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1. Abstract

Introduction: *Bone marrow stimulation has been a successful treatment option in cartilage repair and microfracture was the procedure of choice since the late 1980s. Despite its success in young and active patients, microfracture has inherent shortcomings such as shallow channels, wall compression, and non-standardized depth and diameter. The purpose of this study was to assess bone marrow access comparing microfracture, 1 and 2mm K-Wires, 2mm drill, and a recently introduced standardized subchondral bone needling procedure (nanofracture) that creates 9mm deep and 1mm wide channels.*

Material and Methods: *An ethics approved, adult ovine model was used to assess the effects on the trabecular channel structure following microfracture, nanofracture, K-wire, and drilling. All bone marrow stimulation techniques were conducted on a full thickness articular cartilage defect on the medial femoral condyles; surgery was performed by the same surgeon (DS). MicroCT (Inveon Scanner, Siemens, Germany) was performed using 3D reconstruction and 25 micron slice analysis (MIMICS, Materialise, Belgium).*

Results: *Microfracture elicited shallow depth with bone compression surrounding the channels. Trabecular channel access was limited; the channel depth and diameter were non-standardized and highly user and instrument dependent. Nanofracture demonstrated deep cancellous bone perforation with a high number of open trabecular channels. K-Wire drilling with both diameters resulted in well defined channel walls, outlined by fine osseous deposits. Trabecular channel access was limited. The diameter of bone perforation is standardized, but depth is defined by visual controls. 1mm drill bit reaming demonstrated better osseous evacuation, but still limited trabecular marrow access.*

Conclusion: *Nanofracture resulted in thin, fragmented cancellous bone channels without rotational heat generation. Compared to microfracture and K-Wire stimulation, nanofracture showed superior bone marrow access with multiple trabecular access channels extending 9mm into subchondral bone.*

2. Purpose

The purpose of this study was to compare the subchondral bone behaviour of various mesenchymal stemcell stimulation techniques to ascertain bone marrow access through microCT examination in an adult ovine model.

Bone marrow stimulation in cartilage repair using microfracture has been the primary cartilage repair procedure for more than 20 years, however, the technique has not been standardized leaving diameter and depth user dependent. Previous studies by Chen et al. (2,3) and Fortier et al. (4) have demonstrated shallow channels and wall compression with increased trabecular wall thickness and density leading to limited open trabecular channel access.

The current investigation expands on these findings adding comparative techniques to micro-CT based assessment of subchondral bone stimulation for cartilage repair. The results are placed in context of a new subchondral bone needling procedure (1).

3. Methods and Materials

An ethics approved, adult ovine model was used to assess the effects on the trabecular channel structure following microfracture (Arthrex, Naples, FL), Nanofracture (Arthrosurface, Franklin MA), 1 mm and 2mm stainless steel K-wires (Small Bone Innovations, Morrisville, PA), and a 2 mm stainless steel 2 -fluted drill (Small Bone Innovations, Morrisville, PA). All bone marrow stimulation techniques were conducted on a full thickness articular cartilage defect in the weight bearing area of the medial femoral condyles. All surgical *procedures were performed by the same surgeon (DS). Micro-computed tomography (micro-CT) (Inveon Scanner, Siemens, Germany) was performed using 3D reconstruction and 25 micron slice analysis (MIMICS, Materialise, Belgium).*

The study hypothesis was based on several assumptions:

- **Microfracture** *(Fig 1A) through its axial force on a V-shaped tip leads to peri-channel bone compaction with little or no evacuation of displaced bone resulting in limited trabecular channel access.*

Microfracture Channel Depth: ~3mm

Technical Considerations:

- *Depth was controlled by color marking at the awl tip per manufacturer recommendations (2.5 -3.0mm); Arthrex, Naples, FL; 40 degree tip*
- *Caution was exercised to maintain axis of tip and limit leverage once impacted*
- *Consistent and standard mallet force was applied per accepted surgical technique*

fig 1a microfracture awl tip.jpg

- **Nanofracture** *(Fig 1B), a novel subchondral bone needling procedure, performed through axial force on 1mm thick Nitinol needle leads to thin, 9mm deep channels with fragmentation and displacement of cancellous bone. Little or no evacuation of displaced bone was expected.*

