REFERENCE DECK

Biomedical Imaging, Instrumentation & Device Design

A working reference of graduate project and lab work spanning medical imaging physics, biosignal instrumentation, and orthopedic device design: hands-on modality work across X-ray/CT, ultrasound, and MRI systems with Fourier-based reconstruction and image-quality analysis; EEG hardware built and validated against clinical-reference equipment; and a hip implant redesign carried from clinical problem to biomaterial selection.

Medical Imaging
X-ray/CT, ultrasound, MRI — acquisition, reconstruction, and image-quality analysis

Instrumentation
EEG front-end design, built and bench-tested against clinical reference hardware

Device Design
Case study: hip implant redesign from diagnosis to materials selection

Jacky Nam

01

MEDICAL IMAGING SYSTEMS

Experimental and diagnostic work performed with DeskCAT (simulated X-ray/CT), Clarius L15 and C3 (ultrasound), the Earth’s Field MRI apparatus (NMR), and the 0.345T ilumr MRI system — applying Fourier-transform theory to image formation, reconstruction, and analysis in MATLAB and Python.

LAB INSTRUMENTATION

SYSTEMS USED

Experimental and diagnostic work performed with the following systems:

- DeskCAT for simulated X-ray and CT
- Clarius L15 and C3 for ultrasound
- Earth's Field MRI apparatus for NMR
- 0.345T ilumr system for MRI

Takeaway: hands-on operation of four distinct imaging modalities — projection X-ray/CT, handheld ultrasound, and two MRI/NMR platforms — spanning benchtop teaching systems to a clinical-field-strength scanner.

DeskCAT — simulated X-ray/CT scanner with phantom insert

Clarius handheld ultrasound transducer (L15/C3 series)

Earth's Field MRI apparatus — NMR coil assembly

0.345T ilumr MRI system

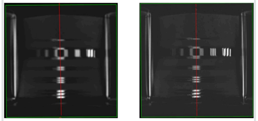
X-RAY & CT — RECONSTRUCTION AND IMAGE QUALITY

Applied Fourier transform theory to medical image formation, reconstruction, and analysis across multiple imaging modalities using MATLAB/Python scripting. CT/X-ray work shown here on a resolution phantom.

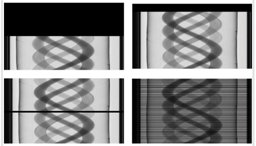
Analyzed sources of noise, artifacts, and resolution limits in X-ray and CT.

Evaluated image quality metrics (PSF, MTF) and QA/QC phantom calibration standards for clinical imaging systems.

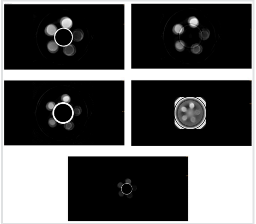
> **Takeaway:** phantom X-ray/CT acquisition on DeskCAT, MATLAB/Python reconstruction, and quantitative PSF/MTF/LSF calibration analysis against QA/QC phantom standards.



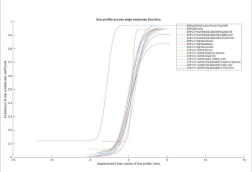
DeskCAT phantom X-ray captures, resolution bar targets



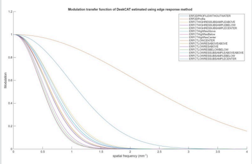
CT reconstruction, phantom cross-sections



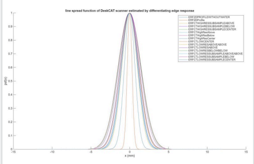
Resolution-target reconstructions



Edge response line profile



Modulation transfer function (MTF) of DeskCAT



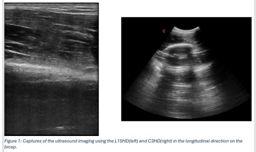
Line spread function (LSF) of DeskCAT

ULTRASOUND & ELASTOGRAPHY

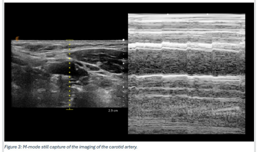
Conducted hands-on ultrasound imaging and elastography using handheld Bluetooth-connected US systems on iPads.

Analyzed sources of noise, artifacts, and resolution limits in ultrasound.

