Restoration of limb function after high energy lower extremity trauma

current research and insights that inform clinical decision making

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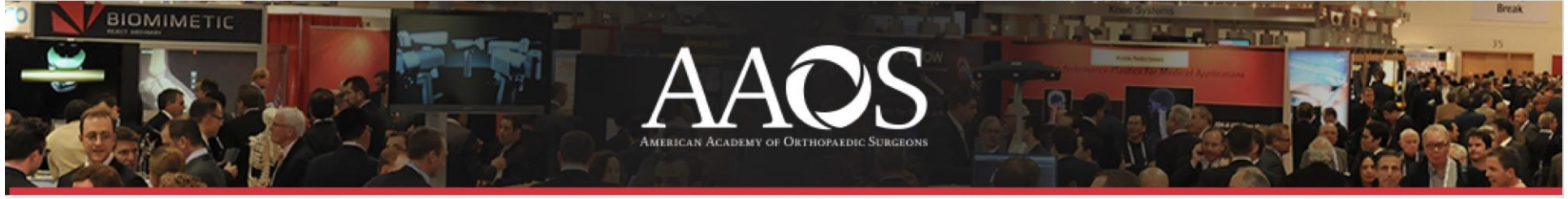

I have nothing to disclose regarding this talk.

Detailed disclosure information is available via:

AAOS Orthopaedic Disclosure Program on the AAOS at
http://www.aaos.org/disclosure

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Bill

45 year old man, high speed motorcycle collision.

Crohn’s, Diabetes, Smoker

Single unemployed construction worker

Reconstruct

~~Salvage~~ or amputate?

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What factors matter most in determining Bill's outcome?

Objectives

- Summarize evidence
- Review conditions where amputees might do better
- Discuss evolving therapies available to both amputees and those undergoing limb salvage
- Consider the patient's autonomy in this shared decision-making process

In 1987, Hansen introduced the ethical conundrum

Salvage of Type 3C tibial fractures would leave patient:

- Divorced
- Demoralized
- Destitute

Is a patient's amputation a surgeon's failure?

Hansen *JBJS* 1987
Pierce *Orthop* 1993

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The New England Journal of Medicine

AN ANALYSIS OF OUTCOMES OF RECONSTRUCTION OR AMPUTATION OF LEG-THREATENING INJURIES

MICHAEL J. BOSSE, M.D., ELLEN J. MACKENZIE, PH.D., JAMES F. KELLAM, M.D., ANDREW R. BURGESS, M.D., LAWRENCE X. WEBB, M.D., MARC F. SWIONTKOWSKI, M.D., ROY W. SANDERS, M.D., ALAN L. JONES, M.D., MARK P. MCANDREW, M.D., BRENDAN M. PATTERSON, M.D., MELISSA L. MCCARTHY, SC.D., THOMAS G. TRAVISON, PH.D., AND RENAN C. CASTILLO, M.S.

- 8 center prospective cohort study
- 569 civilian lower extremity trauma patients with severe, limb-threatening injuries
- Primary Outcome: Sickness Impact Profile (136 items describing ADL's in 12 categories)
- Secondary Outcomes: Complications (rehospitalizations, reoperations, cost)

Bosse *NEJM* 2002

Scoring Systems

Mangled Extremity Severity Score (MESS)
Predictive Salvage Index (PSI)
Limb Salvage Index (LSI)
Nerve, Ischemia, Soft tissue, Skeletal, Shock, Age Score (NISSSA)
Hannover Fracture Scale 97 (HFS)

Specific, but not sensitive

Low scores predictive of limb salvage

High scores not predictive of amputation

Bosse *JBJS* 2001

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NO Difference

	Amp	Recon
Sickness Impact Profile:	**12.2**	**11.7**
Return to Work: (2 years post injury)	**53%**	**49%**

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Higher infections rate and more surgery with reconstruction

	Amp	Recon	
Rehospitalization	34%	48%	(p = 0.002)
Osteomyelitis	3%	9%	(p = 0.02)
More Surgery	5%	19%	(p < 0.001)

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LONG-TERM PERSISTENCE OF DISABILITY FOLLOWING SEVERE LOWER-LIMB TRAUMA

RESULTS OF A SEVEN-YEAR FOLLOW-UP

BY ELLEN J. MACKENZIE, PHD, MICHAEL J. BOSSE, MD, ANDREW N. POLLAK, MD, LAWRENCE X. WEBB, MD, MARC F. SWIONTKOWSKI, MD, JAMES F. KELLAM, MD, DOUGLAS G. SMITH, MD, ROY W. SANDERS, MD, ALAN L. JONES, MD, ADAM J. STARR, MD, MARK P. MCANDREW, MD, BRENDAN M. PATTERSON, MD, ANDREW R. BURGESS, MD, AND RENAN C. CASTILLO, MS

Telephone interview at 7 years

Still NO DIFFERENCE

Both groups worsened with time

50% with SIP > 10

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Patients' economic, social and personal resources predicted outcome

Rehospitalization
Low Education
Non-white race
Poverty
No health insurance
Poor social support
Poor self efficacy
Smoking
Litigation

Table 2

Sickness Impact Profile Scores and Return to Work by Baseline Self-Efficacy and Social Support

Quartile of Measure at 3 Months Post-Injury	Mean SIP at 2 years	Mean SIP at 7 years	RTW at 2 years	RTW at 7 years	Mean days to RTW*
SE – Lowest	16.1	18.8	26%	38%	594
SE – Second	12.5	14.2	45%	55%	392
SE – Third	11.4	12.5	52%	61%	335
SE – Highest	8.5	10.9	66%	78%	308
SS – Lowest	15.3	17.1	37%	42%	362
SS – Second	12.8	14.4	50%	64%	404
SS – Third	10.2	10.2	59%	73%	362
SS – Highest	9.7	12.6	48%	59%	380

RTW = return to work, SE = self-efficacy, SIP = sickness impact profile, SS = social support

* For those working

Bosse *NEJM* 2002
Bosse and MacKenzie *JAAOS* 2006

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Ankle and hindfoot salvages do worse

- 174 severe hindfoot and ankle injuries (116 salvages with flap +/- fusion vs 58 BKA), 75% 24 month follow-up
- Salvages requiring flap or ankle fusion worse off than those undergoing BKA with standard wound closure (mean difference 2.5, p=0.0014) at 24 months

Ellington *JOT* 2013

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Nerve Injury – not predictive of future function

- Salvaged insensate no worse off than amps and salvaged sensate at 24 months
- 55% of both salvage groups had intact plantar sensation at 2 years.

Bosse *JBJS* 2005

Problems with LEAP

- Misinterpretation: Feasible = Advisable

Problems with LEAP

- Misinterpretation: Feasible = Advisable
- No measurement of the quality of prosthesis rendering (or amputation surgery)

Problems with LEAP

- Misinterpretation: Feasible = Advisable
- No measurement of the quality of prosthesis rendering
- Crude measurement of injury severity

Problems with LEAP

- Misinterpretation: Feasible = Advisable
- No measurement of the quality of prosthesis rendering
- Crude measurement of injury severity
- Minimal assessment of performance

Wars in Iraq and Afghanistan

- Joint Theater Trauma Registry 2001-2005
- 1281 wounded warriors with 3575 extremity trauma injuries
- 915 fractures, 81% open (50:50 UE:LE)
- ~50 of LE fractures tibia/fibula
- 75% blast injuries from explosive munitions

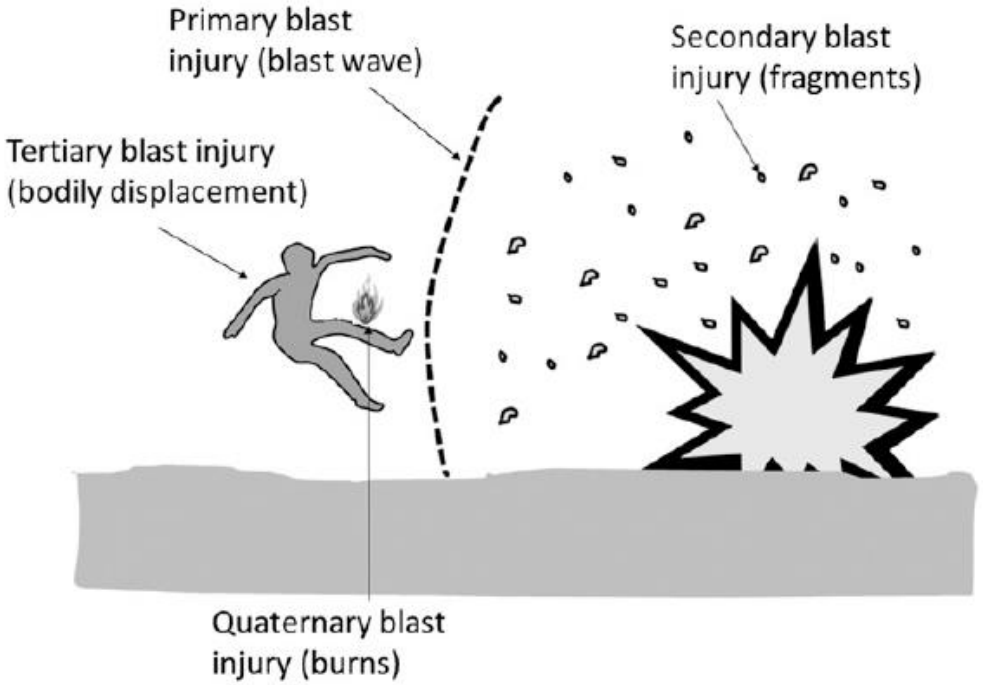

Figure: Ramasamy *JBJS* 2013

Owens *JOT* 2007

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The Military Extremity Trauma Amputation/Limb Salvage (METALS) Study

