculated at the same compression amplitude. Consequently, the calculated electromechanical properties will be independent of the force applied.

Objectives

- Compare streaming potentials on different articular cartilage surfaces of the horse stifle (knee) joint.
- Correlate streaming potentials to biochemical and biomechanical properties of horse cartilage.

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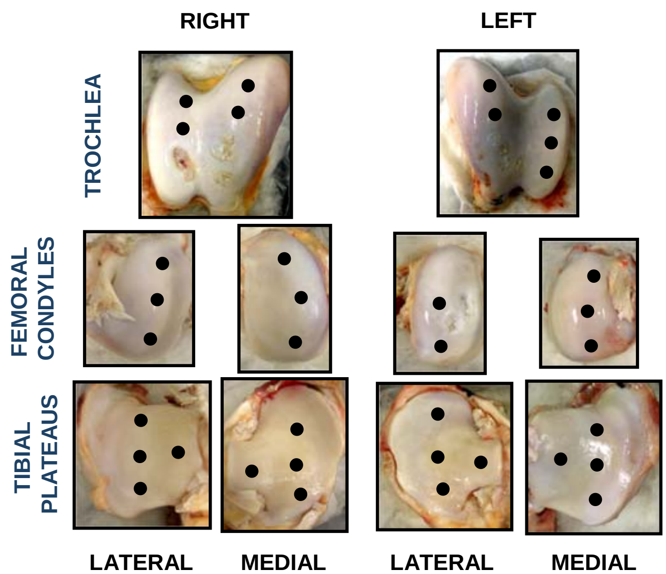
The objectives of this study were to compare streaming potentials on different articular cartilage surface of the horse stifle (knee) joint. And, to correlate streaming potentials to biochemical and biomechanical properties of horse cartilage.

Methods – Horse Stifle Joint



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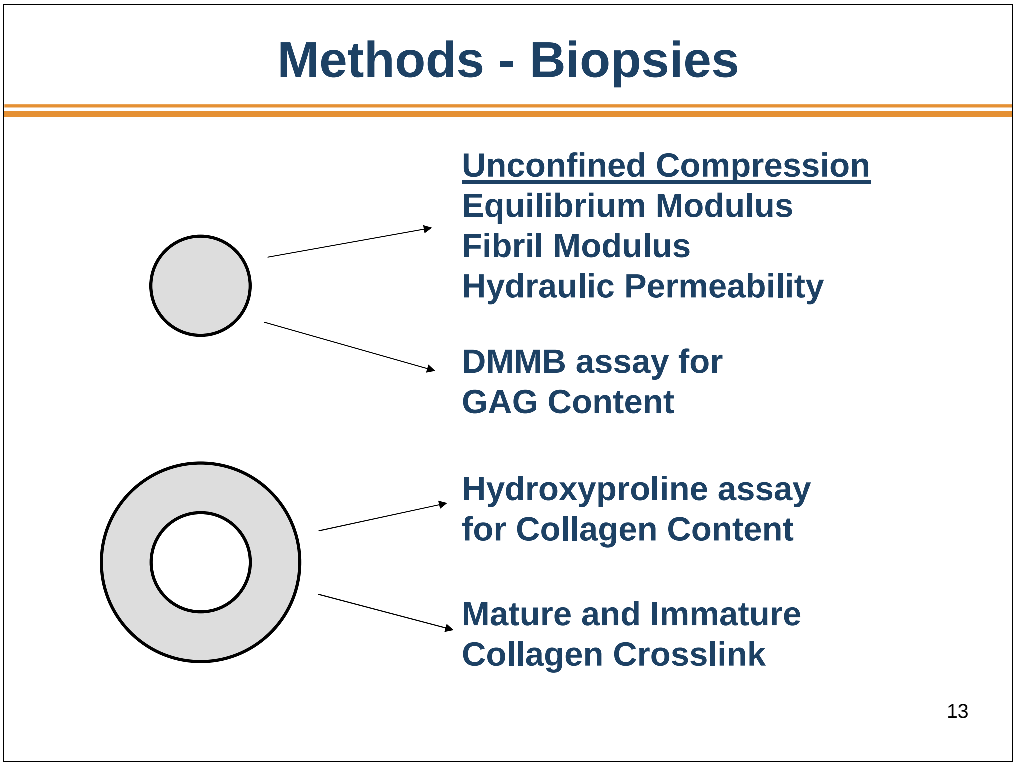
36 positions were tested with the device during an open joint experiment on trochlea, femoral condyles and tibial plateaus of two stifle joints. One user performed 5 consecutives mappings and the 5 measurements averaged.