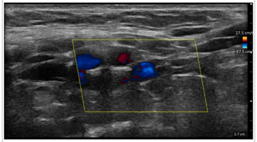
> **Takeaway:** B-mode, M-mode, and color/power Doppler acquisition on handheld Clarius probes, with phantom-target imaging used to characterize noise, artifacts, and resolution limits.



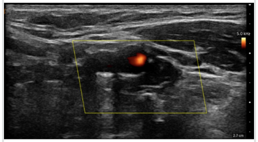
Bicep, longitudinal — L15HD (left), C3HD (right)



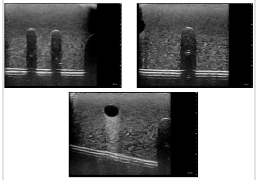
M-mode still capture of the imaging of the carotid artery



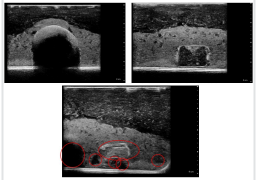
Color Doppler flow imaging capture



Power Doppler flow imaging capture



Phantom target imaging — wire and cyst targets



Phantom imaging, annotated for artifact analysis

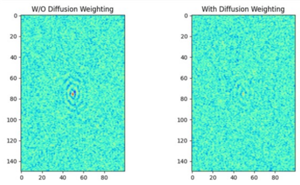
MRI — ACQUISITION & ADVANCED RECONSTRUCTION

Performed MRI experiments on 0.33T Flowerpot MRI systems including calibration, T1/T2 measurement, shimming, and imaging sequence selection (gradient echo, spin echo, RARE).

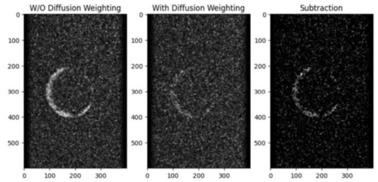
Analyzed advanced MRI data including diffusion weighted imaging (DWI), diffusion tensor imaging (DTI), and functional MRI (fMRI) from human scanning sessions.

Reconstructed in Python.

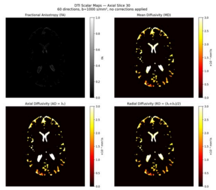
> **Takeaway:** full MRI experimental pipeline — system calibration and sequence selection through to DWI/DTI/fMRI reconstruction and scalar-map analysis (FA, MD, AD, RD) in Python.



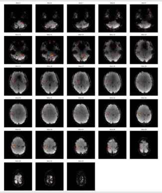
k-space noise maps, with/without diffusion weighting



Diffusion weighting comparison and subtraction image



DTI scalar maps — fractional anisotropy, mean/axial/radial diffusivity



Axial brain slice montage from human scanning session

02

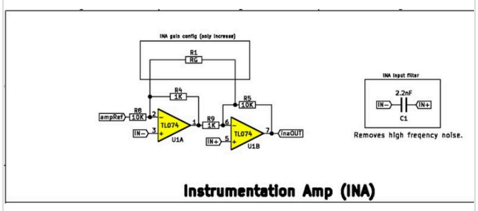
EEG INSTRUMENTATION

2025 — REM sleep EEG. A custom EEG front-end built around the BioAmp EXG Pill, following OpenEEG reference documentation, then benchmarked against clinical reference EEG equipment supplied and tested at McMaster LiveLAB.

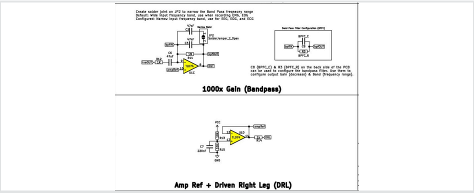
FRONT-END CIRCUIT DESIGN

Hardware used sourced from BioAmp EXG Pill, used with documentation from OpenEEG.

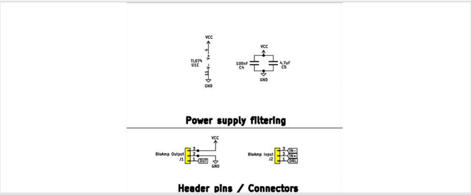
Takeaway: signal chain built from an instrumentation-amplifier input stage, a 1000x-gain bandpass filter with amplifier-reference/driven-right-leg (DRL) stage, and filtered power supply — with a solder-jumper electrode reference supporting 2- or 3-electrode configurations.