Outcomes of Amputation Versus Limb Salvage Following Major Lower-Extremity Trauma

- 324 Iraq and Afghanistan wounded warriors undergoing amp or limb salvage to reconstruct traumatic LE injury (182 amputations: Syme to hip disarticulation vs 142 salvage)

- Average 37.5 month follow-up

- **Amputees had higher physical function (SMFA), lower PTSD, and higher rates of return to vigorous sports**

Doukas *JBJS* 2013

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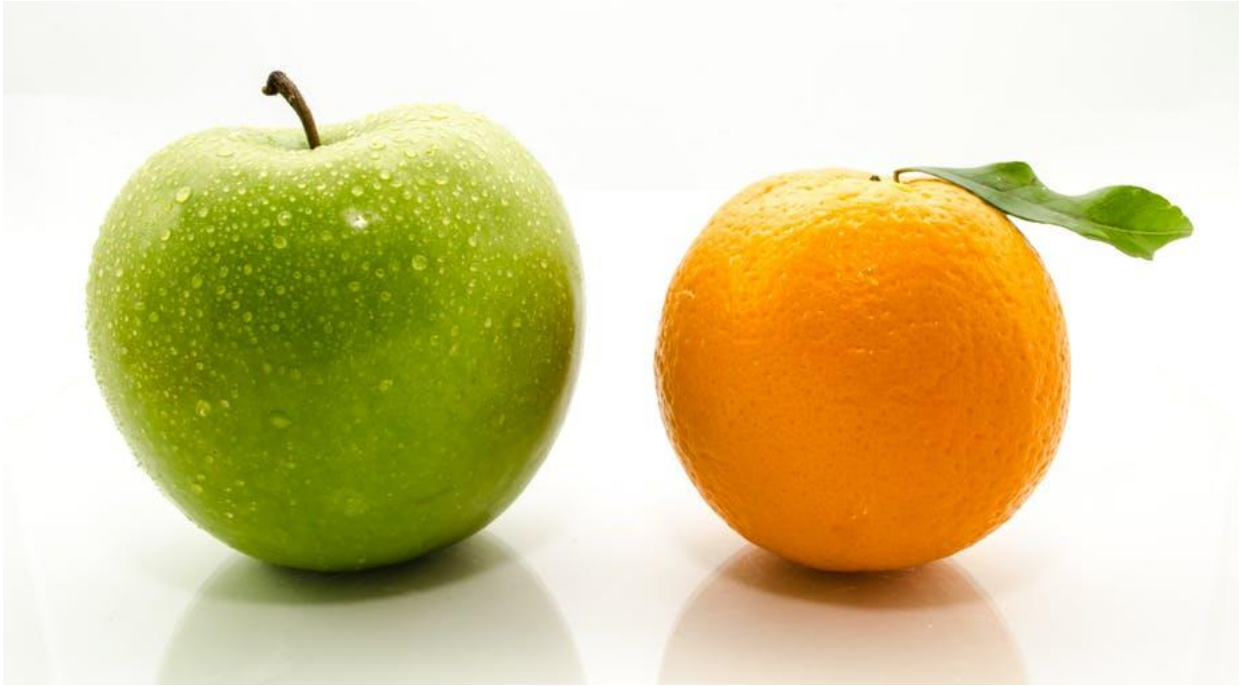
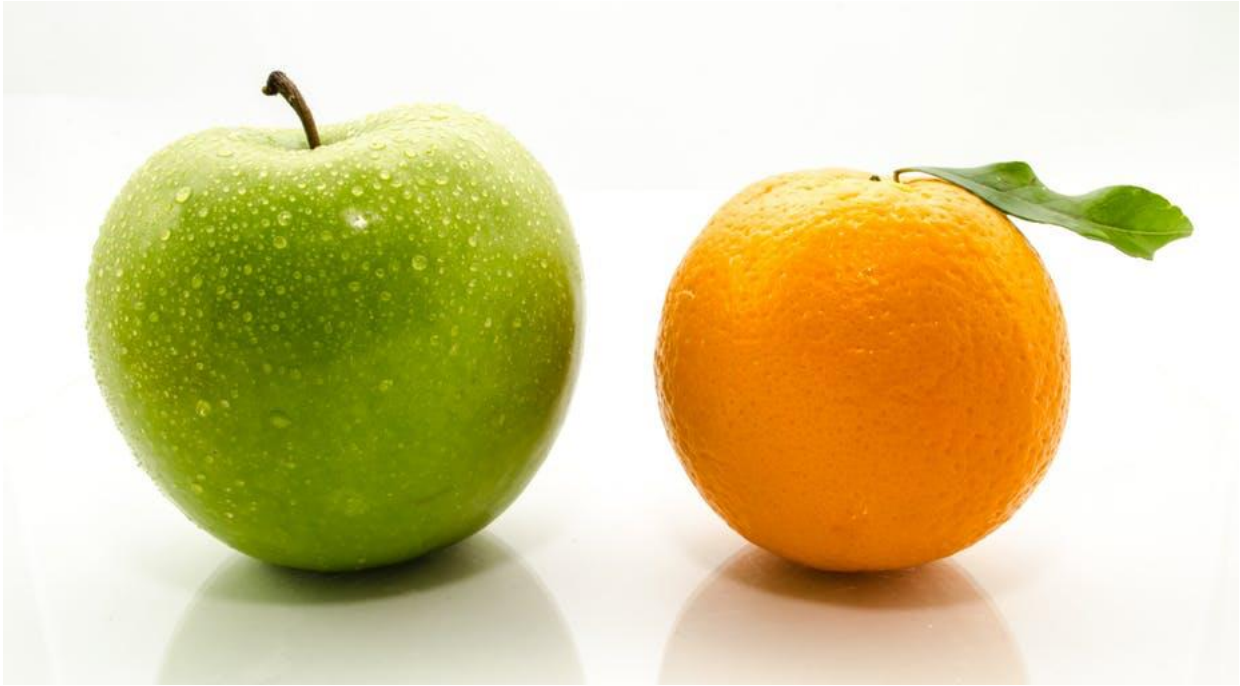
Problem with METALS and comparisons to LEAP

- Follow up amps 65% vs *54% for salvages*



Problem with METALS and comparisons to LEAP

- Follow up amps 65% vs *54% for salvages*
- Younger, fitter subjects



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Problem with METALS and comparisons to LEAP

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- Blast and greater severity injury

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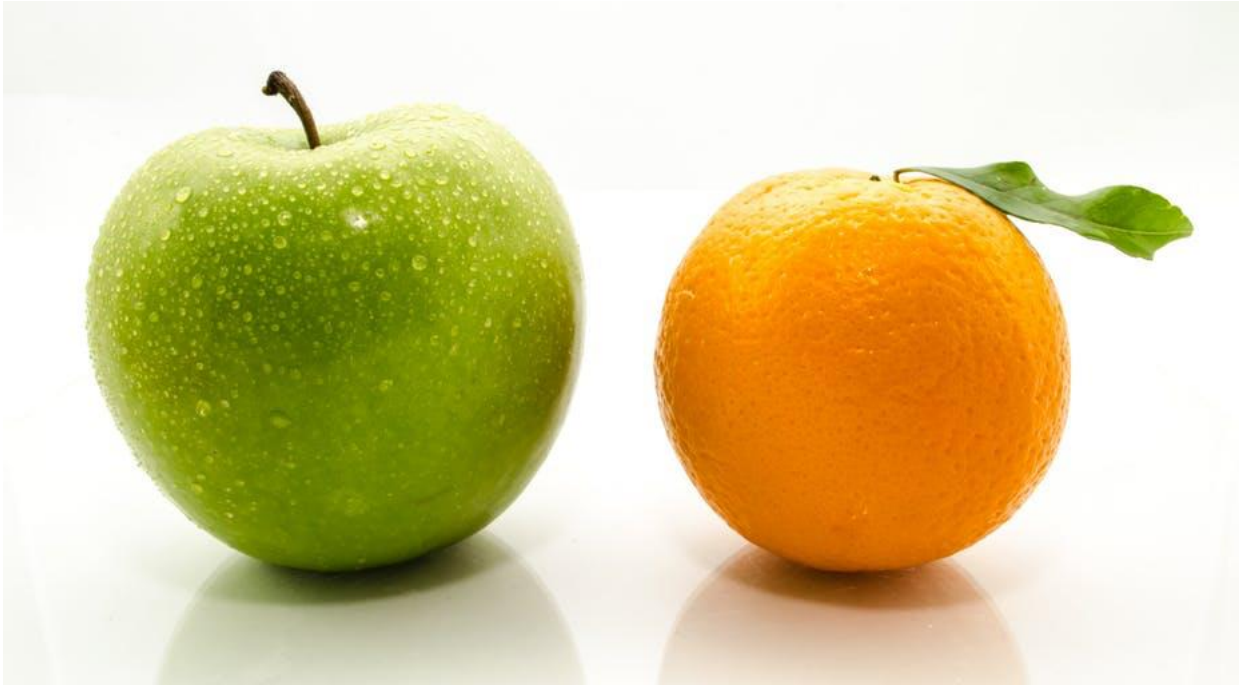
- Greater proportion of distal leg, ankle and hindfoot injuries



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Problem with METALS and comparisons to LEAP

- Follow up amps 65% vs *54% for salvages*
- Younger, fitter subjects
- Blast and greater severity injury
- Greater proportion of distal leg, ankle and hindfoot injuries
- Access to state-of-the-art prosthetics and rehabilitation

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Longer term outcomes

Delayed (>90 day)amputations?

