Laser Osteotomy: A New Frontier in Total Knee Arthroplasty

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INTRODUCTION: Oscillating saws are the primary tool used for bone cutting in total knee arthroplasty (TKA) yet can be inaccurate and damage underlying bone cells vital to osseointegration. These inaccuracies can lead to gaps, implant misalignment, and aseptic loosening, which adversely affects function, causes pain, and increases revision rates. Lasers offer an alternative to saws and other mechanical cutting tools with the potential for greater accuracy. We propose laser bone ablation, the selective removal of bone through targeted pulses of laser energy as an alternative bone preparation technique.

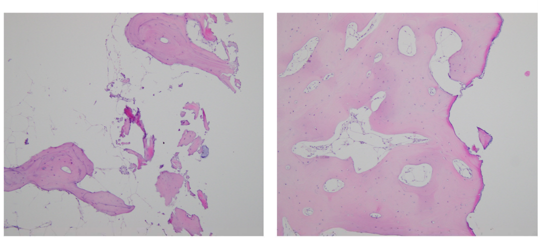
METHODS: Five tibial plateaus harvested from total knee arthroplasty procedures were salvaged under ethics approval. The precision and efficiency of laser ablation was assessed via the selective removal of a volume of cancellous bone measuring 20x20x2mm. A solid state, pulsed Er:YAG laser with a wavelength of 2940nm was used to perform the osteotomy, as this wavelength of light is strongly absorbed by bone with low penetration. Laser pulses were dynamically targeted across the bone surface at a rate of 300Hz. Both the medial and lateral sides of the tibial plateau underwent laser ablation to assess variation within a bio replicate with varying degrees of osteoarthritis, culminating in a total of 10 specimens. The effects of the laser were assessed through histological analysis, accompanied by analysis of the adjacent saw cut surface as control. Hematoxylin and Eosin staining was performed to assess the structure and integrity of the laser and saw cut bone tissue. An additional subset of five bone specimens harvested from the operating theater underwent laser bone sculpting with a tessellated diamond pattern to assess the capability of the laser to prepare complex, non-planar surfaces. The bone surface was scanned using a separate laser triangulation sensor to assess depth of removal and wall thickness.

RESULTS:

The selective removal of bone via laser ablation had an average removal time of 3.8 minutes. The technique enabled adjustments as small as 0.12mm, demonstrating consistency independent of the pathological condition of the specimens with a cut depth variability of 0.07mm. Notably, the laser-cut bone surfaces exhibited no visible signs of carbonization. Both in saw and laser groups, viable osteocytes were identified adjacent to the cut surface. Distinct morphological impacts were observed in the saw group, with bone microfracture and debris across all specimens (Fig 1). Conversely, the laser-cut surfaces showed neither microfracture nor debris, attributable to its distinct removal mechanism. Successful execution of complex three dimensional bone sculpting was accomplished (Fig 2), yielding a mean wall thickness of 1.3mm.

DISCUSSION AND CONCLUSION:

Our results demonstrate the viability of bulk laser ablation of human bone, including the creation of complex geometrical patterns with submillimeter accuracy. Laser bone ablation opens the possibility of prosthetic redesign, with the potential for less bone removal, ligament-preservation, and increased contact area between bone and prosthesis, enhancing osteointegration.



Saw **Laser**

Figure 1. Haematoxylin and Eosin-stained bone cut surfaces

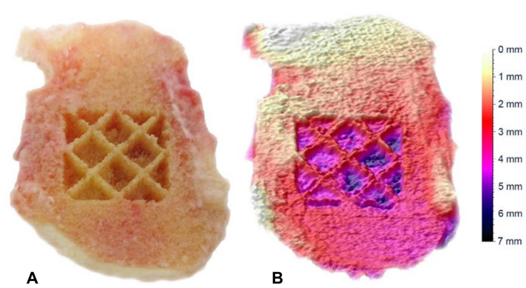


Figure 2. (A) Laser sculpted bone surface with a tessellated diamond pattern. (B) A digital reconstruction of the laser sculpted bone surface derived from laser triangulation sensor data.