Extraction of High Resolution Bone Surface Topology from Micro-CT Data for Identification of Osseous Landmarks

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ABSTRACT

Micro Computed Tomography was used to image seven cadaveric human knees with the aim of investigating the existence, or otherwise, of osseous landmarks – used as a navigation tool during Anterior Cruciate Ligament Reconstruction Surgery. The presence of these landmarks is a hotly debated issue among clinicians. Application of Micro-CT to orthopaedics is a burgeoning field, however post-processing of CT data is a significant problem due to the large file sizes resulting from fine detail in bone trabeculae. A method for isolating the surface topology of the knees was developed, facilitating various analyses including: Relief Mapping, 3D visualisation and 3D printing. This new method, employing a range of post-processing software, permits reduction of Micro-CT volumes from ~40Gb to 15Mb without compromising surface detail – a necessary step to performing meaningful analysis. Quantitative analysis of surface topology allowed objective representation of osseous landmarks which were compared to qualitative, subjective observations made by clinicians in previous research. The relief maps disfavour the current consensus among clinicians, that osseous landmarks are present in 80%+ of samples.
Further work is being conducted to confirm these findings using a larger representative sample. The method developed has

INTRODUCTION

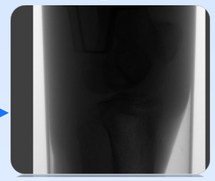
Anterior Cruciate Ligament (ACL) Reconstruction surgery the sixth most common orthopaedic surgery in the USA and as a result has become the most studied musculoskeletal system[1]. Despite this, full recovery after surgery is unsatisfactory with only ≈70% of patients regaining full knee mobility[2]. Attempting to solve this, clinicians have investigated surgical methods that reconstruct the knees original anatomy after rupture[3]. However, to accomplish this physicians need determine where to attach the newly grafted ligament to the Lateral Intercondylar wall - this location is called the ACL footprint. The approach is obviously to place the new ligament in the same location as the old one however this can be identified after a ACL rupture and so other landmarks are needed. According to Wolffs Law there should be thickening (and so supposed ridge) around the original ligament attachment[4]. These ridges, when visible are often used to place the ligament anatomically. However, these ridges, the lateral intercondylar ridge and lateral bifurcate ridge are often not visible and controversy over their actual existence has sparked[1]. The aim of this project was to use micro-CT to investigate the existence of these ridges to a degree of resolution not explored yet in the literature and validate, or otherwise their existence. To ensure objectivity the surface topology was extracted at a high resolution and then used to create relief maps along with other visual methods.

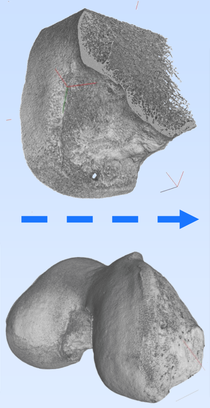
METHODOLOGY

7 Cadaveric Knees were scanned using a Micro-CT scanner

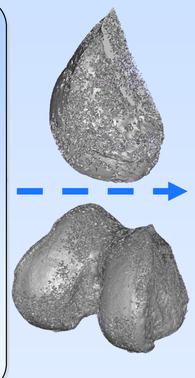
The 2D CT images were reconstructed using CT Pro

The 3D volumes were processed in VGStudio Max isolating the distal femoral head from the tissue

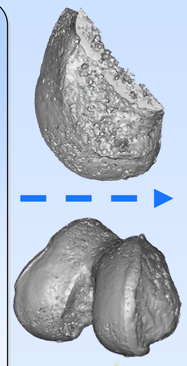




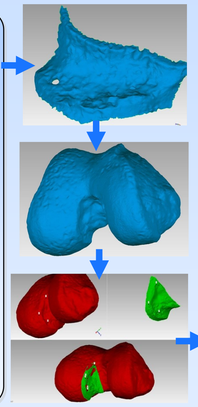
The ACL footprint and Femur were exported separately with the footprint being kept at its highest resolution while the whole femur was exported at a lower resolution to reduce the data size.