- 3.3% (civilian) to 13.5% (military)
- Most performed for pain (50-90%)
- Similar functional outcomes early versus delayed amputation (following limb recon failure)
- Delayed amputations function better than recon at 4-5 years
- Higher rates of anxiety, depression and substance abuse among delayed versus early amputation

Stinner *MilitMed* 2010
Dickens *JBJS* 2013
Ladlow *JBJS* 2016
Bennett *BJR* 2018
Melcer *PLOS* One 2017

Likelihood of return to duty among wounded warriors

- **STRC-** Type 3 open tibias, 20% return to duty, those with amputation less likely (20.5% salvage vs 12.5% amp)
- **METALS** – 1/3rd not working, returned to duty or school
- **SAMC** - Combat-related hindfoot injuries, 20% return to duty (26% salvage vs.12% amp)

Cross *JOT* 2012
Doukas *JBJS* 2013
Sheehan *JOT* 2014

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Early and projected lifetime costs

- **Direct Costs** (medical + orthotics/prosthetics):
  - 2 years - Salvage $81,316 versus Amputation $91,106
  - Lifetime – Salvage $163,282 versus Amputation $509,275

MacKenzie JBJS 2007

Early and projected lifetime costs

- **Direct Costs** (medical + orthotics/prosthetics):
  - 2 years - Salvage $81,316 versus Amputation $91,106
  - Lifetime – Salvage $163,282 versus Amputation $509,275

- **Indirect Costs** (work + productivity loss at one year):
  - High energy lower extremity trauma - $58,547 lost productivity (77% of expected annual wages)
  - Below knee amputation - $64,246

MacKenzie *JBJS* 2007
Levy *JBJS* 2022

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Psychological illness

- **LEAP** - 42% moderate to severe depression, anxiety or other psychological disfunction

- **METALS** - 38% depressive symptoms, 17% PTSD, 13% major depression

- **UK Military** – Mental health outcomes worse for failed limb salvage patients

McCarthy *JBJS* 2003
Doukas *JBJS* 2013
Melcer *PLOS One* 2017, Krueger *Injury* 2015

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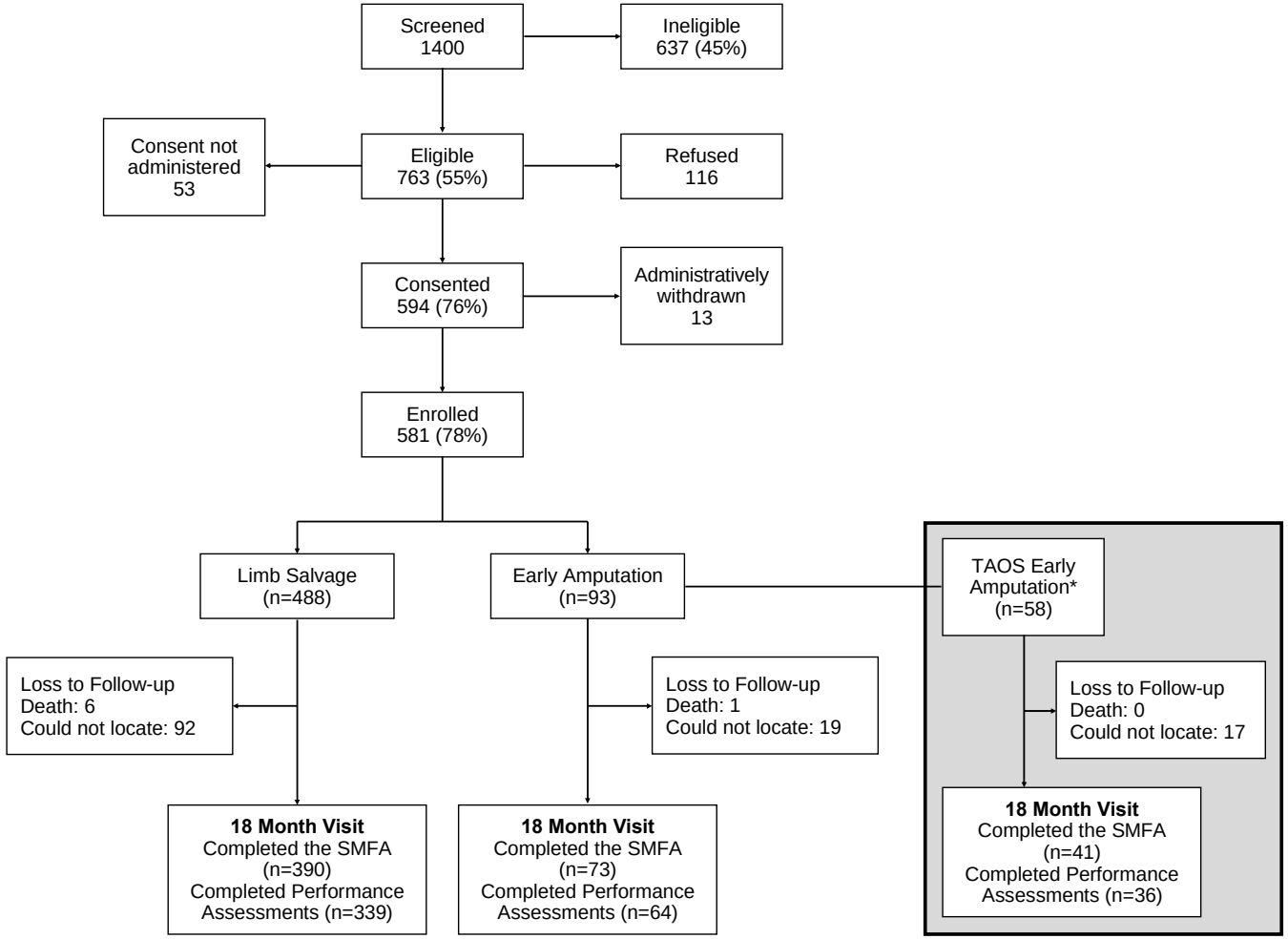
The METRC OUTLET Study



METRC Investigators *JBJS* 2021

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Difference in SMFA Score for Patients Treated with Limb Salvage HAD THEY Been Amputated

	Observed SMFA score (Under Salvage) – Predicted SMFA score (Under Amputation)			
	All Patients (n=410)	III Pilon/ IIIB Ankle (n=171)	Open Hindfoot (n=85)	Flap, Severe articular fxr +/- bone loss (n=154)
Dysfunction	3.38	3.88*	3.85	3.63*
Daily activities	4.03	5.65*	3.35	4.52
Mobility	6.99*	7.96*	7.30*	7.53*
Emotional status	3.49	3.94	2.84	3.95

* $p < .05$

METRC Investigators *JBJS* 2021

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The METRC OUTLET study. . .

- Patients with ***salvaged*** severe distal tibia and/or hindfoot injuries *have SMFA scores that are **worse** than their predicted outcome under amputation.*

- Differences are particularly meaningful among patients sustaining open **Type 3 Pilon** and **3B Ankle** fractures.