After the mapping, 3mm disks were isolated and tested in unconfined compression to obtain the equilibrium modulus, the fibril modulus and the hydraulic permeability. After the unconfined compression, the disk was analyzed for GAG content with the DMMB assay. 6mm rings were also isolated and analyzed for collagen and collagen cross-linking content.

Results – Surfaces Comparisons

	Femoral Condyles	Trochlea	Tibial Plateaus	ANOVA	Condyles		Troch.
					Troch.	Plateaus	
Electromechanical properties, mV·mm^2	17.7	12.6	3.8	***		***	**
Thickness, mm	1.5	2.1	2.2	**	*	**	
Fibril modulus, MPa	8.2	5.0	1.4	**		**	
GAG, % wet weight	2.3%	2.4%	2.4%				
Collagen, % wet weight	15.8%	13.3%	11.5%	**		**	
Collagen crosslink mature ÷ immature	48	55	25	**		**	**

*p<0.05, **p<0.01, ***p<0.001

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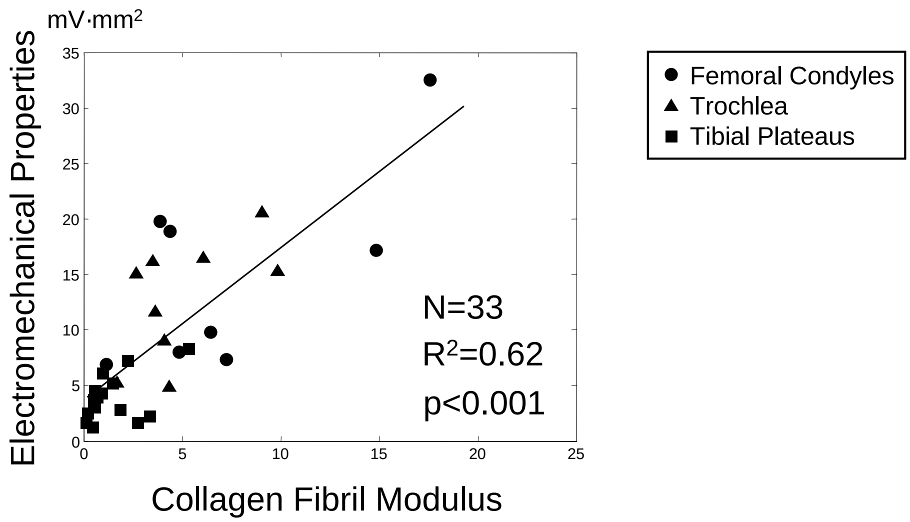
And now the results, the electromechanical properties measured on the femoral condyles and the trochlea were statistically higher compared to the tibial plateaus. The thickness of the trochlea and the tibial plateaus were statistically higher compared to the femoral condyles. The fibril modulus obtain from unconfined compression and the collagen content were higher on the femoral condyles compared to the tibial plateaus. Finally, the ratio of mature collagen crosslinks to immature was higher on the femoral condyles and the trochlea compared to the tibial plateaus. There was no difference between surfaces for GAG content.

