Characterization of Surface Erosion Patterns in Human Knee Cartilage

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BACKGROUND

Cartilage Surface in Health, Aging, and Disease

Osteoarthritis is a degenerative joint disease and is the most common disease with aging. Joint degeneration involves all the tissues of the joint such as the muscles across the joint, ligaments, synovium, articular cartilage, subchondral and metaphyseal bone, and joint capsules [1,2]. The progressive loss of articular cartilage is a key factor to this disease. Osteoarthritis initially starts by disrupting and roughening the superficial zone of cartilage due to fibrillation. As the disease progresses, fibrillation travels deeper to the point where there is no cartilage left to cushion the bone. Due to aging, the chondrocytes have a declined synthetic response and are incapable of fully repairing the damaged tissue.

As osteoarthritis develops, the surface of the cartilage becomes rougher and obtains more cracks due to surface defects. These factors compromise the stability and mechanical function of the joint, not allowing the cartilage to support the applied pressure. These cartilage lesions are common amongst 63% of people undergoing arthroscopy with an average of 2.7 per joint. These defects are significantly related to functionality and pain [3].

Methods of Imaging

There have been many different ways to image cartilage defects. Some popular ways are of Magnetic Rsonance Imaging (MRI), arthroscopy, ultrasound, 2-D histology, 2-D SEM, and 3-D microscopy. MRI is a highly effective way being a non-invasive technique that can detect cartilage lesions as small as 1mm [3]. However some limitations include not visualizing the cartilage surface efficiently.

Arthroscopy is a widely used method to be used in comparison with other imaging modalities such as MRI. However it is limited due to the fact it is an invasive procedure only being used in clinical studies, as well as having a poor resolution only comparing lesions to below or above 50% of the thickness of the cartilage. Although it can detect the cartilage surface, it had difficulty identifying lesions at a deeper level [3].

Ultrasound is also a popular imaging modality, being non-invasive. It can detect cartilage defects between 2-19mm but is has not been explored outside of *in vitro*[3].

<u>Micro Computed Tomography</u>

Micro computed tomography (mCT) is a type of x-ray modality. It is non-invasive and is able to obtain 3-D images at a millimeter level. Coupled with a contrast agent, soft tissue can be enhanced.

HYPOTHESIS AND AIMS

The hypothesis of this study is that the surface characterization of cartilage can be detectable with the progression of osteoarthritis.

Specific Aim1. Develop a method to visualize surface characteristics of osteoarthritic cartilage using micro-computed tomography.

Aim 1.A. Determine if surface roughness and fissures can be seen using microCT at (1um)^3 voxel resolution.

Specific Aim 2. Map changes in the surface characterization of cartilage with the progression of osteoarthritis.

Aim 2.A. Obtain surface characterization data from cartilage slabs at different stages of osteoarthritis.

Aim 2.B. Determine if surface parameters change with severity of osteoarthritis.

METHODS

Preparation

The left lateral femoral condyle (LFC) of three donors, male and female age ranging from 74-80, was used in this experiment. 2.5 mm diameter cartilage cores were punched out of 6 different areas from the proximal to distal region of the LFC. Each core was then submerged in 60% Barium Sulfate in PBS and was scanned using Shimadzu XMS160CTS microCT machine. They were washed 4 times in PBS for 5 minutes each.

Scanning

Each core was placed into a scanning chamber specifically fabricated for the microCT machine. The core was submerged in 20µL of barium sulfate and the top of the chamber was sealed with parafilm to ensure 100% humidity. Voxel resolution range was from 4-8 μm^3 , voltage range from 52-56 kV, and current range from 95-100 µA.

Analysis

Data obtained through microCT was then inputted into Mimics in which the core was segmented and exported as point cloud data. This was then inputted into a MATLAB program in which it identified the surface and fit it to a plane. It then outputted a grayscale topographical image. The topographical image was then inputted through an ImageJ plugin to obtain surface roughness characteristics such as arithmetic mean deviation, root-mean square deviation, skewness, and kurtosis.