METRC Investigators *JBJS* 2021

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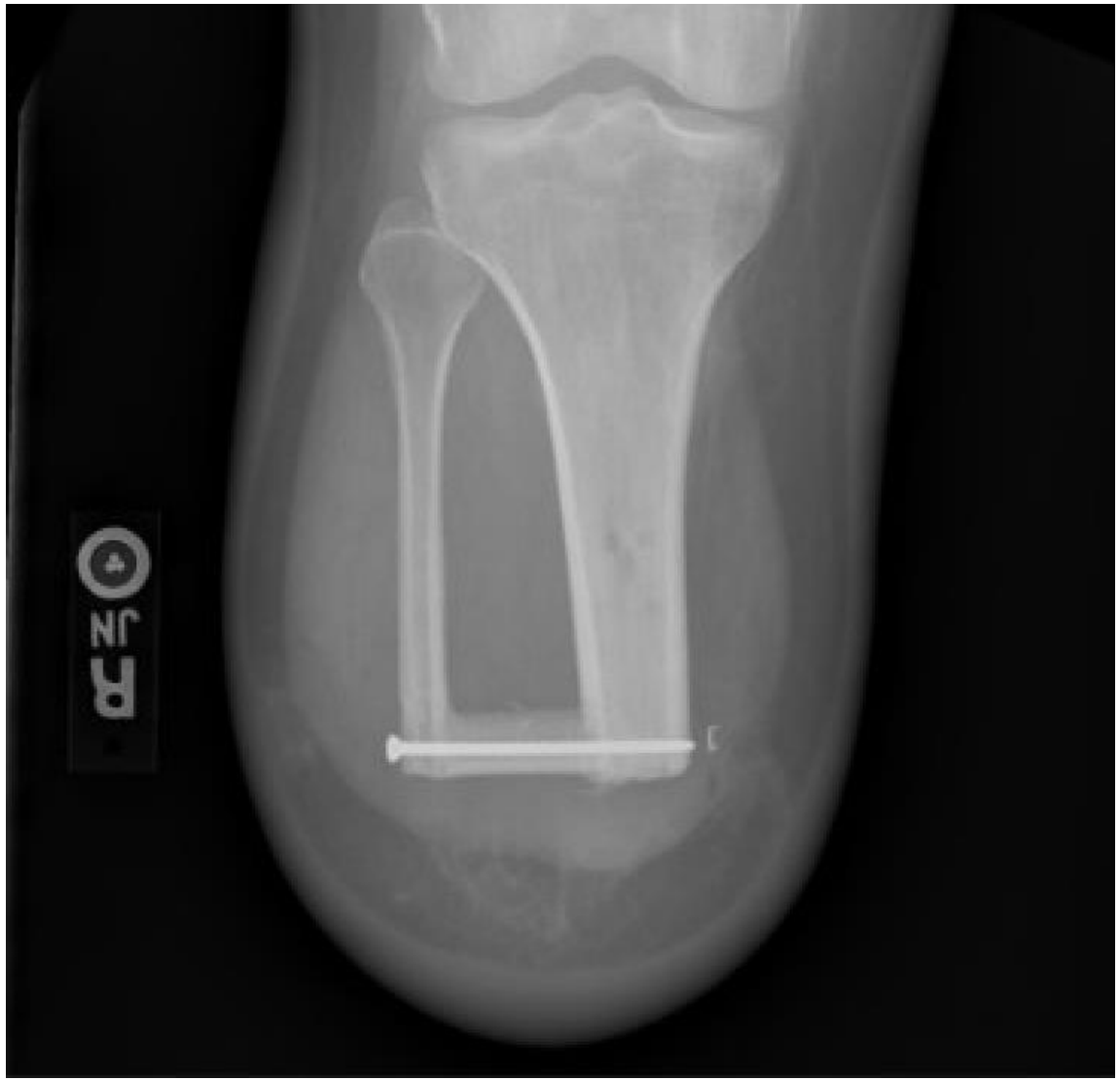
METRC Transtibial amputation outcomes study (TAOS)

106 patients randomized to Burgess versus Ertl (TTA with distal bone-bridge)

- Higher rates of complications and reoperations with Ertl (42% vs 24%, p=0.046)
- No difference in RCT ITT analysis of function (SMFA)
- Combined RCT plus observational cohorts causal analysis showed better (SMFA dysfunction, mobility and daily activities > 7 point) function for Ertl.



METRC Investigators *OTA Annual Meeting 2022*

Treatments are changing . . .




Orthosis evolution

The passive dynamic ankle foot orthosis (PDAFO)

- Patzkowski *J Surg Orth Adv* 2011
- Ladlow *J Royal Army Med Corps* 2019

Importance of an integrated orthotic and rehabilitative program

Among military population sustaining high-energy lower extremity trauma:

- Improved function and performance by 8 weeks
- 51% return to work versus 13% of non-participants
- >80% of those requesting amputation changed their minds
- Results durable > 2 years from injury

Patzkowski *JOAAOS* 2012
Blair *JOT* 2014
Bedigrew *CORR* 2014
Potter *JBJS* 2018

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PDAFO for everyone?

- **Good** for isolated nerve injuries resulting in DF and/or PF weakness
- **No Good** for subjects with CRPS, chronic pain diagnosis, or psychiatric diagnosis

Potter *JBJS* 2018
Franklin *Sport Med Arthrosc* 2019

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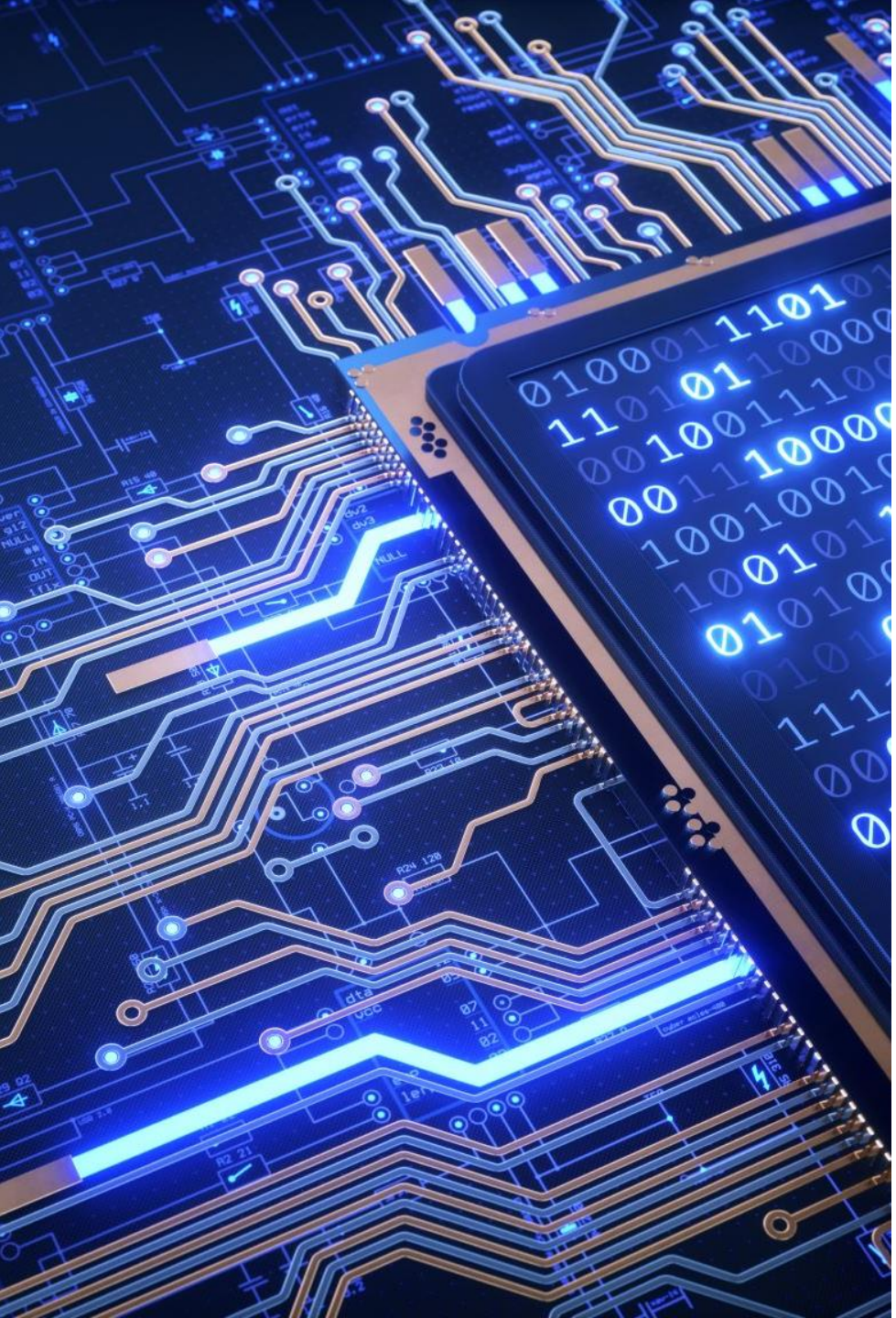
Optimizing amputee outcomes



What is on the bionic horizon?