Nanofracture Channel Depth: 9mm

Technical Considerations:

- *Depth is standardized by stop-controlled Nanofracture handle (9.0mm); Arthrosurface, Franklin, MA; 15 degree tip*
- *Caution was exercised to maintain axis of tip and limit leverage once impacted*
- *Pin puller was used to retract needle with minimal torque (Stryker, Kalamazoo, MI)*
- *3-5 consistent mallet strokes were applied to reach stop-control*

figure 1b nanofracture tip.jpg

- **K-Wire Drilling** *(Fig 1C) with axial force and high speed rotation leads to a smear layer surrounding the inner wall of the channel caused by the negative rake angle at the metal tip/trabecular bone interface which results in limited marrow access and little or no evacuation of displaced bone.*

K-Wire Drilling Channel Depth: ~9mm

Technical Considerations:

- *1.0 and 2mm thick k-wires (SBi, Morrisville, PA)*
- *Depth was guided by visual control*
- *High speed drill was used according to standard medical practice*
- *Caution was exercised to maintain axis of tip and limit leverage*

figure 1c 1mm kwire tip.jpg

- **2-Fluted Drilling** *(Fig 1E) with axial force leads to higher levels of displaced bone evacuation.*

2-fluted Drill Bit Channel Depth: ~9mm

Technical Considerations:

- *2.0mm drill bit (SBi, Morrisville, PA)*
- *Depth was guided by visual control*
- *High speed drill was used according to standard medical practice*
- *Caution was exercised to maintain axis of tip and limit leverage*

figure 1e 2mm fluted drill.jpg

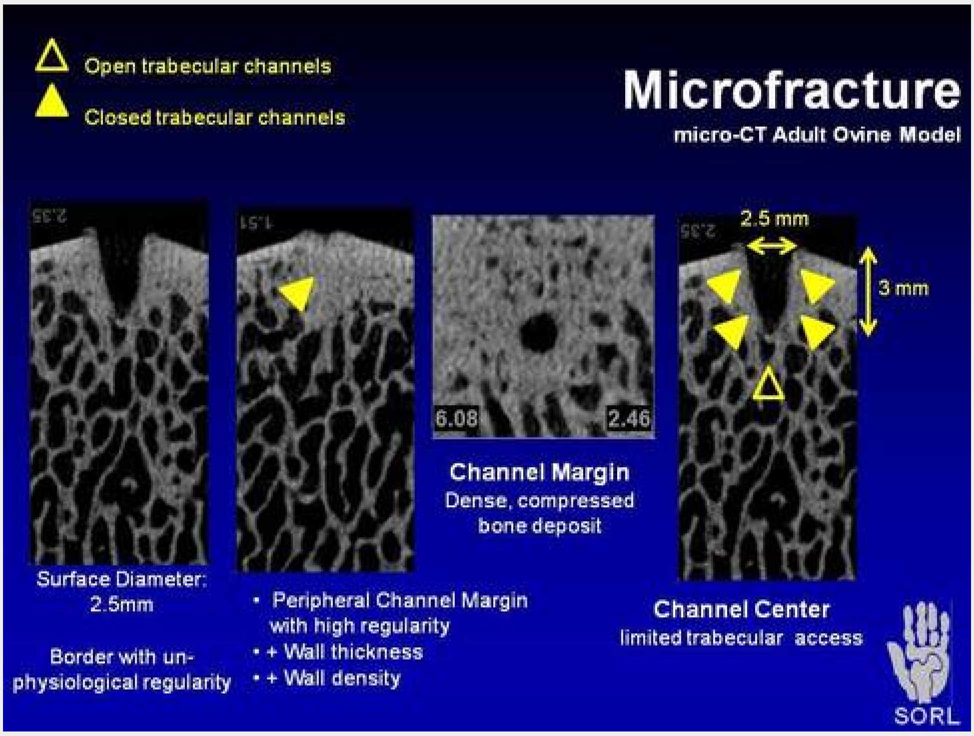
4. Results

Microfracture

25 micron micro-CT slice analysis of Microfracture elicited shallow depth with clearly visible bone compression surrounding the channels. Open trabecular channel access was limited; the channel depth and diameter were non-standardized, difficult to control, and highly user dependent.

