Queensland Health

Rapid-fire review of lower limb prosthetic research

Medical Aids Subsidy Scheme

17 September, 2025

DELIVERING FOR QUEENSLAND | Queensland Government

What is success for lower limb prosthetic users?[1]

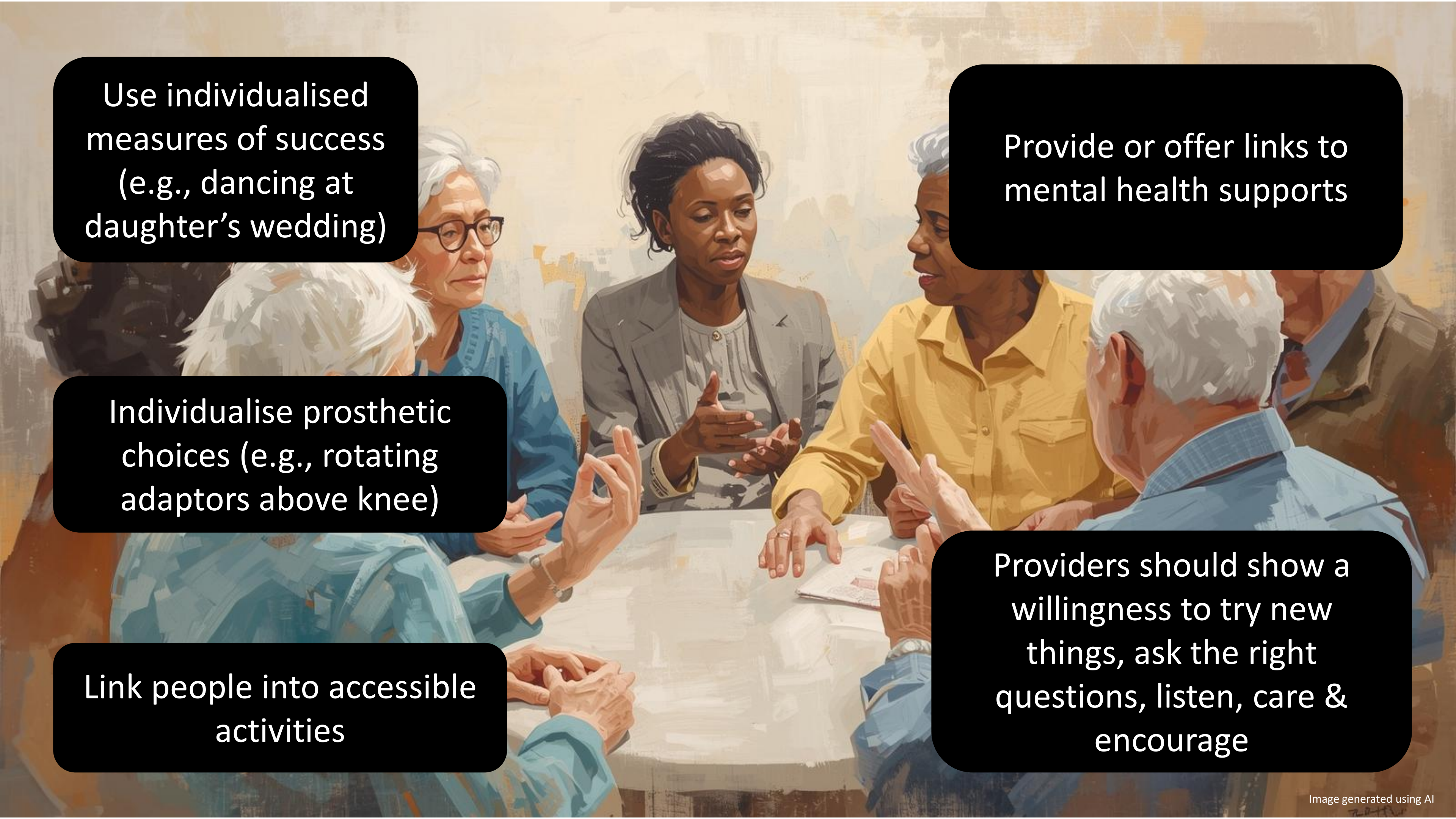
Study design: focus groups (n=31)

Level of evidence: moderate

Key take-home messages:

- Keep moving forward, despite ups & downs
- Being able to living MY normal life and do the things I want to do with ease
- Learning what works for me and how to manage my prosthesis
- Only I can define my success
- What about my mental health?

1. McDonald, C.L., Balkmann, G.S., & Hafner, B.J. (2025). How do users define success with a lower limb prosthesis? A focus group study. *Disability & Rehabilitation, 47*(3), 736-750.


Use individualised measures of success (e.g., dancing at daughter’s wedding)
Individualise prosthetic choices (e.g., rotating adaptors above knee)
Link people into accessible activities
Provide or offer links to mental health supports
Providers should show a willingness to try new things, ask the right questions, listen, care & encourage
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Peer support groups[1]

Study design: cross-sectional mixed-methods survey (n=82)

Level of evidence: emerging

Key take-home messages:

- Preference for open-discussion (65%) vs lectures (34%)
- Benefits: ‘companionship’, ‘altruism’*, ‘information’
- Participation in support groups association with better PLUS-M scores after controlling for amputation cause, level and time since amputation

1. Lee, S-P., Maluotoga, M., Thind, R., et al. (2024). Utilization and perception of peer-support after lower limb loss in the United States: potential benefits on mobility outcomes. *Archives of Physical Medicine & Rehabilitation, 105*, 939-46.

Recognise the possible physical & psychosocial benefits of amputee peer-support groups

Know how to connect clients to amputee support groups, e.g., Amputees Queensland

Have the conversation, don't assume

Image generated using AI

Depression & anxiety in traumatic LLAs[1]

Study design: cross sectional study (n=72) investigating demographics, TAPES-R (adjustment and prosthetic satisfaction) and Hopkins Symptom Checklist (anxiety and depression)

Level of evidence: emerging

Key take-home messages:

- Depression influenced by psychosocial adjustment, activity restriction, prosthetic satisfaction and unemployment
- Unemployed 3.4 x more likely to experience depression than employed
- Anxiety influenced by activity restriction, unemployment and low educational level

1. Saleh, N.E.H., Hamiye, F., Summaka, M., et al. (2024). Depression and anxiety symptoms among Lebanese lower limb traumatic amputees: association with education, employment, adjust to amputation and prosthetic satisfaction. *Psychiatry: Interpersonal & Biological Processes, 87*(1), 51-64.