- Osseointegration
- Brain-computer interface devices

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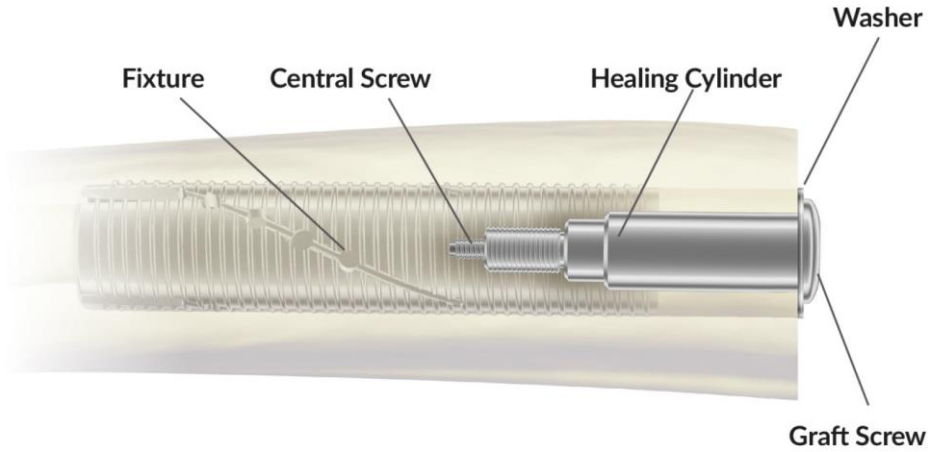
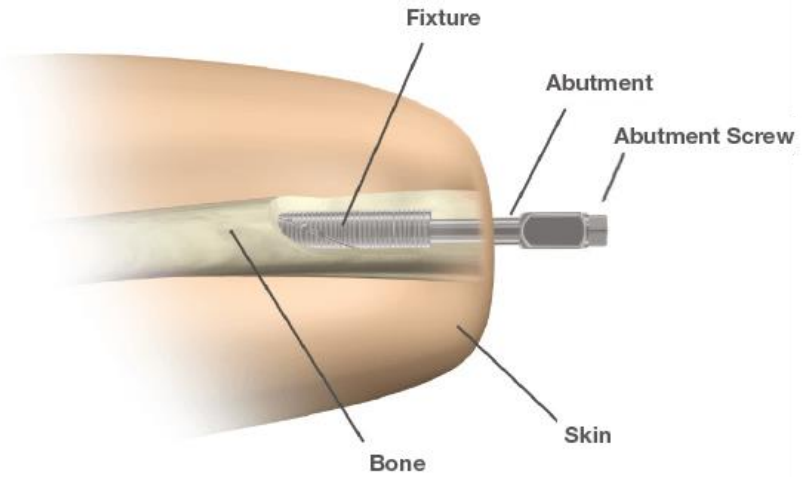
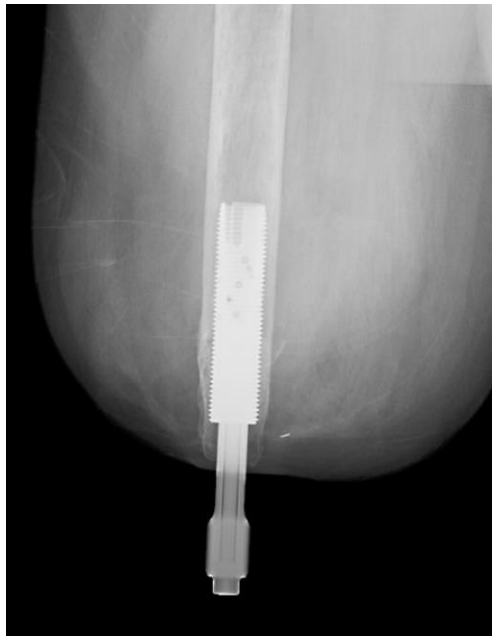
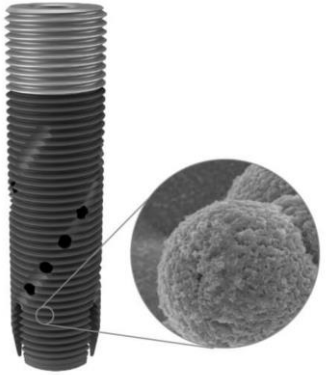
Conventional osseointegration for amputation: **OPRA**


Fixture
Central Screw
Healing Cylinder
Washer
Graft Screw


Fixture
Abutment
Abutment Screw
Bone
Skin





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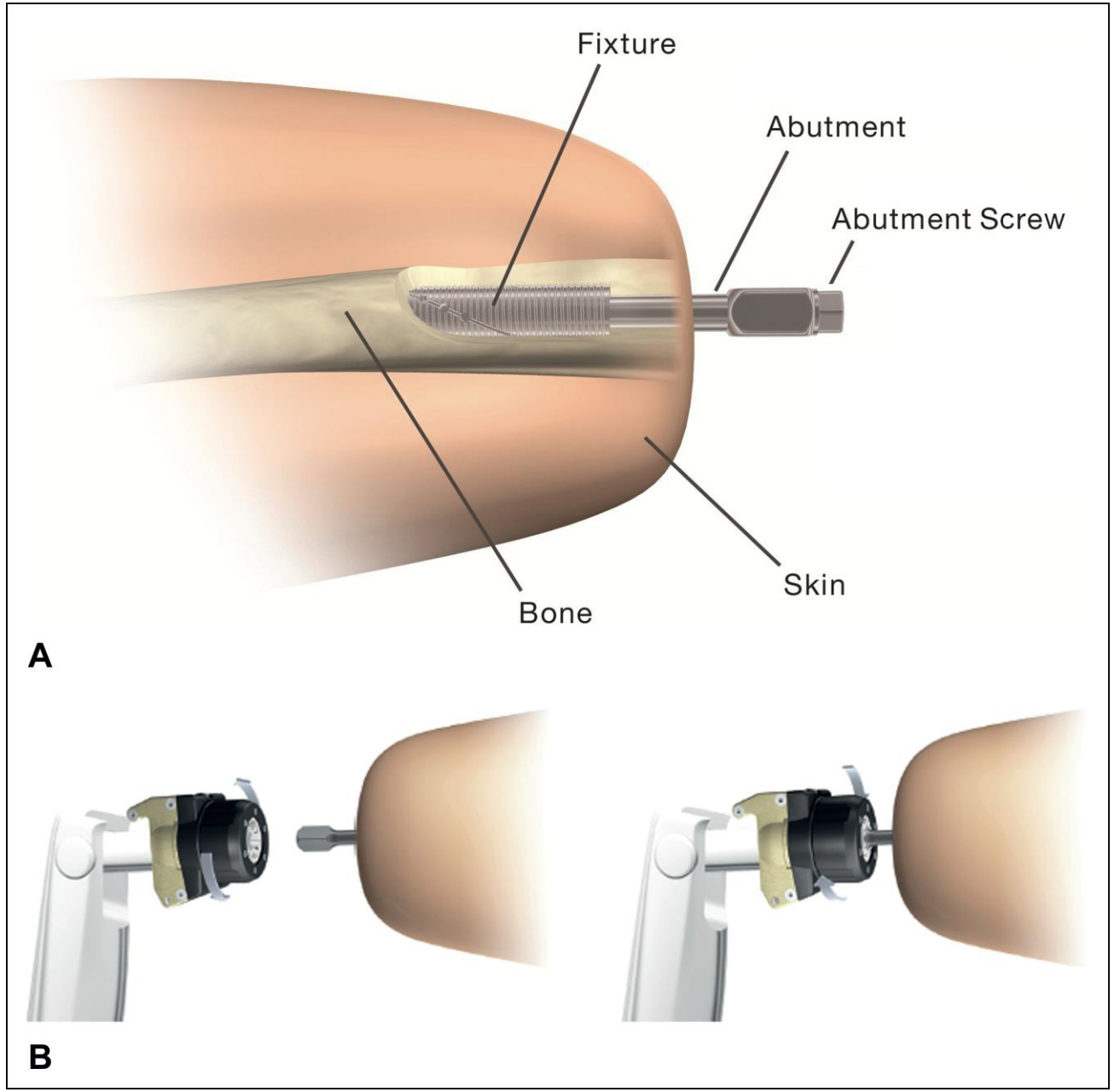

Artificial sensory feedback with terminal device control

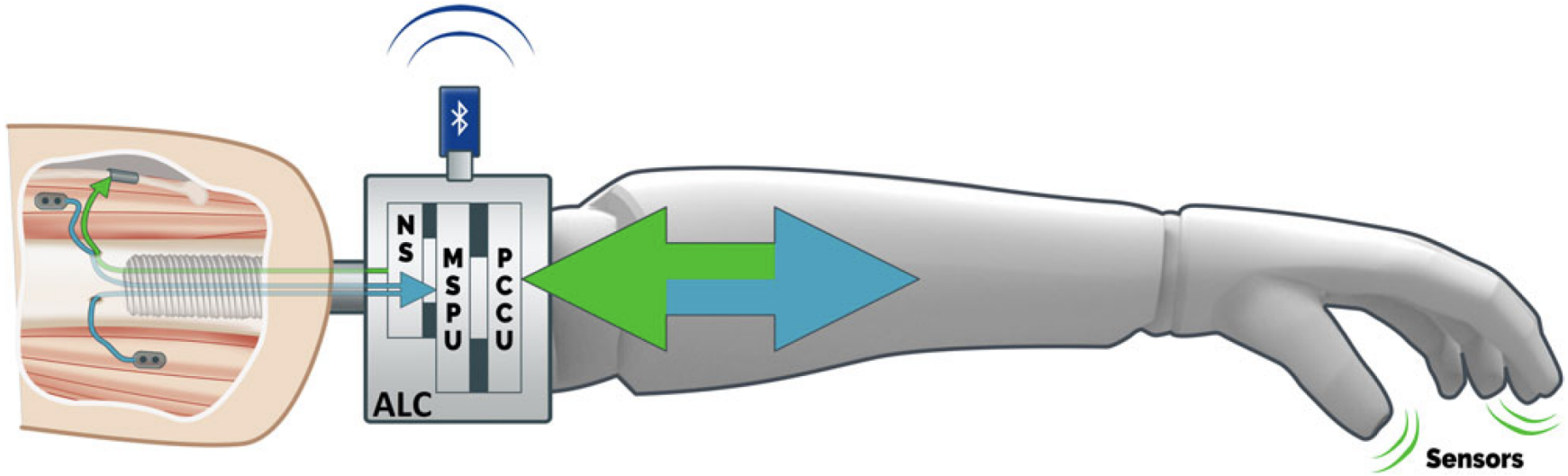

Fig. 1. Artificial Limb Controller (ALC). The system is composed by three modules: Neurostimulator (NS), Mixed Signals Processing Unit (MSPU) and Prosthetic Control and Communication Unit (PCCU). An external module can be plugged on the side of the system to achieve Bluetooth communication. Myoelectric signals are acquired from the implanted epimysial electrodes and then digitally processed to decode the motor intention of the user. In parallel, sensors on the prosthesis are periodically read and their output converted into stimulation pulses to the nerve via cuff electrode.