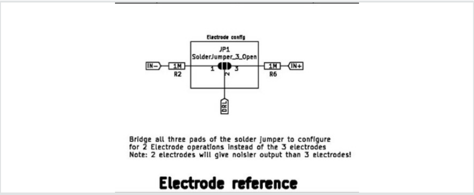
Instrumentation amplifier (INA) input stage



1000x gain bandpass filter; amp reference + driven right leg (DRL)



Power supply filtering; header pins and connectors

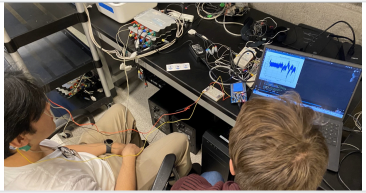


Electrode reference — 2- or 3-electrode solder-jumper configuration

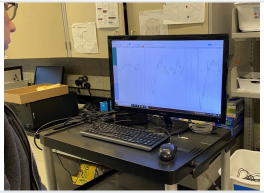
CLINICAL REFERENCE VALIDATION

Clinical reference EEG equipment supplied and tested at McMaster LiveLAB.

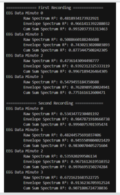
> **Takeaway:** the custom front-end's recorded signal was compared directly against LiveLAB's clinical-reference EEG recording, alongside raw/envelope/cumulative-sum spectrum analysis of the captured data.



Recording session with the custom EEG front-end



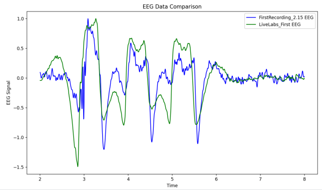
Clinical reference EEG monitoring station, McMaster LiveLAB



```
============= First Recording =============
EEG Data Minute 0
        Raw Spectrum R²: 0.4818934173922921
        Envelope Spectrum R²: 0.9661411392288032
        Cum Sum Spectrum R²: 0.9932037351313463
EEG Data Minute 1
        Raw Spectrum R²: 0.5088660188246688
        Envelope Spectrum R²: 0.7430213020803893
        Cum Sum Spectrum R²: 0.8773447508242305
EEG Data Minute 2
        Raw Spectrum R²: 0.4736143094498777
        Envelope Spectrum R²: 0.9392312325333119
        Cum Sum Spectrum R²: 0.9967189426464305
EEG Data Minute 3
        Raw Spectrum R²: 0.5479455184358688
        Envelope Spectrum R²: 0.7628989520024941
        Cum Sum Spectrum R²: 0.775161612600471

============= Second Recording ============
EEG Data Minute 0
        Raw Spectrum R²: 0.5343477230401192
        Envelope Spectrum R²: 0.9847871910660738
        Cum Sum Spectrum R²: 0.9994075701595474
EEG Data Minute 1
        Raw Spectrum R²: 0.48244575691037406
        Envelope Spectrum R²: 0.9455509804021429
        Cum Sum Spectrum R²: 0.9830070405271604
EEG Data Minute 2
        Raw Spectrum R²: 0.53592029950613 4
        Envelope Spectrum R²: 0.9671612619510352
        Cum Sum Spectrum R²: 0.9976695150274284
EEG Data Minute 3
        Raw Spectrum R²: 0.6721621683522725
        Envelope Spectrum R²: 0.9136236705912524
        Cum Sum Spectrum R²: 0.9071806724738036
```

Raw / envelope / cumulative-sum spectrum R^2 log, first and second recordings



Custom front-end recording vs. LiveLAB clinical-reference EEG

03

CASE STUDY: HIP IMPLANT REDESIGN

2022 — a 51-year-old male presented with progressive symptoms following a left total hip arthroplasty, later diagnosed with aseptic periprosthetic osteolysis. The following pages trace the case from symptom progression, through the underlying wear-debris mechanism, to a biocompatible implant designed in response.

DP2 Project Team 16: Kristina Siiman, Jacky Nam, Megan Saunders, Ali Hussin

PROBLEM — SYMPTOM PROGRESSION

PROBLEM

Addressed concerns of a 51-year-old male after a left total hip arthroplasty.