Image generated using AI

Support for caregivers[1]

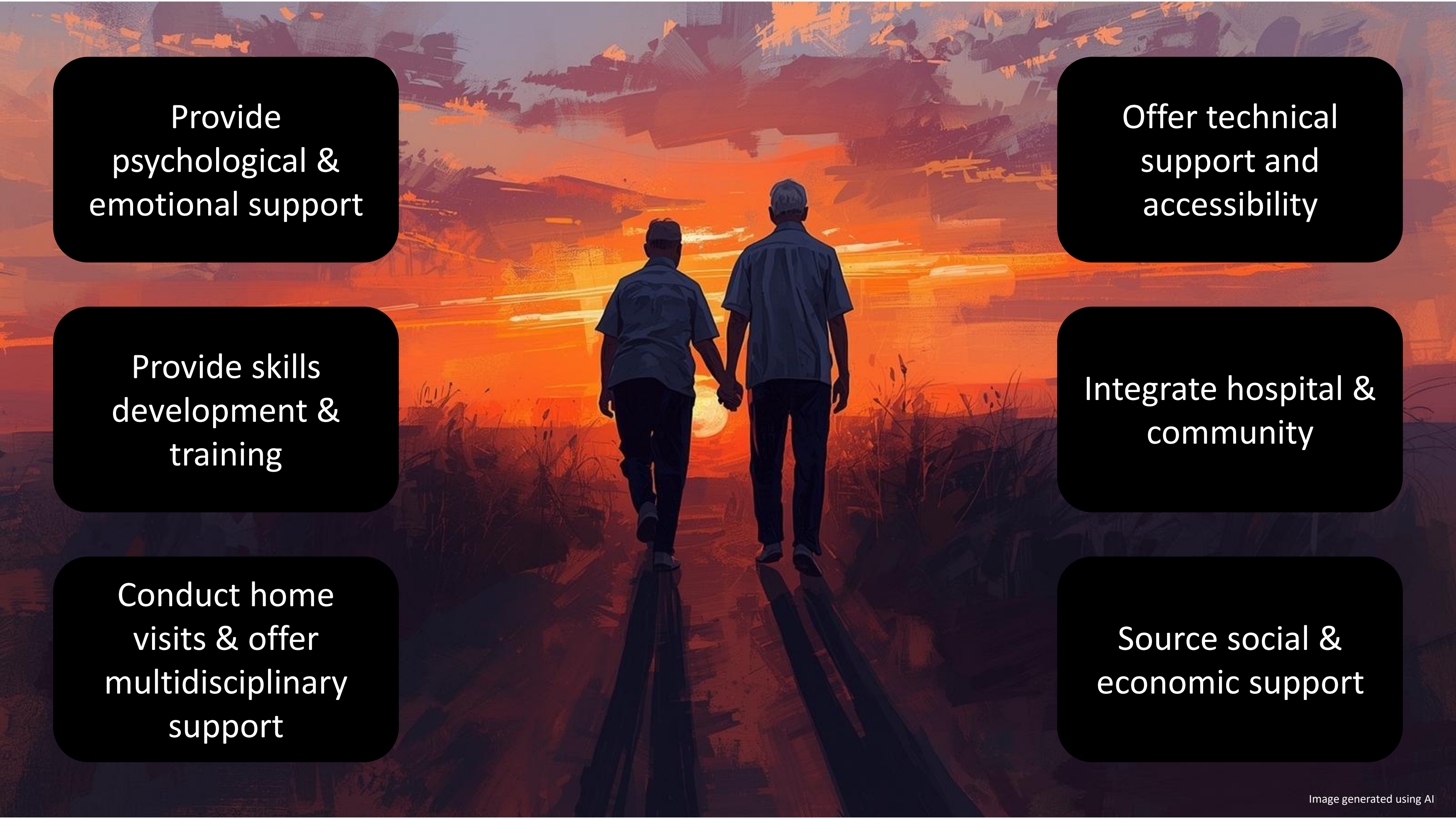
Study design: qualitative phenomenological study for amputee-caregiver dyads using semi-structured interviews and qualitative content analysis

Level of evidence: moderate to good

Key take-home messages:

Difficulties faced	Autonomy & mobility
	Architectural barriers and home adaptation
	Self-care
	Transition & adaptation to the new context
Home discharge	Functional training & empowerment
	Family & community support
Impact of amputation	Awareness & acceptance
	Psychological & emotional impact
	Changes in lifestyle & routine

1. Rodrigues, D., Carvalho, L., & Pinto, C. (2025). Lower-limb amputees and family caregivers: challenges, needs, and strategies for empowerment – a qualitative study. *Nursing Reports, 15*, 166.


Provide psychological & emotional support
Provide skills development & training
Conduct home visits & offer multidisciplinary support
Offer technical support and accessibility
Integrate hospital & community
Source social & economic support
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Correlates with the OPUS[1]

Study design: cross-sectional study with 22 persons with LLA, exploring correlates between OPUS Lower Extremity Functional Status (LEF) and Satisfaction with Devices (SWD) with TUG, 2MWT, 6MWT, body composition, and centre of pressure (CoP) during walking.

Level of evidence: emerging

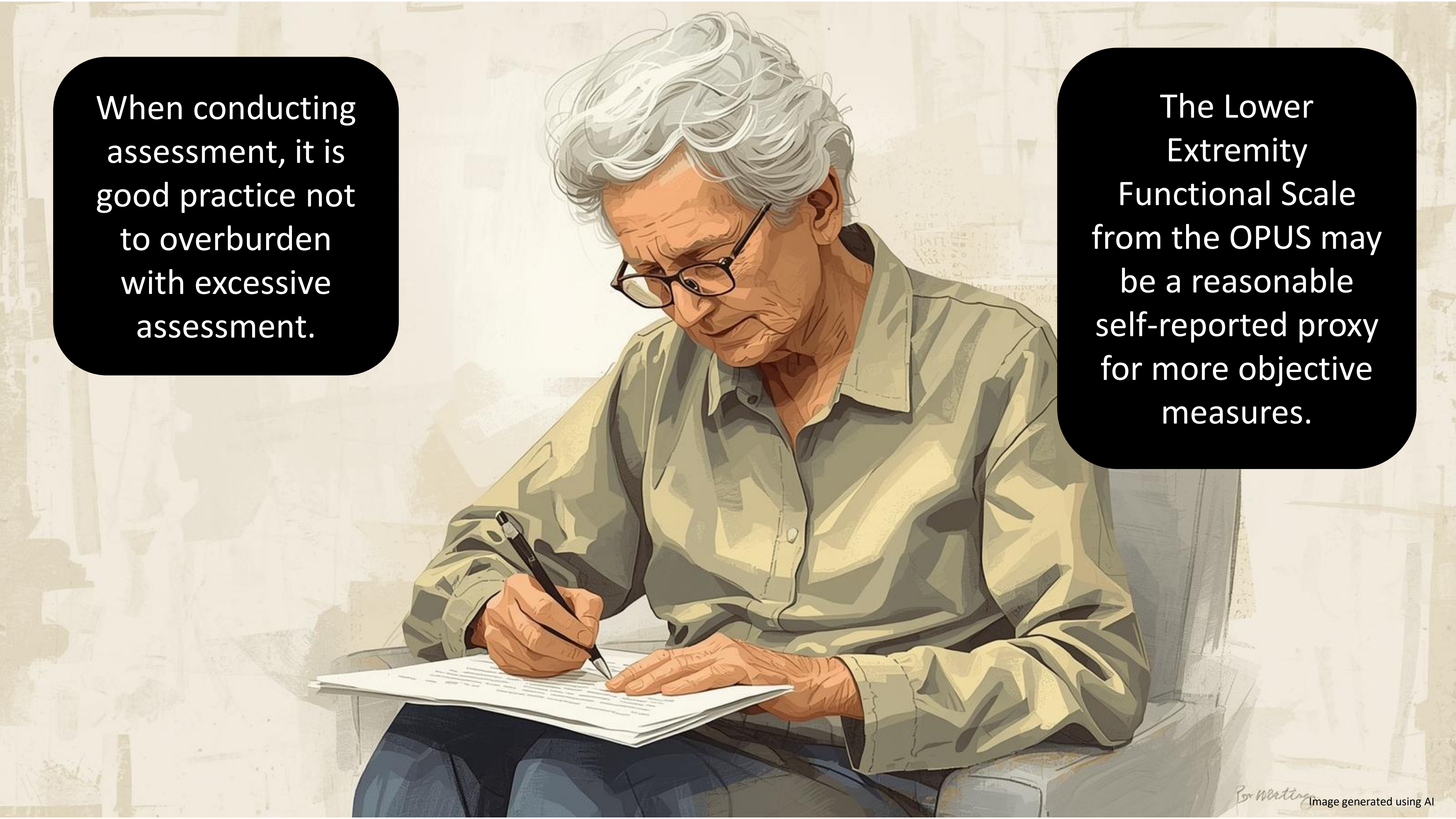
Key take-home messages:

- LEF is moderately correlated with TUG, 2MWT, 6MWT, and CoP.
- LEF appears to capture the balance components of other assessments.

1. Smith, J.D., & Guerra, G. (2025). Correlates of Orthotic Prosthetic User Survey, performance-based outcome measures and balance in lower limb prosthetic users. *Prosthesis, 7*, 66.

When conducting assessment, it is good practice not to overburden with excessive assessment.

The Lower Extremity Functional Scale from the OPUS may be a reasonable self-reported proxy for more objective measures.



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Predicting K-levels after rehab[1]

Study design: cohort study before & after rehab investigating demographic, anthropometric, balance & psychosocial factors predicting K-level, TUG & 2MWT after rehab using machine learning

Level of evidence: moderate

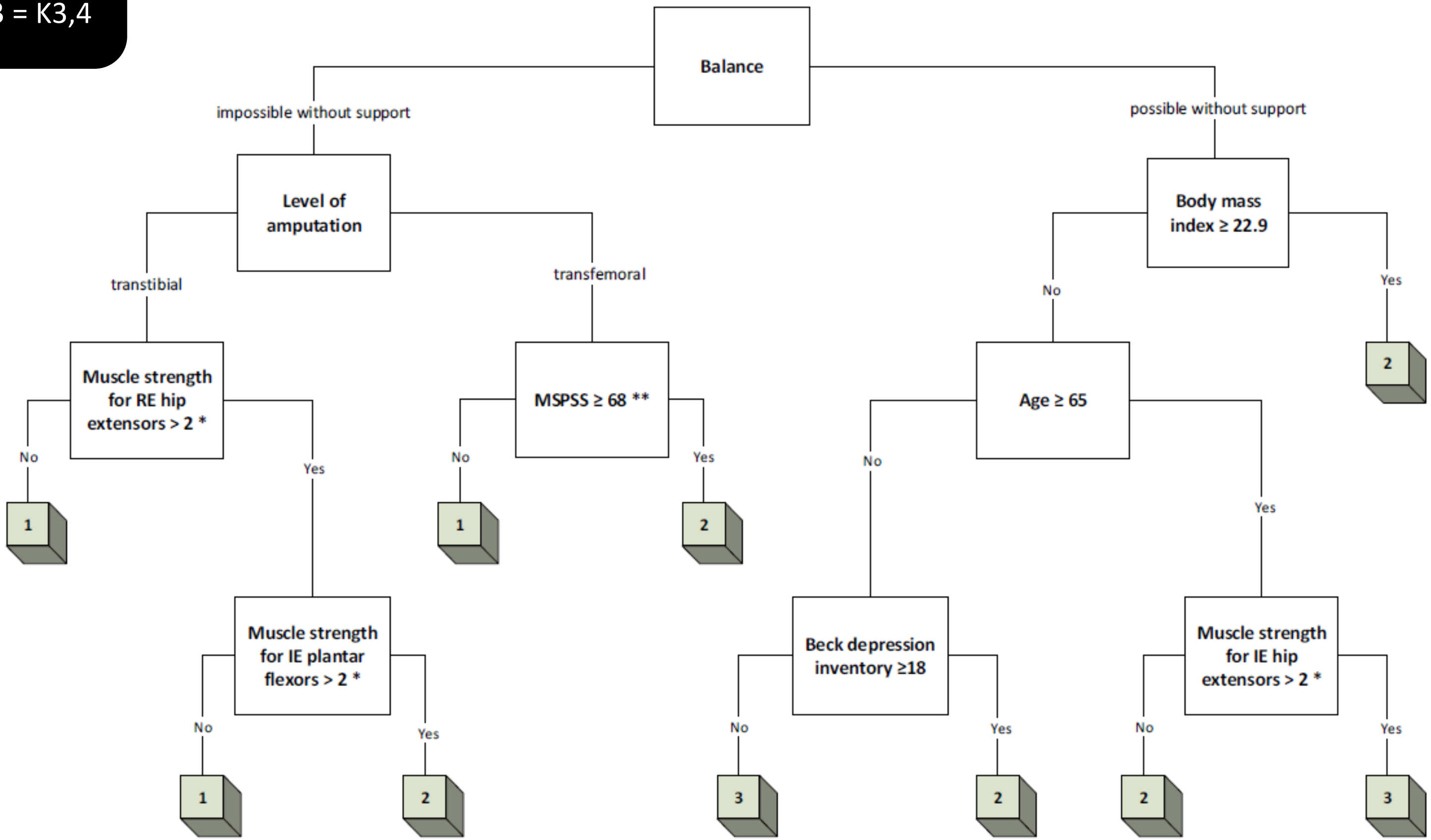
Key take-home messages:

- A decision tree for predicting K-levels shows excellent sensitivity, specificity, accuracy & precision (>85%)
- Decision trees for predicting TUG and 2MWT outcomes show reasonable sensitivity, specificity, accuracy & precision (>70%)

1. Knezeis, A., Arsenovic, J., Garipi, E., et al. (2024). Machine learning model for predicting walking ability in lower limb amputees. *Journal of Clinical Medicine, 13*, 6763.