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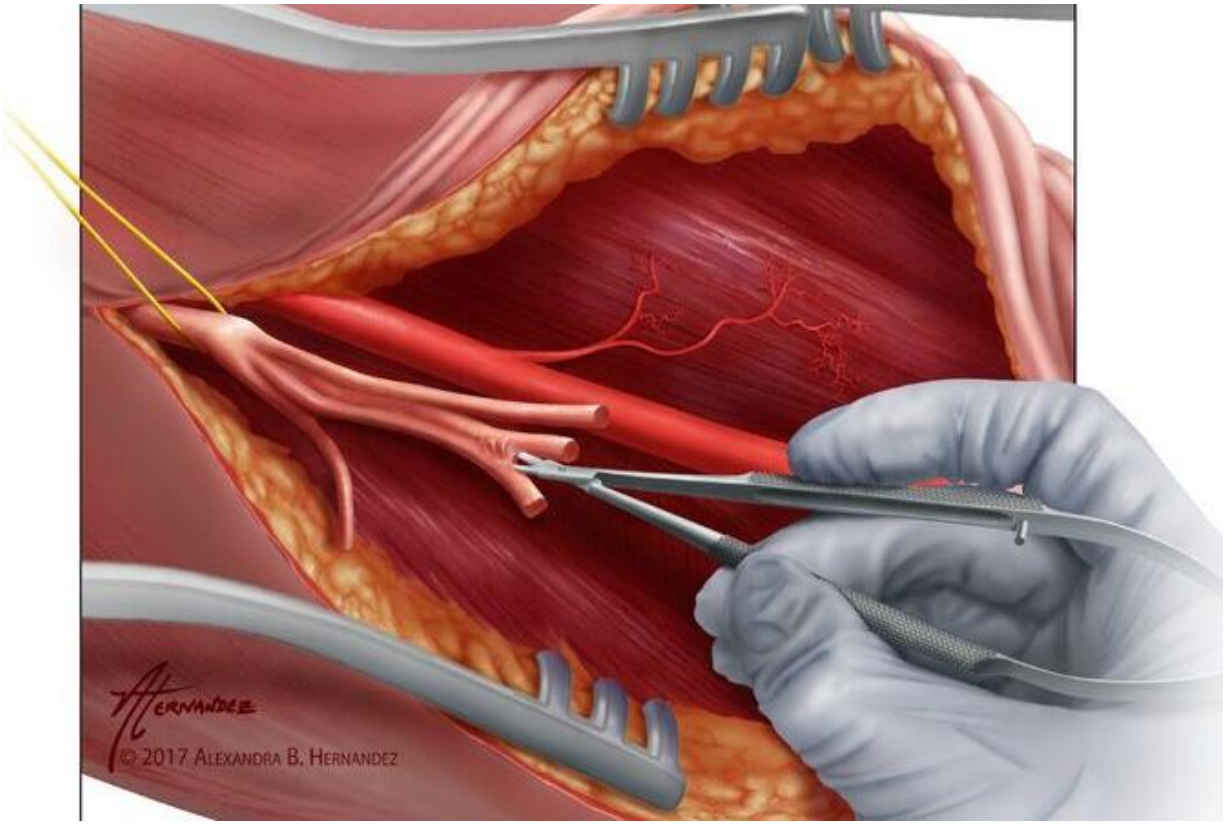
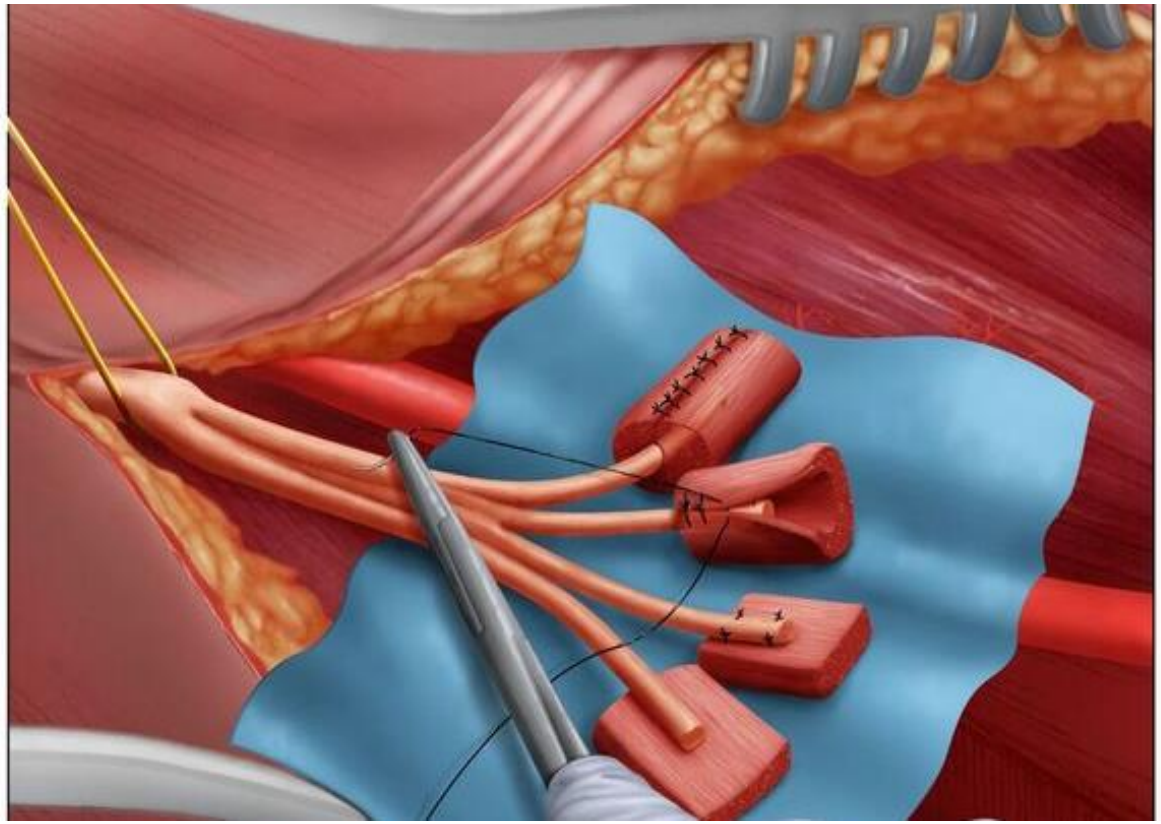
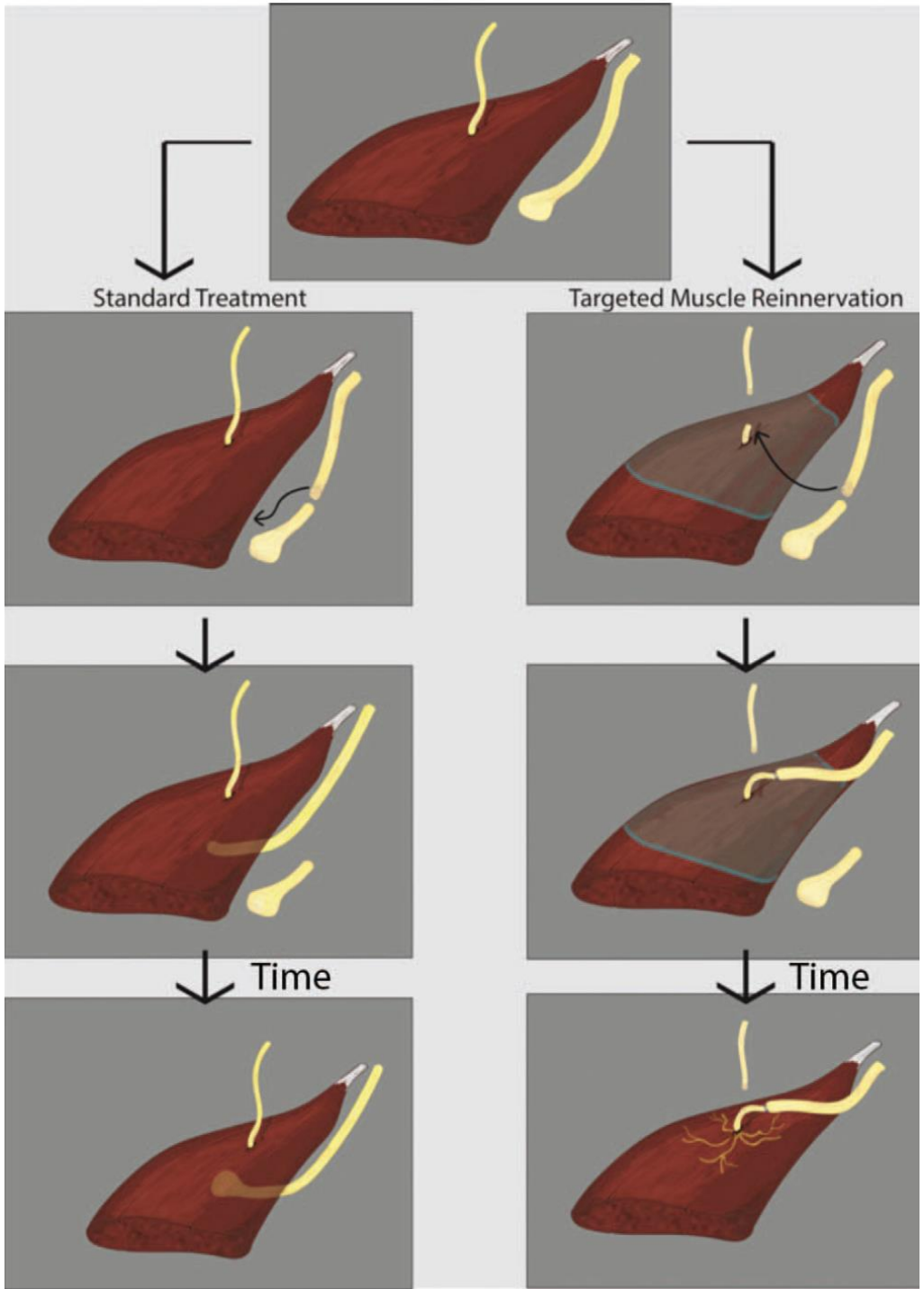
Regenerative Peripheral Nerve Interface