Slice analysis through the center of a microfracture channel demonstrated an unphysiological regularity of the channel wall caused by the bone compression. Peripheral channel margins showed dense, compressed bone deposits. Trabecular channel access was limited (Fig 2A).

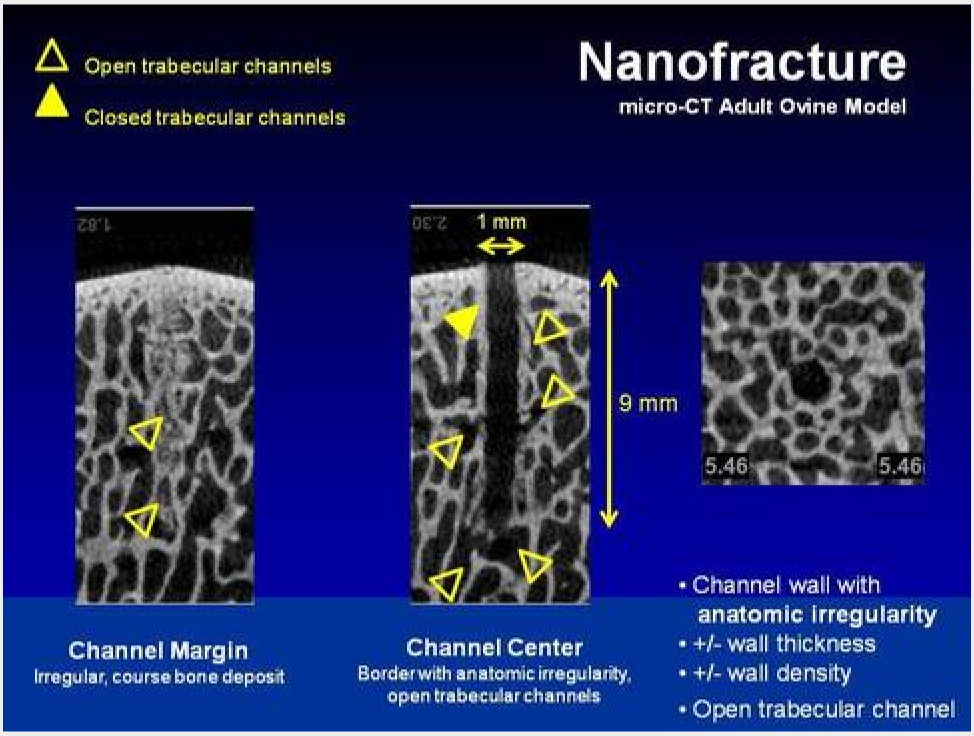
fig 2a mxfx.jpg



<u>*Nanofracture*</u>

Nanofracture demonstrated deep cancellous bone perforation with a high number of open trabecular channels. Slice analysis through the center of nanofracture channels demonstrated normal trabecular bone irregularity. Peripheral channel margins showed course, fragmented bone deposits with a high number of open trabecular channel access (Fig 2B).