Group 1 = K0,1
Group 2 = K2
Group 3 = K3,4

K-level prediction decision tree



Correlates of hip strength and functional measures[1]

Study design: Cross-sectional study of 13 TT and 13 TF LLA prosthesis users exploring correlates of hip strength and objective walking and balance (10mWT, 2MWT, NBWT, FSST) grouped by TA / TF. MPK users.

Level of evidence: emerging-moderate

Key take-home messages:

- TTA users - *walking speed & endurance* related to residual & intact limb peak torque (residual limb hip extensor and abductors, R^2 = 0.6/0.69)
- TTA users - *balance* related to residual & intact limb torque steadiness (residual limb hip abductor, R^2 = 0.52)
- TFA users - walking speed, endurance & balance related to intact limb peak torque (intact limb hip abductor, R^2 = 0.33-0.48)

1. Sawers, A., & Fatone, S. (2024). The relationship of hip strength to walking and balance performance in unilateral lower limb prosthetic users differs by amputation level. *Physical Medicine & Rehabilitation, 17*, 147-158.

Walking speed, balance and endurance are highly related to hip strength

For TTA - residual limb hip extensors and abductors are key

For TTF - intact limb hip abductors are key

Image generated using AI

Gait parameters in the intact limb[1]

Study design: biomechanical lab study (n = 29 control, 13 transtibial, 10 transfemoral [9 of which had MPKs]) measuring ground reaction force (GRF)

Level of evidence: moderate

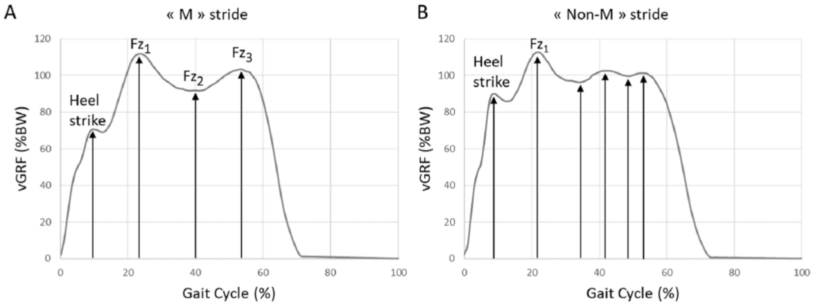
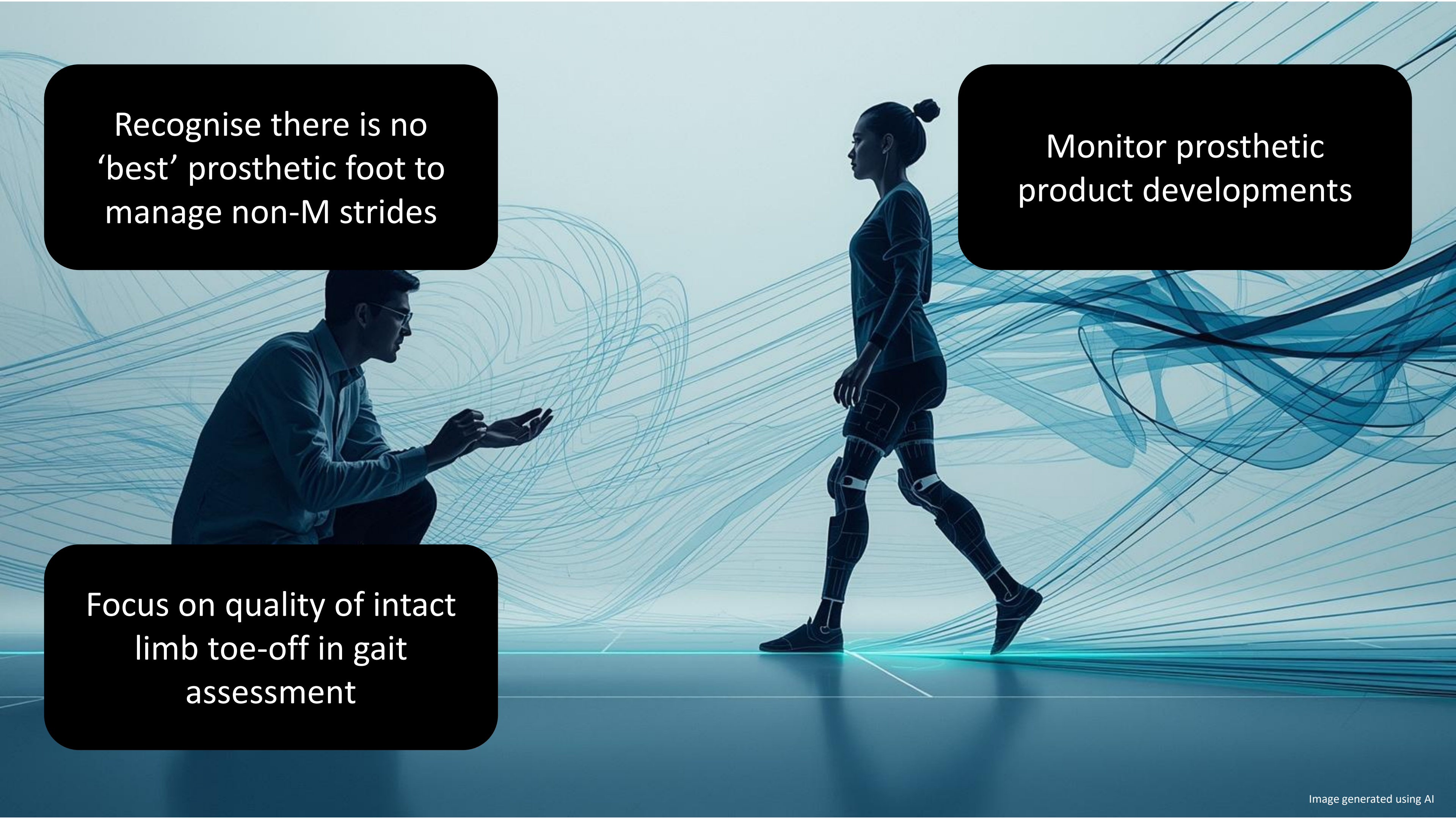


Fig. 1. Example of an "M" (A) and a "Non-M" (B) stride from the intact limb of the same participant (n° 6 in Table 1). For the "M" stride, the heel strike peak has not been counted in the peaks and valleys, the count being thus equal to 3: F_z1, F_z2 and F_z3.

Key take-home messages:

- Prosthetic users walk slower than controls with more time on the <u>intact limb</u>
- Non-M strides are more common in the <u>intact limb</u> than prosthetic limb (mean 19.1% vs 6.2%)
- Non-M strides are independent of age, time since amputation and prosthetic foot (i.e., no foot systematically works better)
- No difference between TF & TT in terms of Non-M strides

1. Mahé, C., De Graaf, J., Bonillo, I., Nadeau, S., Calistri, L., & Mesure, S. (2025). Gait of lower limb amputees: Unusual time-course of vertical ground reaction forces of the intact limb. *Gait & Posture, 119*, 70-76.