Kung *Plastic Reconstruct Surg* 2014







Targeted Muscle Reinnervation

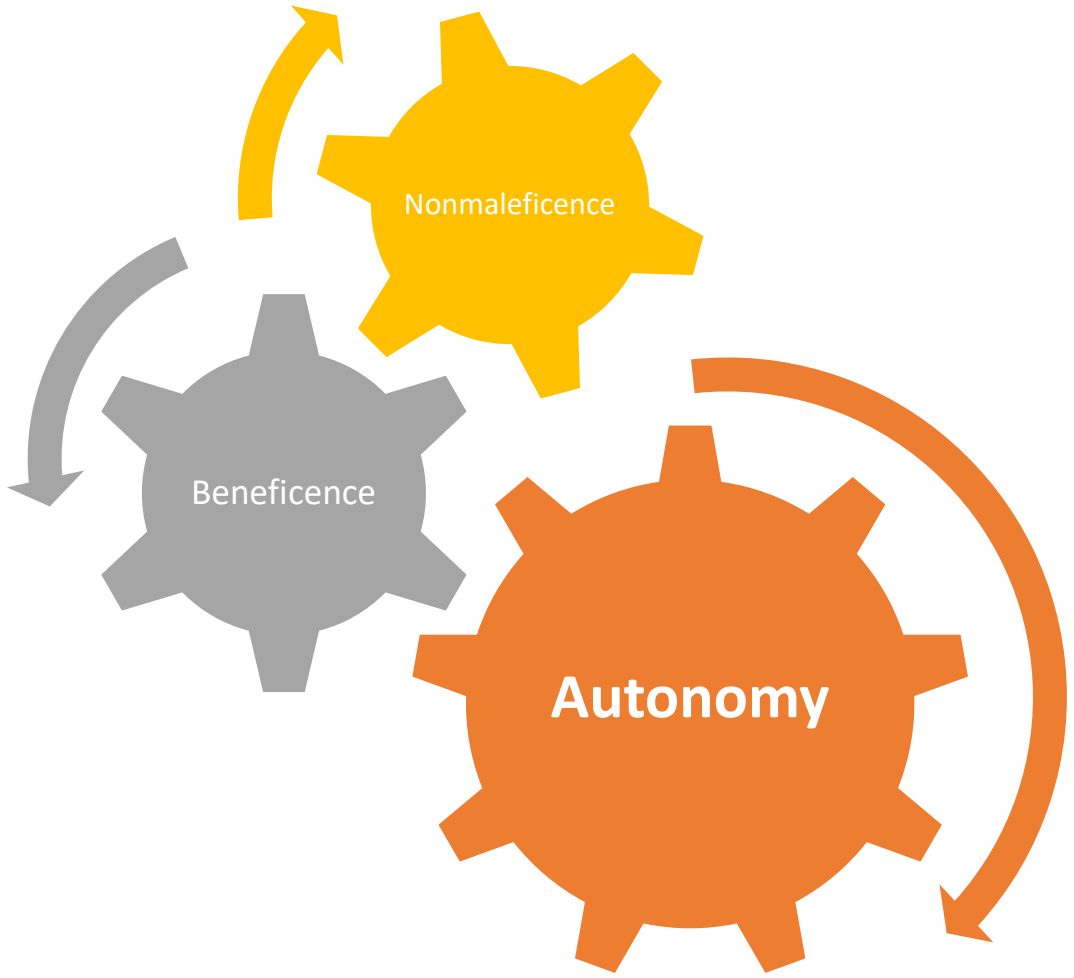
Souza *CORR* 2014

RPNI and TMR both effective treatments or phantom nerve pain and neuromata

Woo *Plast Reconstr Surg Glob Open* 2016

Dumanian *Ann Surg* 2019

Ethical obligation

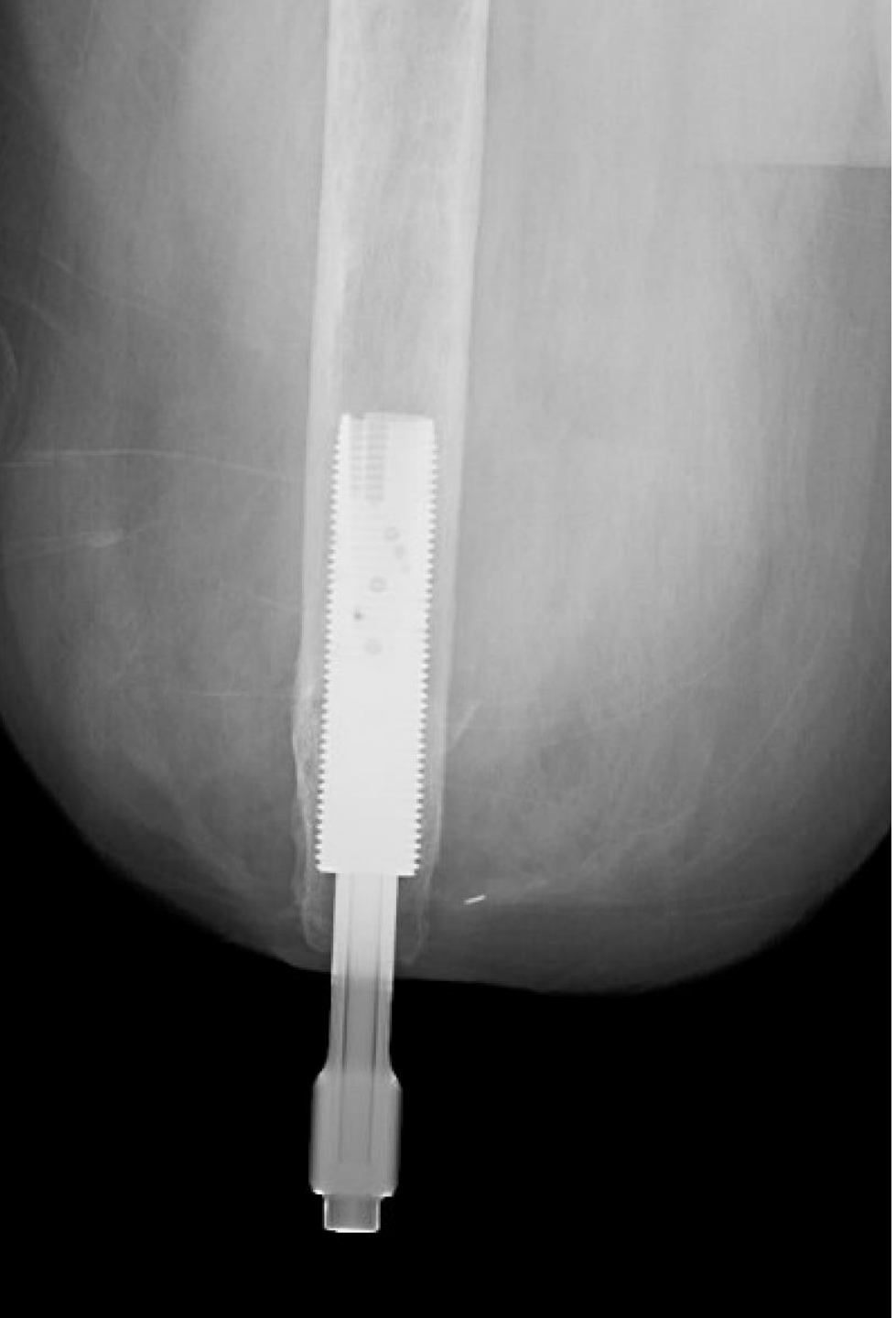


- Mind the gulf in understanding
- Avoid framing discussion around the long-term goal of “saving limb”
- Patients should be encouraged to reflect on their values, and choose treatment accordingly