SYMPTOMS PRESENTED

- Increasing pressure on hip affecting mobility
- Excessive increase in weight (lack of exercise, poor diet, quitting smoking)
- Arthritis in hip causing little to no pain with occasional flare-ups

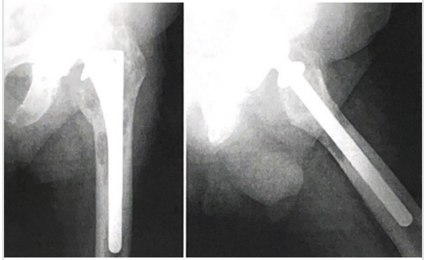
5 YEARS AFTER ARTHROPLASTY

- Persistent, slight pain in thigh and groin

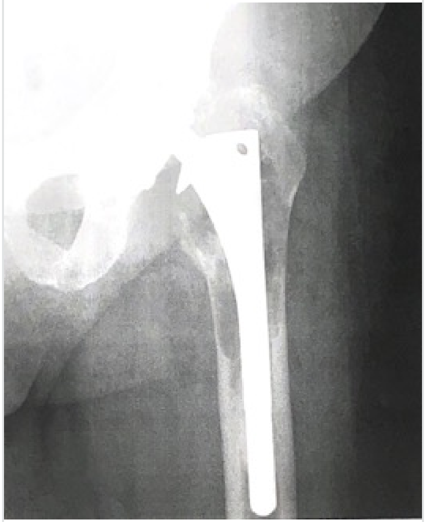
7 YEARS AFTER ARTHROPLASTY

- Severe pain radiating towards the hip
- Shortness of breath after light exercise
- Slight gait disturbance

Fast facts: 51 years old, 111 kg, 181 cm, BMI = 33.9. Diagnosed with aseptic periprosthetic osteolysis — designed a biocompatible implant able to sustain lifestyle and exercise patterns.



Left hip, 5 years post-replacement



7 years post-replacement — cavitation worsening

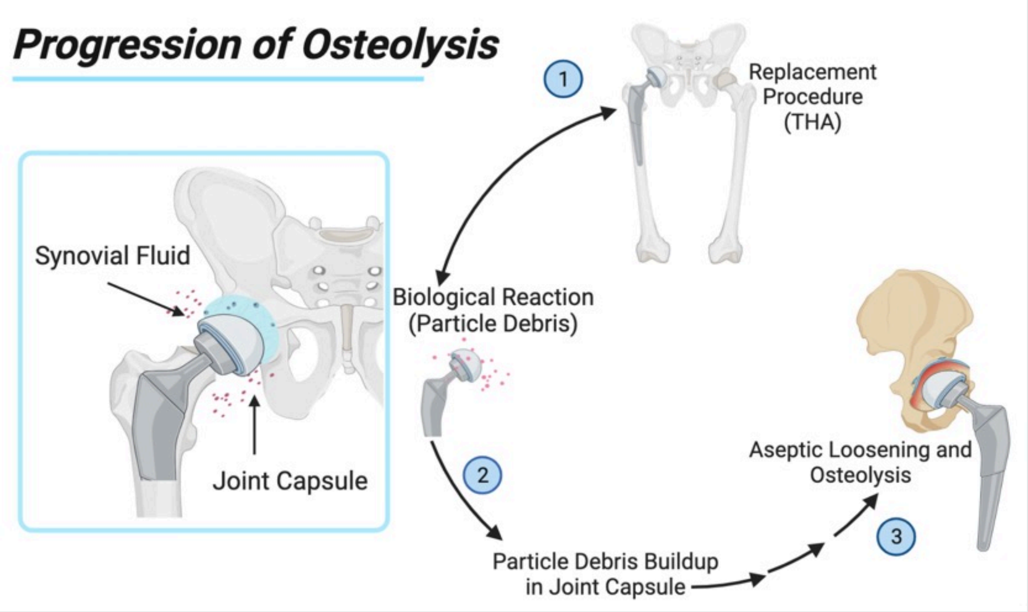
ANALYSIS — MECHANISM OF FAILURE

ANALYSIS

BACKGROUND: ARTHRITIS & OSTEOLYSIS

- Synovial fluid is the natural lubricating fluid allowing for smooth joint movement, protecting bones and cartilage.
- Inability of the synovial joint fluid to naturally regenerate leads to cartilage degradation and inflammation of the joints, causing arthritis.
- A lack of seal on the bone-implant interface and friction can lead to particulate debris from the implant causing inflammatory biological reactions.
- Wear on bearing surfaces releases particles into the joint capsule which migrate to the tissues.
- Foreign response to particle debris initiates bone loss.