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Gait asymmetry in transtibial amputees[1]

Study design: biomechanical lab study (n = 5 transtibial) measuring ground reaction force and motion capture

Level of evidence: poor-emerging

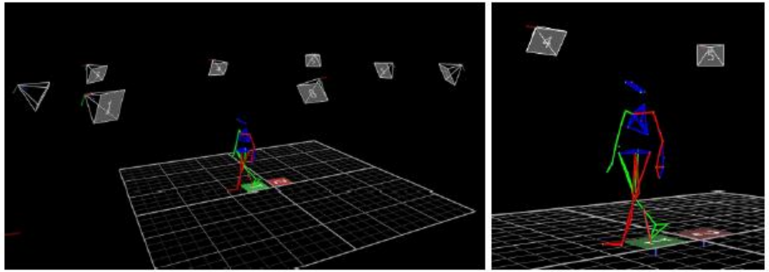


Figure 2: Amputee's walking tracked in the Motion capture system.

Key take-home messages:

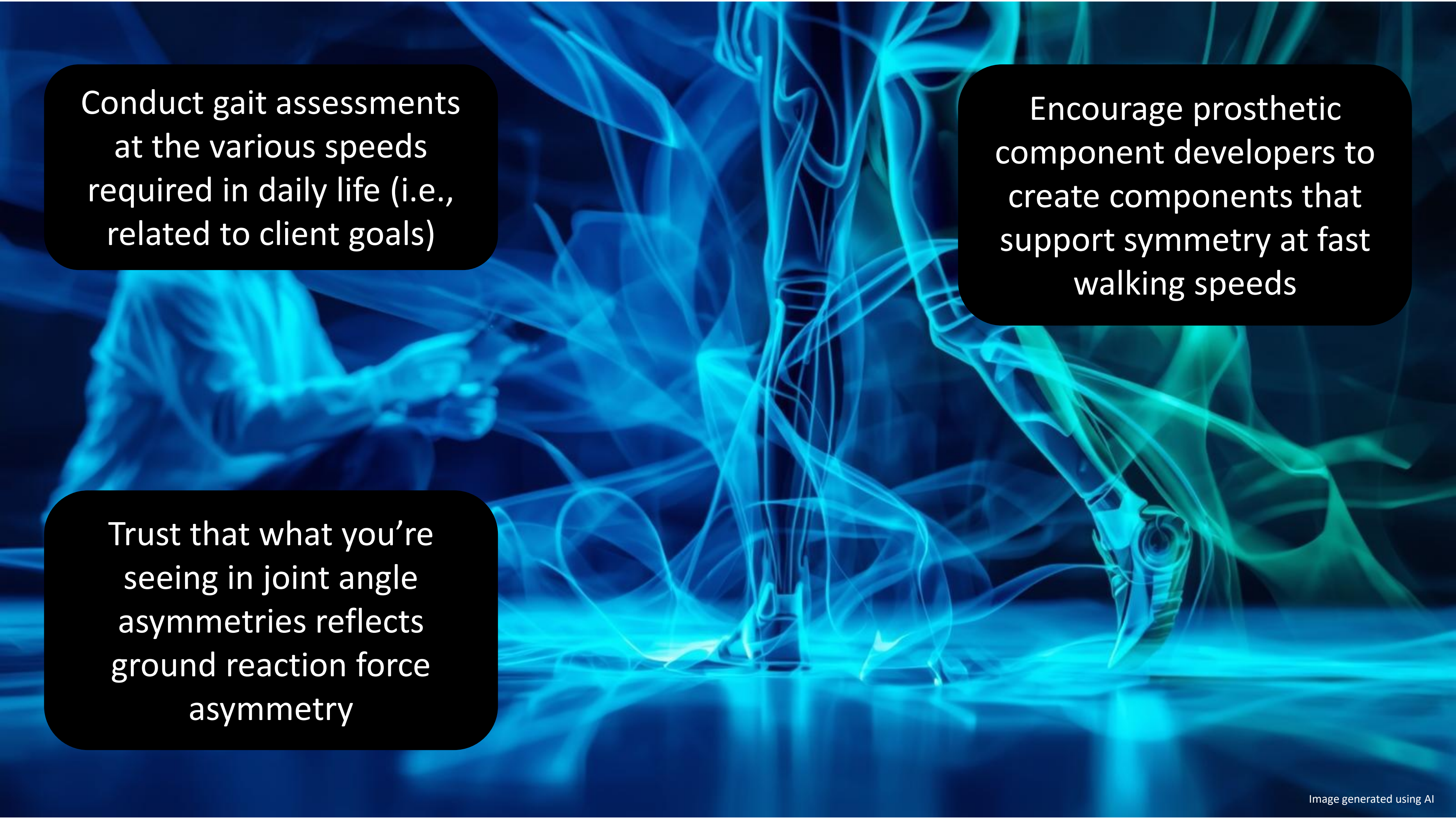
- Gait asymmetry is evident from both Symmetry Index (SI) related to ground force reactions and Dynamic Symmetry Function (SF) from motion tracking
- At slow walking speeds, the main asymmetry is heel strike
- Asymmetry in other gait phases increases with walking speed

1. Shi, Q-Q., & Yick, K-L. (2024). Evaluating the impact of prosthetics on gait symmetry in unilateral lower limb amputees. *Human Dynamic, Product Evaluation & Quality, 131*, 81-89.

Conduct gait assessments at the various speeds required in daily life (i.e., related to client goals)

Encourage prosthetic component developers to create components that support symmetry at fast walking speeds

Trust that what you’re seeing in joint angle asymmetries reflects ground reaction force asymmetry



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Transfemoral amputees have high instability at lower than comfortable walking speeds[1]