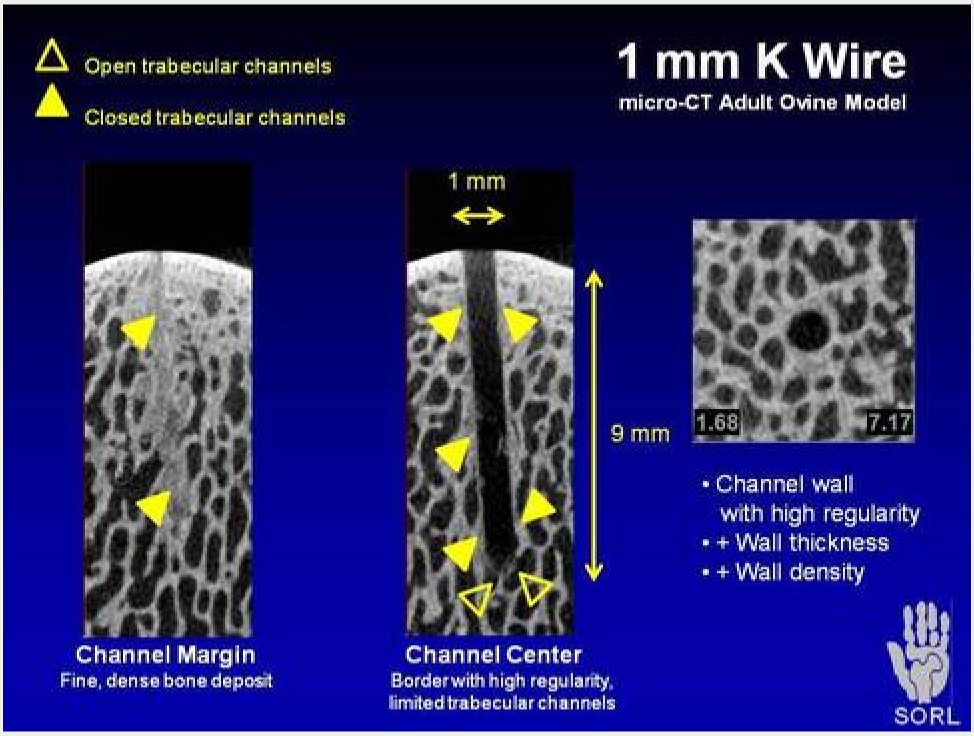
fig 2b nanofx.jpg



<u>*K-Wire Drilling*</u>

K-Wire drilling with both diameters resulted in well defined channel walls, outlined by fine osseous deposits. Trabecular channel access was limited (Fig 2C). The diameter of bone perforation is standardized, but depth is defined by visual controls.

