Surface Morphology Characterization of Retrieved Orthopedic Titanium Alloy and Stainless-Steel Implants

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INTRODUCTION

- Orthopedic implant failure rates range are between 4.9-14.4% depending on underlying pathologies.[1,3,6]

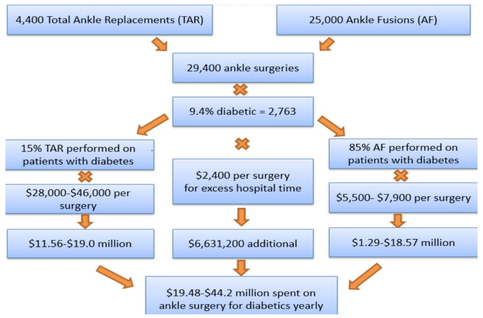

Fig 1. Ankle Surgery Expenditures Yearly. [1,7]

- Surgical error and mechanical failure are the most common complications.[8]
- A compromised oxide layer can result in metal ions leeching into surrounding tissues.[1,5]
  - Evidence of surface damage includes corrosion, pitting, scratches, and delamination. [5]
- Corrosion products migrate along prostheses components and accumulate systematically, causing chronic inflammation evidenced by a variety of myeloid and lymphoid cells, rather than neutrophils and macrophages.[5-8]
- Decreased osteoblast proliferation leads to impaired osseointegration or disrupted existing osseointegration, which can lead to periprosthetic bone loss and subsequent implant failure. [8]

OBJECTIVES AND METHODS

- Identify and classify surface characteristics of retrieved orthopedic implants in various early and late stage failure modes.
- Following IRB 19-85 approval, fifty steam-sterilized, failed orthopedic implants were retrieved from the John Peter Smith Hospital in Fort Worth, TX.
- Optical Microscopy (OM) and Scanning Electron Microscopy (SEM) imaging were conducted to macroscopically characterize damage.
  - SEM images were then analyzed with Image J software to quantify damages.
- Electron Dispersive Spectroscopy (EDS) was used to analyze microscopic components.

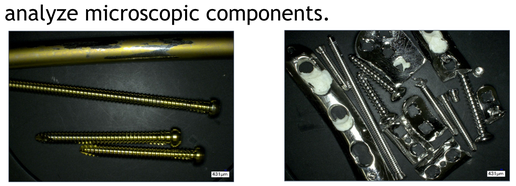

Fig 2. Examples of TiAl6V4 and stainless-steel orthopedic implants received.

RESULTS AND DISCUSSION

Results:

- All implants studied had imperfections that were visible to the naked eye.
  - Increased surface roughness helps cells osseointegrate but increases the propensity for wear.[3]
  - Also associated with increased loosening rates.[6,8]
- The orthopedic screws that were analyzed showed the most discoloration, mainly occurring at the ridges of threads and the interface of the head-thread junction.
- Delamination damage was widely observed at the neck and ridges of screws, less delamination was seen in rods.
  - Multiple sites of delamination per screw, not just localized to the threads.
- Deep and abrasive scratches seen in the notch of the head.
  - Undetermined if caused by surgeon during placement or during implant removal.
- Discoloration present on the heads and grooves of screw threads as well as at the multiple contact points in long rods.

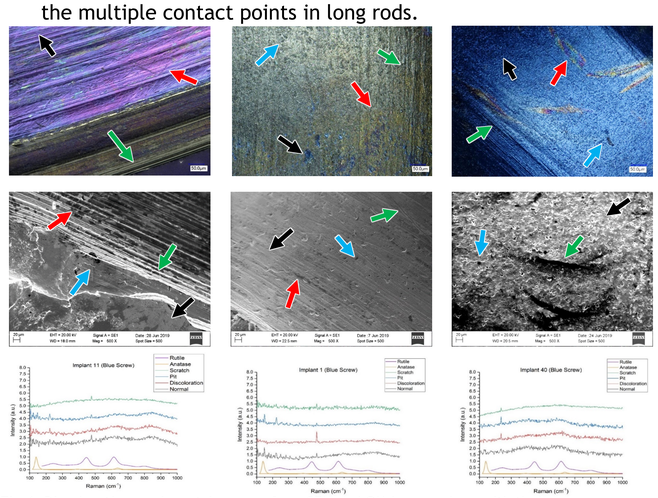

Fig 4. Discoloration and scratches seen from SEM and OM images along with their respective Raman graphs.