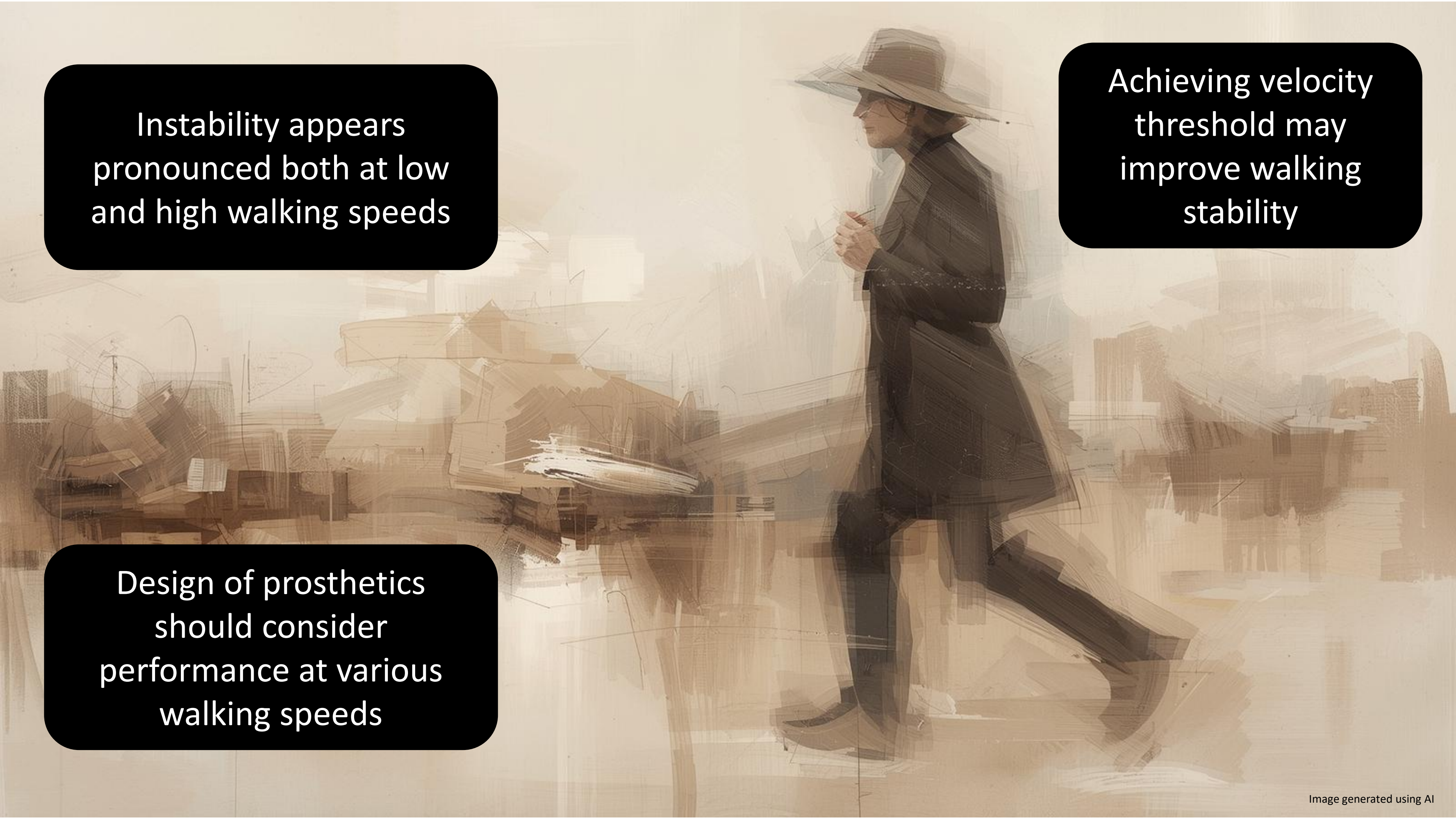
Study design: biomechanical lab study (n=8 TF with Genium X3 knees, 8 controls) using motion capture with Fuzzy Entropy modelling, Lyapunov Exponents and Probabilistic Principal Component Analysis

Level of evidence: moderate

Key take-home messages:

- Slower than comfortable walking (1km/hr) is particular unstable in amputees (compared with 2 & 3 km/hr)
- Stability of the prosthetic side is prioritised in walking with compensatory adjustment in the intact side
- Changes in gait are distributed about the body (including trunks and arms)

1. Krauskopf, T., Pelke, F., Meyer, B., et al. (2025). Altered gait stability and regularity in lower limb amputees observed across different body segments. *Journal of Biomechanics, 186*, 112723.



Instability appears pronounced both at low and high walking speeds

Achieving velocity threshold may improve walking stability

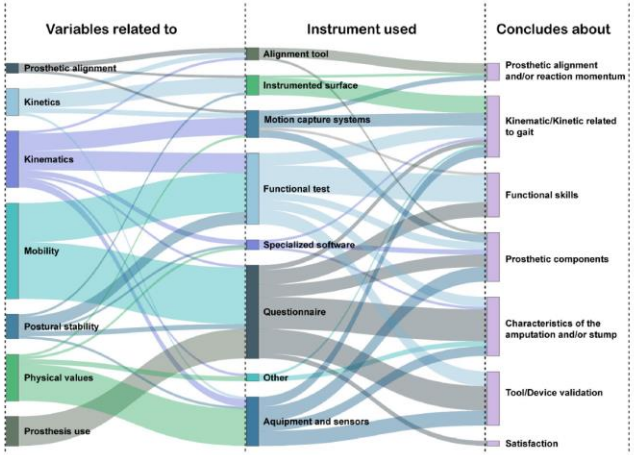
Design of prosthetics should consider performance at various walking speeds

Image generated using AI

Outcome measure options[1]