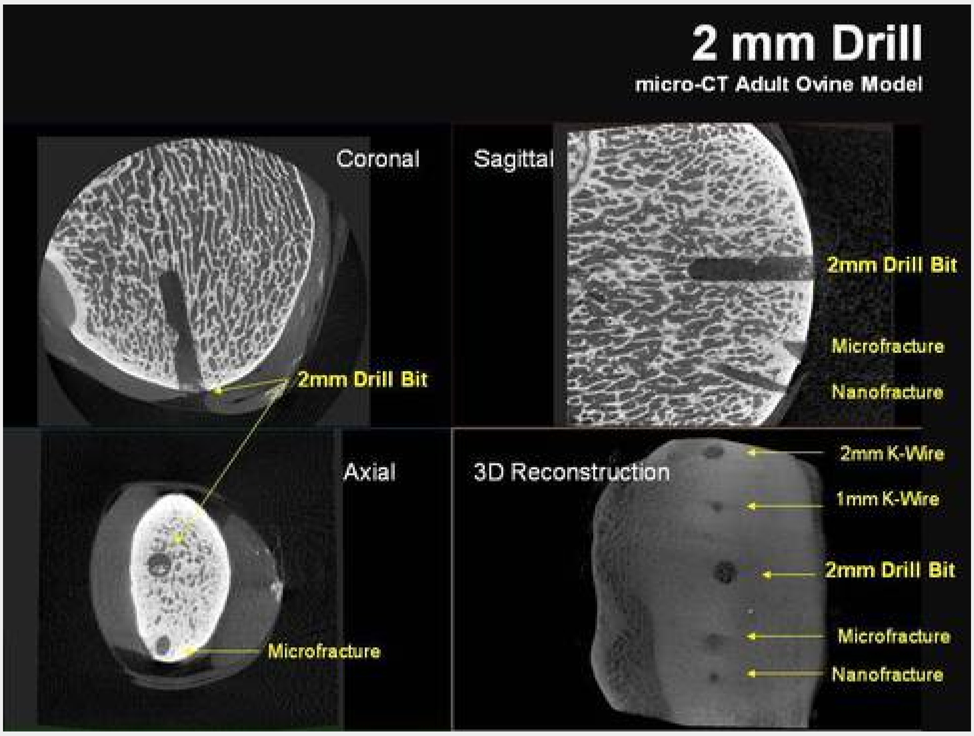
fig 2c kwire.jpg



<u>2mm Fluted Drill Bit</u>

2mm drill bit drilling demonstrated better osseous evacuation, but still limited trabecular marrow access (Fig 2D). Similar to k-wire drilling, the diameter of bone perforation is standardized, but depth is defined by visual controls.

fig 2d drill.jpg



Summary: Nanofracture resulted in thin, fragmented cancellous bone channels without rotational heat generation. Compared to microfracture and K-Wire stimulation, nanofracture showed superior bone marrow access with multiple trabecular access channels extending 9mm into subchondral bone. Simmilar to previous studies, microfracture demonstrated a shallow depth and low number of trabecular access channels. K-wire drilling showed the highest level of margin outline limiting bone marrow access channels through pulverized deposits in the channel periphery. The 2 mm drill bit showed the highest level of tissue evacuation, however, the channel wall remained in a unphysiologically, well defined order with moderate trabecular channel access.

5. Conclusion

Mesenchymal stemcell stimulation is in need of further standarization to allow for an improved execution and better comparability of clinical results.

Results from this study confirm that deeper subchondral bone perforation leads to an improved bone marrow access when using non-rotational bone perforation such as nanofracture. Combined with a standardized diameter and depth, the subchondral bone needling procedure showed a less invasive and more physiological bone marrow access than rotational methods such as k-wires or drills. Future studies will need to address cartilage fill rates and tissue durability across these methods to support their role in cartilage repair.