Diagnosis: aseptic periprosthetic osteolysis — an inflammatory response to particles excreted by the polyethylene implant, causing implant degradation and aseptic loosening. This explains the implant's cavitation and resulting weakness.



Progression of osteolysis: replacement procedure → biological reaction to particle debris → debris buildup in joint capsule → aseptic loosening and osteolysis

DESIGN RESPONSE — IMPLANT & MATERIALS

DESIGN RESPONSE

The new implant uses novel layered materials to strike balances between biocompatibility and wear resistance (in the femoral head and acetabular cup), and ultimate strength and bone density reduction (in the stem). A spring connects the femoral head to the stem, removing mechanical load and absorbing shock.

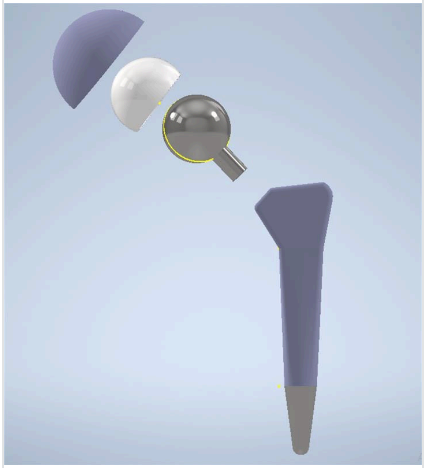
Coatings & Combinations

316 Stainless Steel interior of femoral stem coated with Porous Tantalum of high ultimate strength; Zirconia Toughened Alumina (ZTA) acts as a protective coating on the femoral head; acetabular cup is lined with Highly Crosslinked Polyethylene (XLPE) against a Porous Tantalum cup.

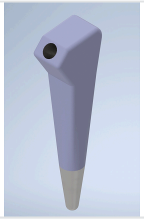
Spring

Cobalt Chromium alloy, chosen for high corrosion resistance and biocompatibility.

> **Takeaway:** cup-and-liner implant using Porous Tantalum, 316L steel, ZTA, and XLPE for bone-stiffness matching and wear resistance, with a Co-Cr spring absorbing compressive load.



CAD assembly — cup-and-liner, spring, and stem



Femoral stem CAD render

HIGHLY CROSS-LINKED POLYETHYLENE = XLPE
ZIRCONIA TOUGHENED ALUMINA = ZTA

COMPONENT	STAINLESS STEEL	POROUS TANTALUM	XLPE	ZTA	PHYNOX CO-CR ALLOY
Acetabular Cup		✓	✓		
Femoral Head	✓			✓	
Femoral Stem	✓	✓			
Spring					✓

Materials selection by component

MATERIALS JUSTIFICATION — STRUCTURAL METALS & CERAMIC

Porous Tantalum

Preserves bone strength and density over long-term recovery periods; nearly identical elastic modulus to accurately mimic bone stiffness, reducing bone loss.