Study design: ‘systematic review’ of lower limb prosthetic outcome measures

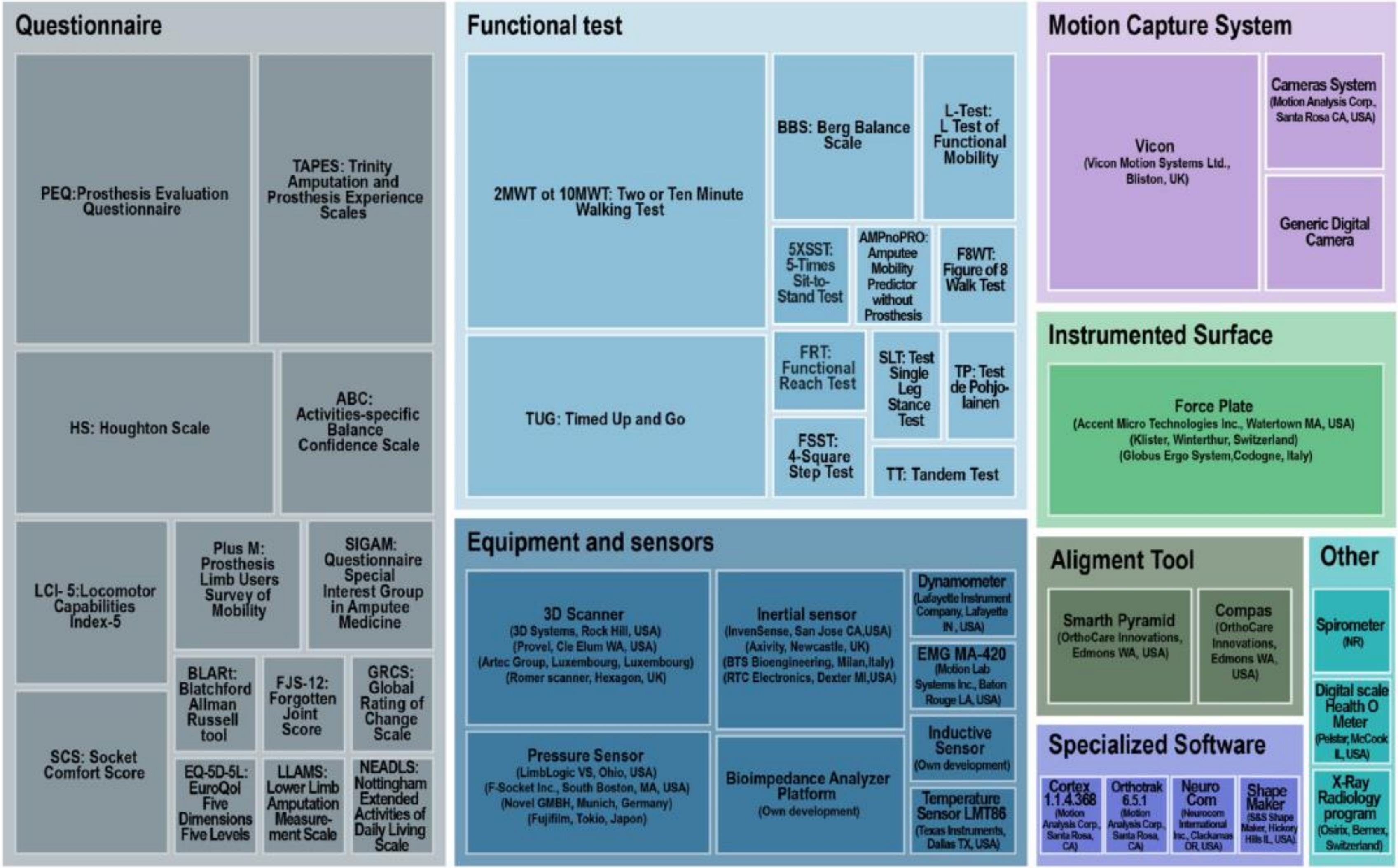
Level of evidence: emerging



Key take-home messages:

- Multiple tools can be used to measure each outcome.
- Outcomes include prosthetic alignment, gait kinematics, functional skills, prosthetic components, residual limb characteristics, and satisfaction.
- Some tools are used more commonly than others.

1. Olaya-Mira, N., Gómez-Hernández, L.M., Viloria-Barragán, C., & Soto-Cardona, I.C. (2025). Methods to assess lower limb prosthetic adaptation: a systematic review. *Journal of NeuroEngineering & Rehabilitation, 22*, 100.


Questionnaire
PEQ:Prosthesis Evaluation Questionnaire
TAPES: Trinity Amputation and Prosthesis Experience Scales
HS: Houghton Scale
ABC: Activities-specific Balance Confidence Scale
LCI- 5:Locomotor Capabilities Index-5
Plus M: Prosthesis Limb Users Survey of Mobility
SIGAM: Questionnaire Special Interest Group in Amputee Medicine
BLARt: Blatchford Allman Russell tool
FJS-12: Forgotten Joint Score
GRCS: Global Rating of Change Scale
SCS: Socket Comfort Score
EQ-5D-5L: EuroQol Five Dimensions Five Levels
LLAMS: Lower Limb Amputation Measure-ment Scale
NEADLS: Nottingham Extended Activities of Daily Living Scale
Functional test
2MWT ot 10MWT: Two or Ten Minute Walking Test
BBS: Berg Balance Scale
L-Test: L Test of Functional Mobility
5XSST: 5-Times Sit-to-Stand Test
AMPnoPRO: Amputee Mobility Predictor without Prosthesis
F8WT: Figure of 8 Walk Test
TUG: Timed Up and Go
FRT: Functional Reach Test
SLT: Test Single Leg Stance Test
TP: Test de Pohjo-lainen
FSST: 4-Square Step Test
TT: Tandem Test
Motion Capture System
Vicon (Vicon Motion Systems Ltd., Bliston, UK)
Cameras System (Motion Analysis Corp., Santa Rosa CA, USA)
Generic Digital Camera
Instrumented Surface
Force Plate (Accent Micro Technologies Inc., Watertown MA, USA) (Klister, Winterthur, Switzerland) (Globus Ergo System,Codogne, Italy)
Equipment and sensors
3D Scanner (3D Systems, Rock Hill, USA) (Provel, Cle Elum WA, USA) (Artec Group, Luxembourg, Luxembourg) (Romer scanner, Hexagon, UK)
Inertial sensor (InvenSense, San Jose CA,USA) (Axivity, Newcastle, UK) (BTS Bioengineering, Milan,Italy) (RTC Electronics, Dexter MI,USA)
Dynamometer (Lafayette Instrument Company, Lafayette IN, USA)
EMG MA-420 (Motion Lab Systems Inc., Baton Rouge LA, USA)
Inductive Sensor (Own development)
Pressure Sensor (LimbLogic VS, Ohio, USA) (F-Socket Inc., South Boston, MA, USA) (Novel GMBH, Munich, Germany) (Fujifilm, Tokio, Japon)
Bioimpedance Analyzer Platform (Own development)
Temperature Sensor LMT86 (Texas Instruments, Dallas TX, USA)
Aligment Tool
Smarth Pyramid (OrthoCare Innovations, Edmons WA, USA)
Compas (OrthoCare Innovations, Edmons WA, USA)
Specialized Software
Cortex 1.1.4.368 (Motion Analysis Corp., Santa Rosa, CA)
Orthotrak 6.5.1 (Motion Analysis Corp., Santa Rosa, CA)
Neuro Com (Neurocom International Inc., Clackamas OR, USA)
Shape Maker (S&S Shape Maker, Hickory Hills IL, USA)
Other
Spirometer (NR)
Digital scale Health O Meter (Pelstar, McCook IL, USA)
X-Ray Radiology program (Osirix, Bernex, Switzerland)

Osseointegration improves mobility[1]