6. References

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8. Mediafiles

fig 1a microfracture awl tip.jpg

fig 2a mxfx.jpg

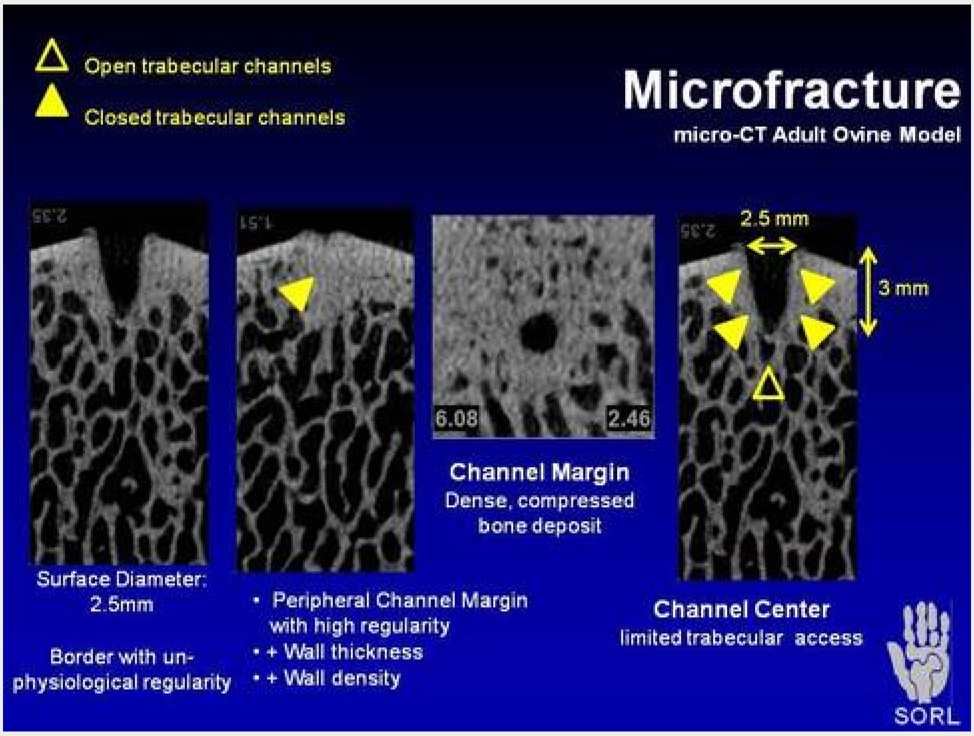

fig 2b nanofx.jpg

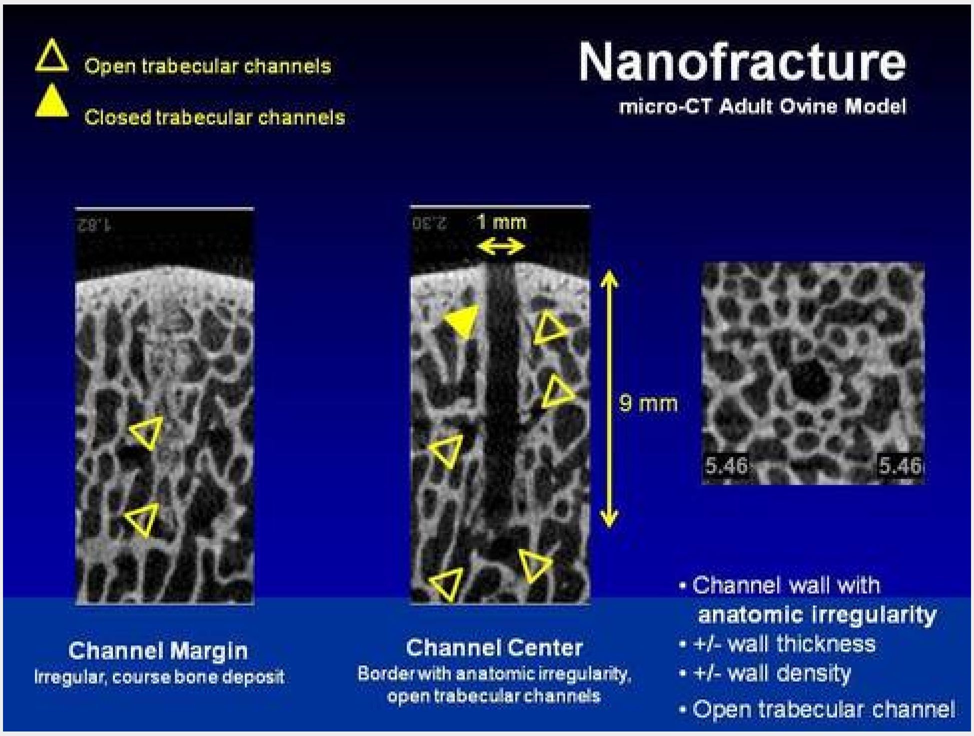