The ACL footprint was 'Shrink-wrapped' in Magics to extract the surface detail at its highest resolution. The femur was also shrink-wrapped but to a lower detail.

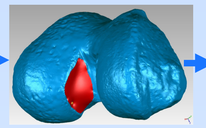


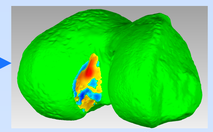
Both the ACL footprint and femur were imported into Geomagic where they were 'tidied' and merged back together



Finished surface model of knees in a versatile file format ready for further analysis

Relief maps of the ACL footprint were produced by smoothing a baseline knee and applying a coloured deviation analysis



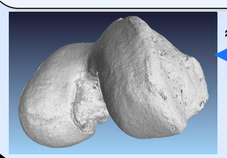


Knees were imported in AutoDesk Showcase for bone material rendering and visual optimisation. They were then viewed in a 3D interactive virtual environment by surgeons during a survey looking at ridge visibility

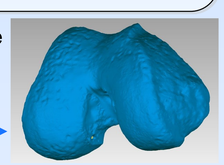
Knees were sent for 3D printing

RESULTS

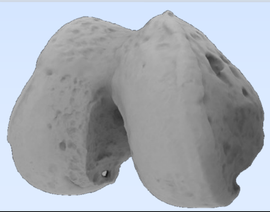
Result 1
A high-resolution surface topology was extracted from Micro-CT data removing non-ROIs and hence reducing data size significantly from ≈40GB-15Mb. Furthermore the finished surface model exists in a versatile format that can be used for printing, finite element analysis photo rending and so on.



≈40GB volume to **≈15Mb** surface model

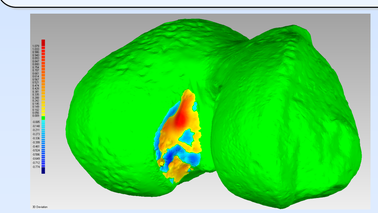


Result 2
A photo-rendered 3D object that can be viewed in a 3D virtual environment

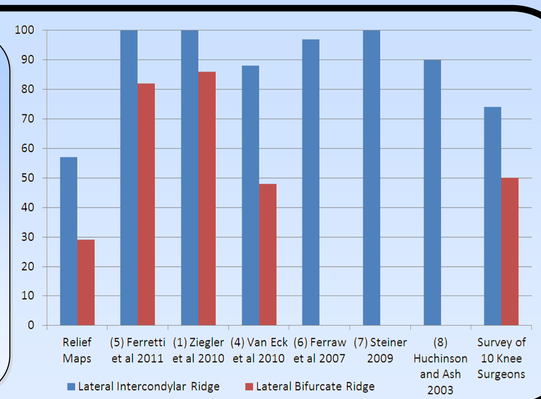


Result 3
Physical models to scale produced using a high resolution 3D printer

Result 5
Relief maps of the controversial osseous landmarks on the ACL footprint allowing for a quantitative observation



Result 6
Using objective quantitative results regarding the surface topology of the ACL footprint a graph was produced to compare the findings with previous observations in the literature. Our results disfavour the current consensus.



CONCLUSIONS

- Micro-CT, coupled with this method for extracting surface topology, can be an effective way for investigating anatomical features at a very high resolution (60µm).
- Surface extraction from CT can create versatile files allowing for further analysis.
- Relief maps of osseous landmarks can be created therefore allowing for a more objective approach to identifying controversial osseous landmarks.
- The quantitative observations from the relief maps about the presents of the ridges disfavours the general consensus as seen in the results graph.
- We note that our sample size was small and aged (60-80 years old) and hence further work is needed.

FURTHER WORK

Further work is being conducted to verify the results including:

- Using a larger sample size of knees that haven't been operated on post-mortem before CT scanning.
- Considering the cortical thickening under the ACL footprint in an attempt to understand the underlining physiology behind these osseous features.
- Investigating the effects of perception relating to the 'identification' of these landmarks.
- Using different CT software to appreciate the different visual results.

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