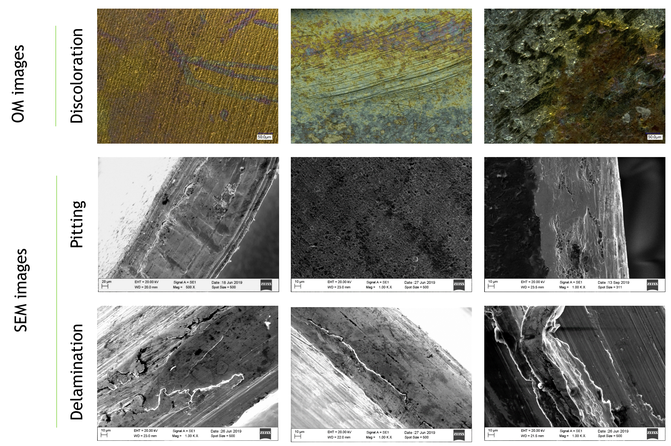

Fig 5: Cracks and delamination seen from SEM and OM images.

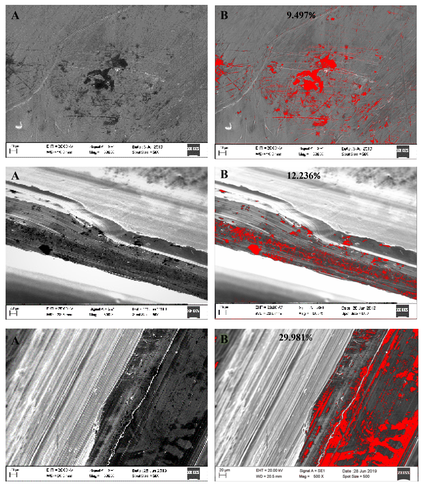

Fig 3. Example Image J analysis for surface area.

Discussion:

- The TiO2 material promotes bone cells attaching and fusing with the implant surface over stainless steel.[4-6]
- Screws bear a great deal of stress and are subjected to near constant tension in anaerobic conditions.[2,4-5]
  - Corrosion and micromotion may further degrade the TiO2 layer when combined with surgically induced scratches.
  - Exacerbates severe localized pitting, delamination, and etching.
- Wear-particle-induced bone loss is hypothesized as the major mechanism of late implant loosening.[8]
  - Leached ions may induce a foreign body inflammatory response in the joint capsule and along implant-bone interfaces.[3]
  - Results in bone loss and aseptic loosening.

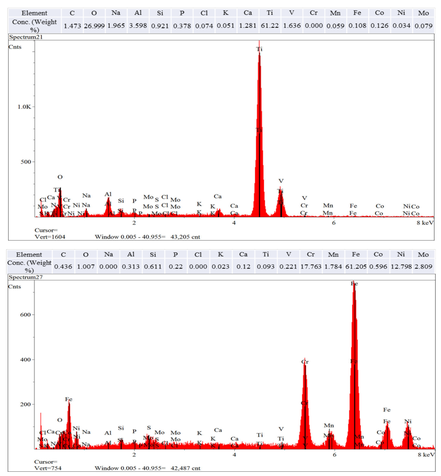

Fig 6. EDS graphs of titanium and stainless-steel screws.

CONCLUSIONS

- Durability of implant fixation in the internal environment relies on a variety of factors.
- Fretting or micromotion combined with alkaline body fluids has the potential to produce metallic debris, particularly at screw junctions.
  - Induction of oxidative stress results in damage to cellular components including DNA, interference with DNA repair, and deregulation of cell proliferation.[2]
- Future studies such as computer modeling of wear patches and surface damage may eventually help to determine how implant placement and surface characteristics affect metal leeching and overall implant survival rates.
- As the field of orthopedics evolves, it grows increasingly more important to understand how surface characteristics contribute to osseointegration.

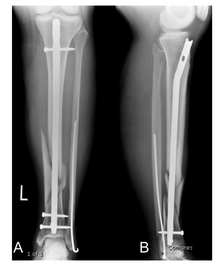

Fig 7. Example X-rays of ankle and tibia implants.

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