fig 2c kwire.jpg

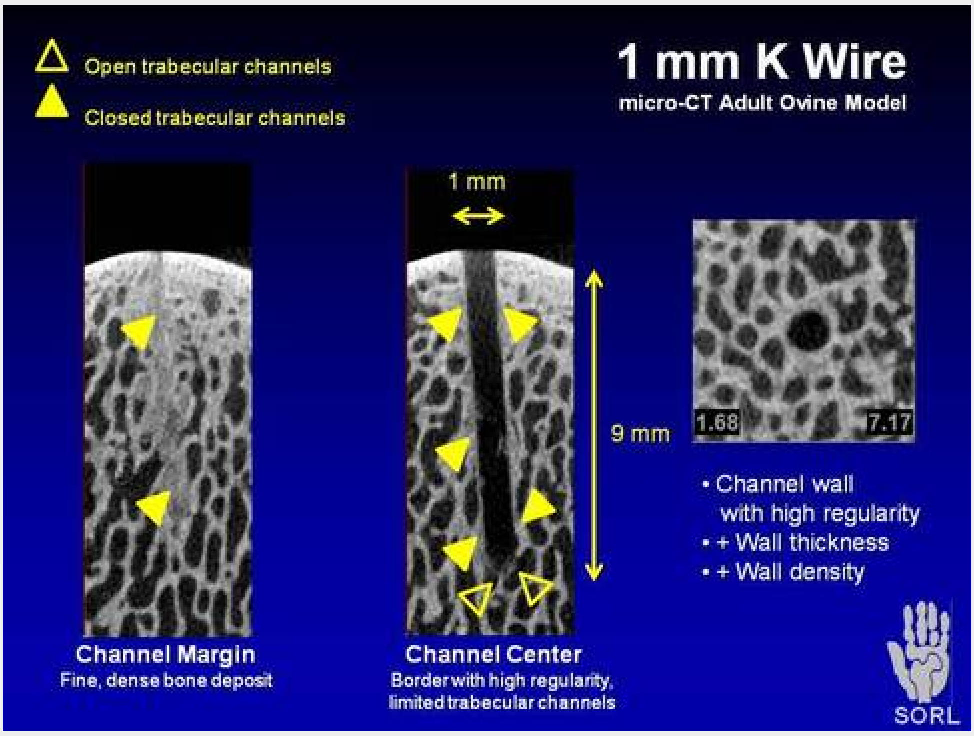

fig 2d drill.jpg

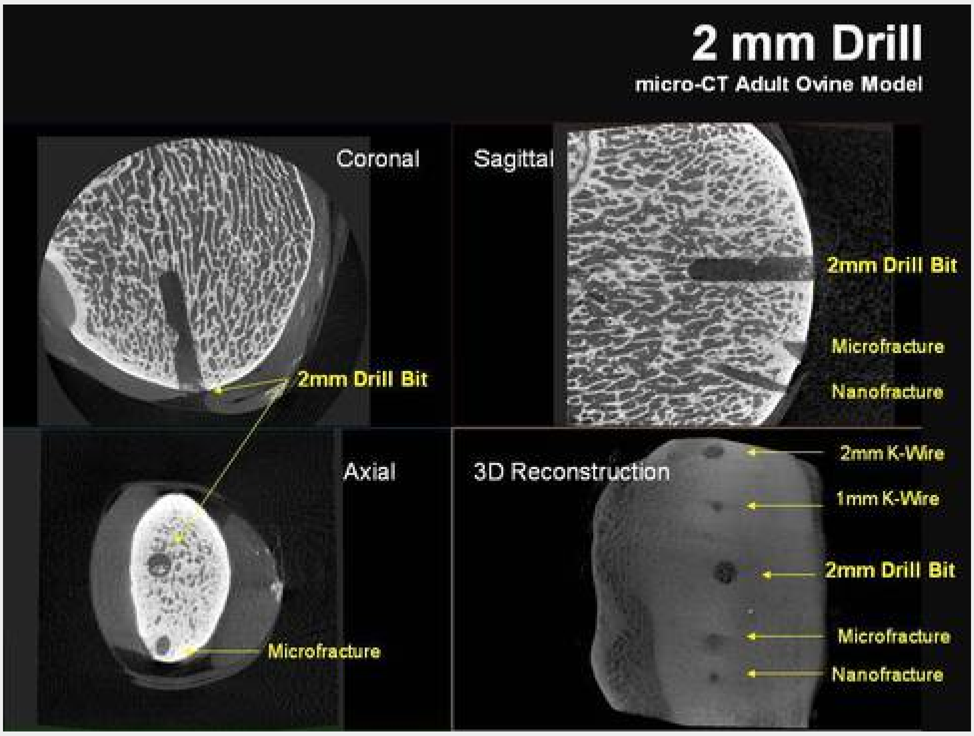

figure 1b nanofracture tip.jpg

figure 1c 1mm kwire tip.jpg

figure 1e 2mm fluted drill.jpg