Humbyrd and Rieder *JBJS* 2018

We know

- Outcomes are poor regardless of treatment
- Reconstruction has more complications
- Amputation more expensive
- Psychosocial traits and resources drive outcomes
- Plantar sensation not predictive
- Severe open ankle/hindfoot injuries may do better under amputation, even if *delayed* and especially among military cohorts
- PDAFO's improve function and reduce late amputations when combined with appropriate rehabilitation



In the future

- Decision-making tools that personalize treatment and optimize O&P prescriptions
- Osseointegration
- Artificial sensory feedback and terminal device control
- These new technologies are likely to keep the pendulum swinging between amputation and reconstruction for a long time to come

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Remember

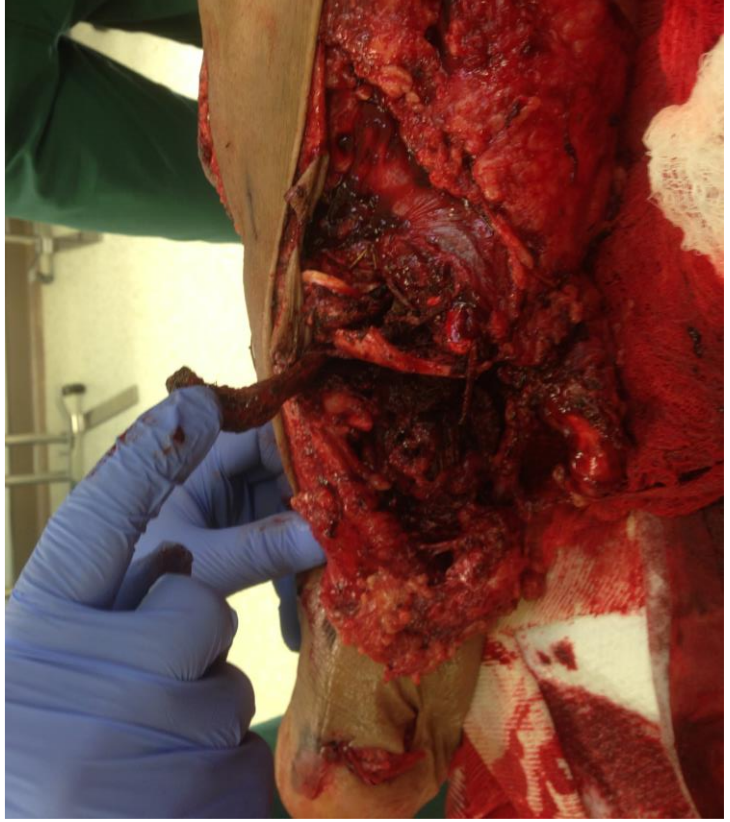
- Frame as amputation versus reconstruction . . . not salvage
- Inform your patient . . . Respect their autonomy
- Draw on the expertise of those around you

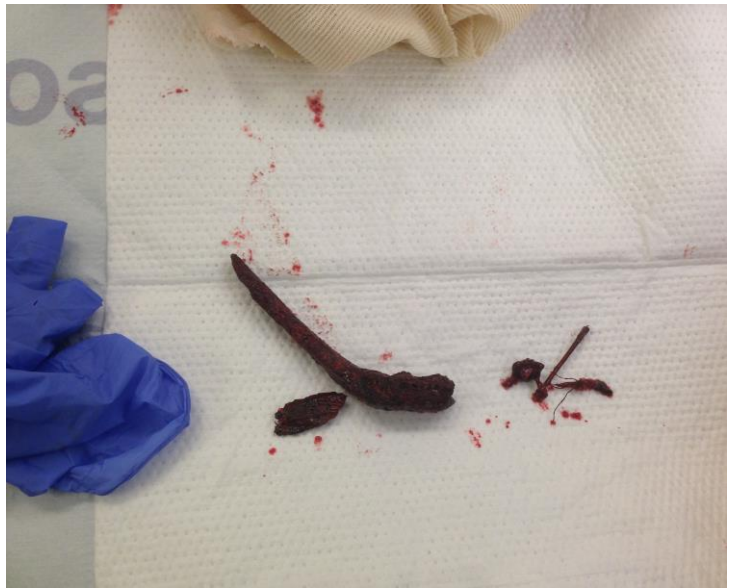
Bill's initial I&D

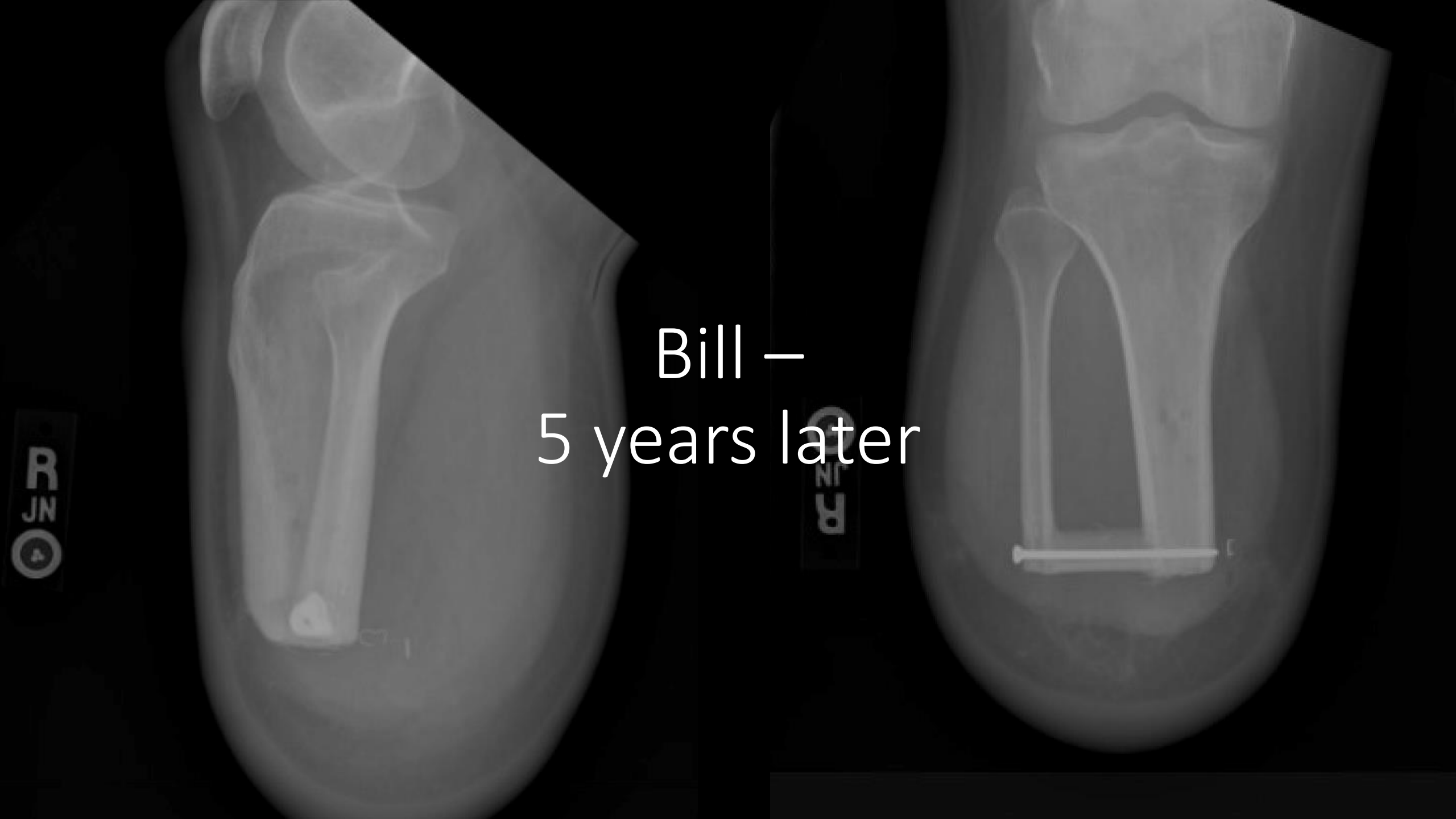
Single patent vessel (AT) to foot

Gross contamination

Segmental bone and muscle loss







Bill –
5 years later

Thank you

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