RESULTS

17 cartilage cores were sucessfully scanned. Sample 10-031 only contained 5 cores.

Table 1: Average Voxel Resolution and Ranges of Each Sample Group

Sample	Voxel Resolution (μm)	Range (μm)
10-010	7.47	7.32-8.00
10-031	5.74	5.10-6.34
10-041	5.56	4.46-6.14

Table 2: Sample Specifics and Scanning Parameters of Sample 10-010A

Sample	10-010A
Sex	F
Age	75
LFC Grade	2
Resolution	8.00 μm
Voltage/Current	52 kV/ 100 μA
Rotational Step	0.3°
Type	360°

Table 3: Surface Roughness Characteristics Outcome of Sample 10-010A

Arithmetic mean deviation	0.0297 px
Root-mean square deviation	0.0215 px
Skewness	5.57
Kurtosis	156.4

Table 4: Sample Specifics and Scanning Parameters of Sample 10-031B

Sample	10-031B
Sex	
Age	74
LFC Grade	1
Resolution	6.34 μm
Voltage/Current	55 kV/ 100 μA
Rotational Step	0.3°

Type	360°

Table 5: Surface Roughness Characteristics Outcome of Sample 10-031B

Arithmetic mean deviation	0.0255 px
Root-mean square deviation	0.0137 px
Skewness	8.00
Kurtosis	289

Table 6: Sample Specifics and Scanning Parameters of Sample 10-041A

Sample	10-041A
Sex	M
Age	80
LFC Grade	2
Resolution	5.90 µm
Voltage/Current	52 kV/ 100 µA
Rotational Step	0.3°
Type	360°

Table 7: Surface Roughness Characteristics Outcome of Sample 10-041A

Arithmetic mean deviation	2619 px
Root-mean square deviation	1880 px
Skewness	1.079
Kurtosis	34.6

DISCUSSION

Cartilage cores taken from the left lateral femoral condyle of human knee were scanned in barium sulfate using microCT. Although 1μm^3 voxel resolution was not obtained, a range of 4-8 μm^3 was scanned. This range of voxel resolution proved to be sufficient enough to observe the surface contours as roughness and fissures could be seen. Due to the solubility constant of Barium Sulfate, it produced a thick fluid. This is a limitation in scanning because possible air bubbles may appear. This was later seen during image precessing and some air bubbles were seen on the surface of the core, making it difficult to distinguish between the two. Although the images obtained through microCT were sufficient, and alternative method needs to be explored to compensate for the double images that appear. This could either be due to the scanning chamber and the movement of the sample during scanning or a reconstruction problem. This, however, did not have a significant affect on obtaining the image of the surface.

Data from the microCT machine was then inputted into Mimics to segment the core. This proved sufficient to a certain degree. Thresholding and masking was used to segment the core from the surrounding medium, however some noise still appeared. This was then deleted by hand. Limitations include not deleting all of the noise around the surface or the air bubbles on the surface previously mentioned.

Once the point cloud data was obtained and inputted though a MATLAB program, the surface was determined and a plane was fitted. This method is acceptable for reasonably flat surfaces. If an abnormal surface was to be inputted, this would fail. A topographic image was then obtained by vertically analyzing the statistical differences in height, assigning different grayscale values, white being the highest and black being the lowest . This, however, is not able to detect fissures that propagate diagonally or horizontally to the surface.

The grayscale topographic image was then inputted into an Image J plugin. Surface roughness characteristics were then obtained. Some limitations of this plugin include that fact that it cannot analyze a circular image. When inputting the original image of the core, outputted data included the blank space around the core since the core was a cylindrical shape. Thus, a square was cropped out of the center of each core and ran though again. Another limitation to this plug in is that data obtained for each core is very difficult to compare to others. These are relative values.

Future plans would include altering the current method of obtaining surface roughness characteristics or finding another method altogether.

References

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