Results – Correlation to Collagen Fibril Modulus



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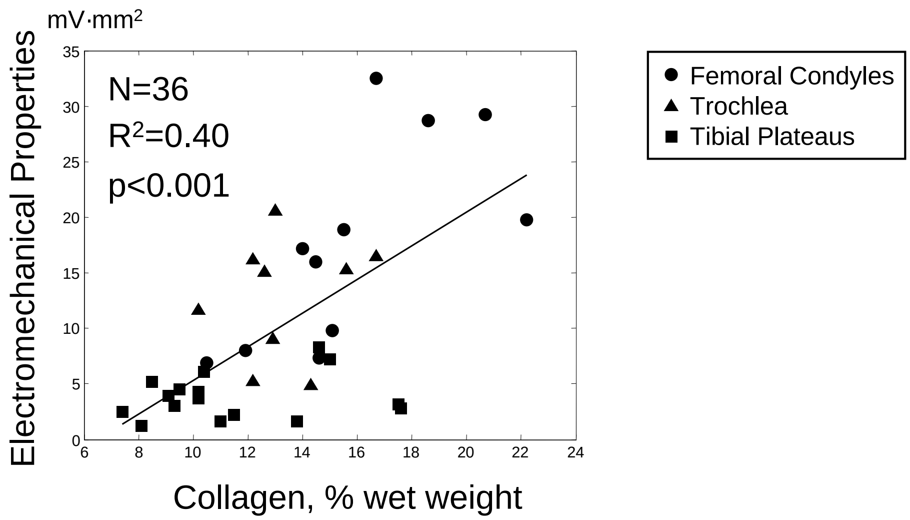
Electromechanical properties were statistically correlated to the collagen fibril modulus at a highly significant level.

Results – Correlation to Collagen Content



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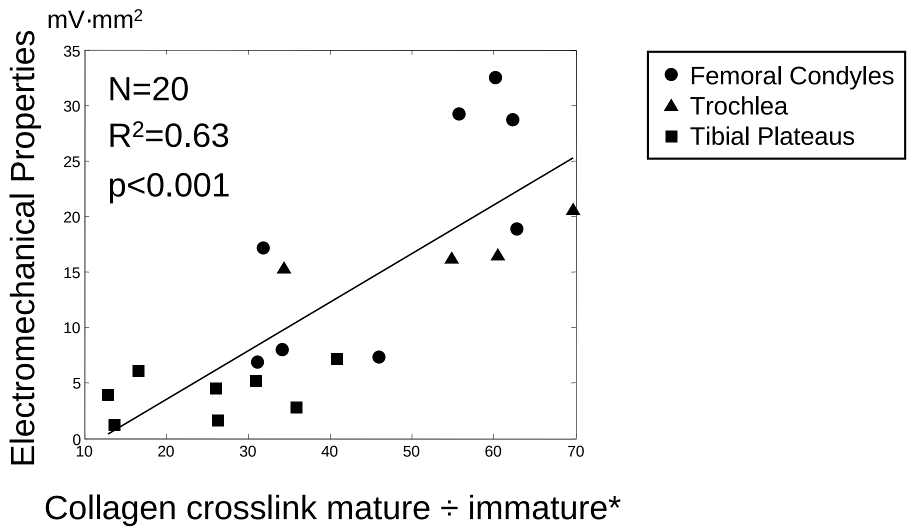
Electromechanical properties were also statistically correlated to the measured collagen content. There was no correlation between the GAG content and the electromechanical properties in this healthy cartilage, probably since GAG content did not vary too much as observed between surfaces.

Results – Correlation to Collagen Crosslink



Hollander, et al., 2006.

Electromechanical properties were also statistically correlated to the ratio of collagen mature crosslink to immature that has been used previously to assess cartilage maturity. We can now see that streaming potentials represents an integrated indicator of cartilage function that depends on biochemical and biomechanical parameters that are mainly related to collagen.

Conclusion – Streaming Potential Measurement

- Distinguished cartilage from tibial plateau versus femoral condyles and trochlea
- Correlates with biomechanical and biochemical properties related to collagen. (collagen content, crosslink and fibril modulus)

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In conclusion, the streaming potential measurements were able to distinguish cartilage located on tibial plateaus compared to femoral condyles and the trochlea, and correlated with biomechanical and biochemical properties related to collagen, like collagen content, crosslink and fibril modulus. An ongoing study is using this device to follow cartilage degeneration following an impact trauma in an horse model. Future studies will be done to follow cartilage repair methods in animals models and people.

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