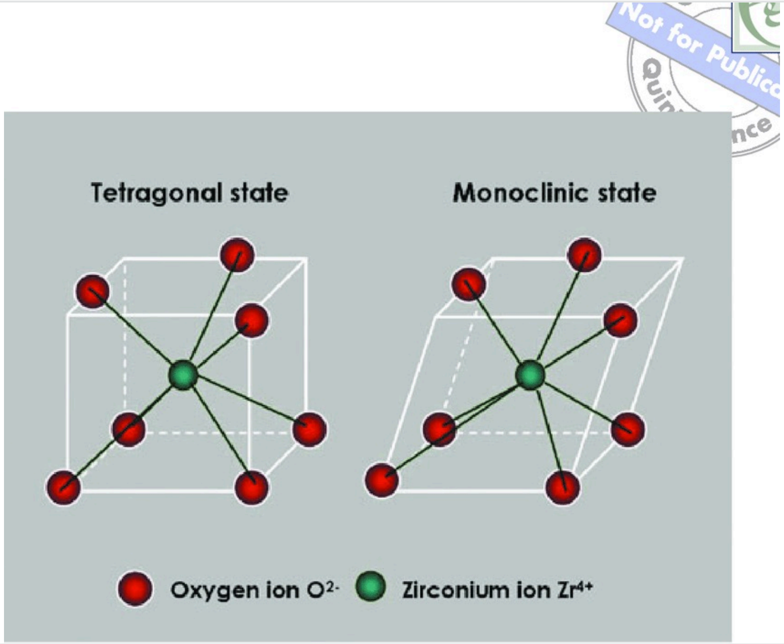
Stainless Steel 316L

Compensates for the lack of initial stiffness of Porous Tantalum with a higher elastic modulus than titanium; long-lasting reliability in biocompatibility and corrosion resistance.

ZTA — Zirconia Toughened Alumina

Resistant to increased corrosion with low brittleness, reducing fracture; high elastic modulus, limiting implant stress.

> **Takeaway:** the stem and femoral head pair a bone-matching Porous Tantalum / Stainless Steel 316L structure with a ZTA wear surface, chosen for elastic-modulus matching and corrosion resistance.



ZTA tetragonal vs. monoclinic crystal states

MATERIALS JUSTIFICATION — BEARING SURFACE & SURGERY

XLPE — Highly Crosslinked Polyethylene

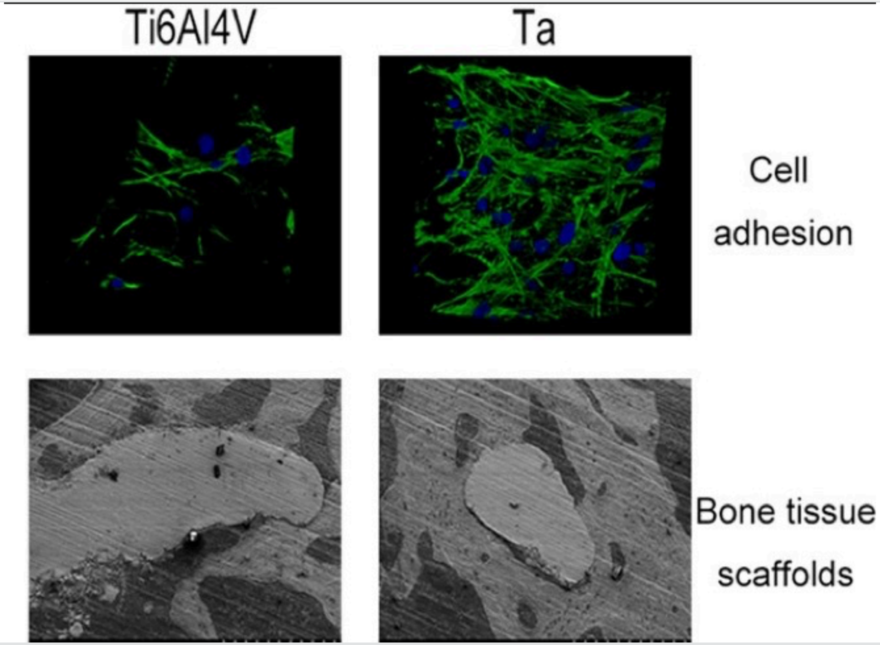
1200 GPa ultimate strength with reduced particle debris; crosslinked property minimizes wear, reducing inflammation.

Spring & Phynox

Absorbs shock from compressive stress on the implant by removing mechanical load; a stiffer spring accounts for increased weight, decreasing compression. Extremely high corrosion wear and fatigue life.

Surgical Considerations

Cemented implant fixation mimics natural bone, keeping the implant stable where reduced bone mass cannot otherwise hold it. Pre-op: weight loss. Operative: posterior approach, bariatric equipment, IV antibiotics. Post-op: higher nursing vigilance, epidural anesthetics, physiotherapy.



Cell adhesion and bone tissue scaffold microstructure, Ti6Al4V vs. Ta

Jacky Nam

Edu: namj10@mcmaster.ca

Personal: jackynam@outlook.com