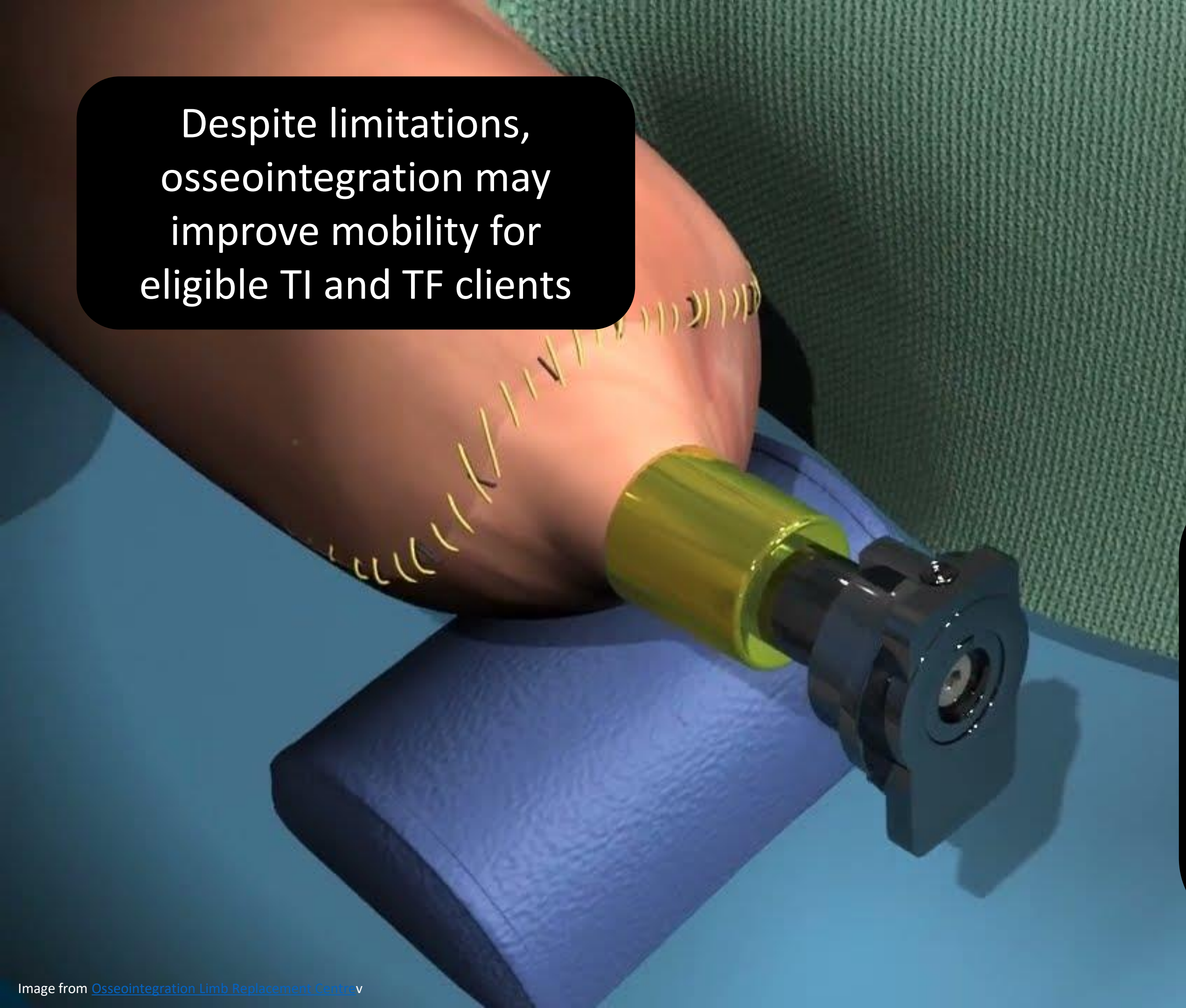
Study design: cross-sectional study (OI, n=30) compared with PLUS-M norms (socket based)

Level of evidence: emerging

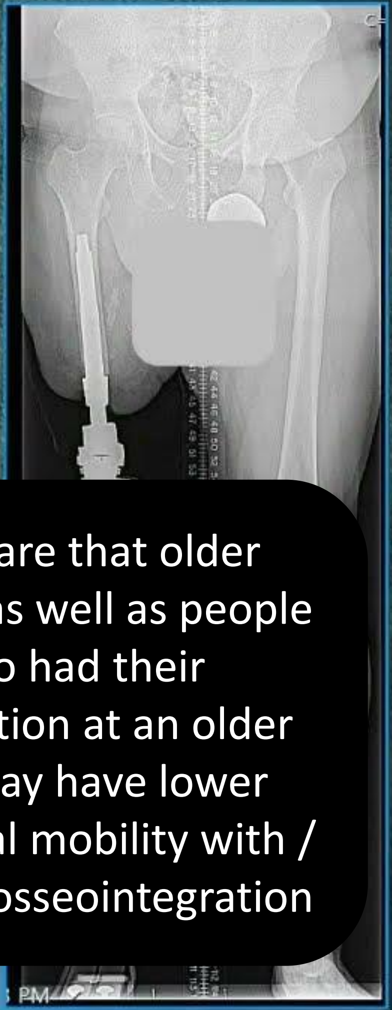
Key take-home messages:

- TT amputees (and possibly TF) amputees with OI had significantly better mobility than traditional-socket based norms
- PLUS-M scores were negatively correlated with age
- PLUS-M scores were negatively correlated with age at amputation

1. Page, B.J., Sheridan, G.A., Greenstein, M.D., Hoellwarth, J.S., Reif, T.J., & Rozburch, S.R. (2025). PLUS-M mobility values of osseointegration patients: how do osseointegration limb replacement prosthetic users compare to traditional socket amputee prosthesis users? *American Journal of Physical Medicine & Rehabilitation, 104*(8), 687-692.



Despite limitations, osseointegration may improve mobility for eligible TI and TF clients



Be aware that older people, as well as people who had their amputation at an older age, may have lower functional mobility with / without osseointegration

Image from Osseointegration Limb Replacement Centrev

Residual limb skin doesn't 'toughen up'[1]

Study design: cross-sectional study n=7 TFA, n=6 TTA, measured skin composition, thickness, roughness, inflammation, stiffness (indentation), and friction. Comparing residual limb, intact limb and plantar heel. Mean time since amputation = 27 years.

Level of evidence: moderate

Key take-home messages:

In residual limb

- Stratum corneum does not significantly thicken
- Skin becomes rougher, coefficient of friction increases
- Limb stiffness softens
- Natural moisturising factor and lipid content of skin reduce
- Water profile increases
- Inflammation factor increase but not significantly

1. Hayes, J., Andrews, J., Abdelwahab, O., et al. (2025). Skin adaptation in lower limb amputees assessed through Raman spectroscopy and mechanical characterization. *Interface, 22*, 20240475.

Residual limb skin does not develop properties similar to load-bearing skin (e.g., plantar skin). Don’t expect skin to ‘toughen up’.

Some skin changes (e.g., reduced stiffness, reduced lipid content) can put skin at risk

Image from Preuel

TENS for sensory feedback during mobility[1]

Study design: Phase 1: n=13 lab study mapping TENS sensations for tibial/sciatic nerve stimulation. Phase 2: Proof of concept trial n=1 TTA, n=1 TFA, 4 week testing of TENS feedback system for ground reaction forces

Level of evidence: emerging

Key take-home messages:

- TENS provides painless, reproducible sensations in the phantom limb
- Feedback from prosthetic foot sensors via TENS to residual limb appears to improve gait symmetry, reduce pain and neuropathic pain (case studies)
- Benefits increased over time
- TFA was slower to adapt compared to TTA

1. Demofonti, A., Germanotta, M., Zingaro, A., et al. (2025). Restoring somatotopic sensory feedback in lower limb amputees through noninvasive nerve stimulation. *Cyborg & Bionic Systems*, doi: 10.34133/cbsystems.0243

TENS-based biofeedback appears feasible and comfortable

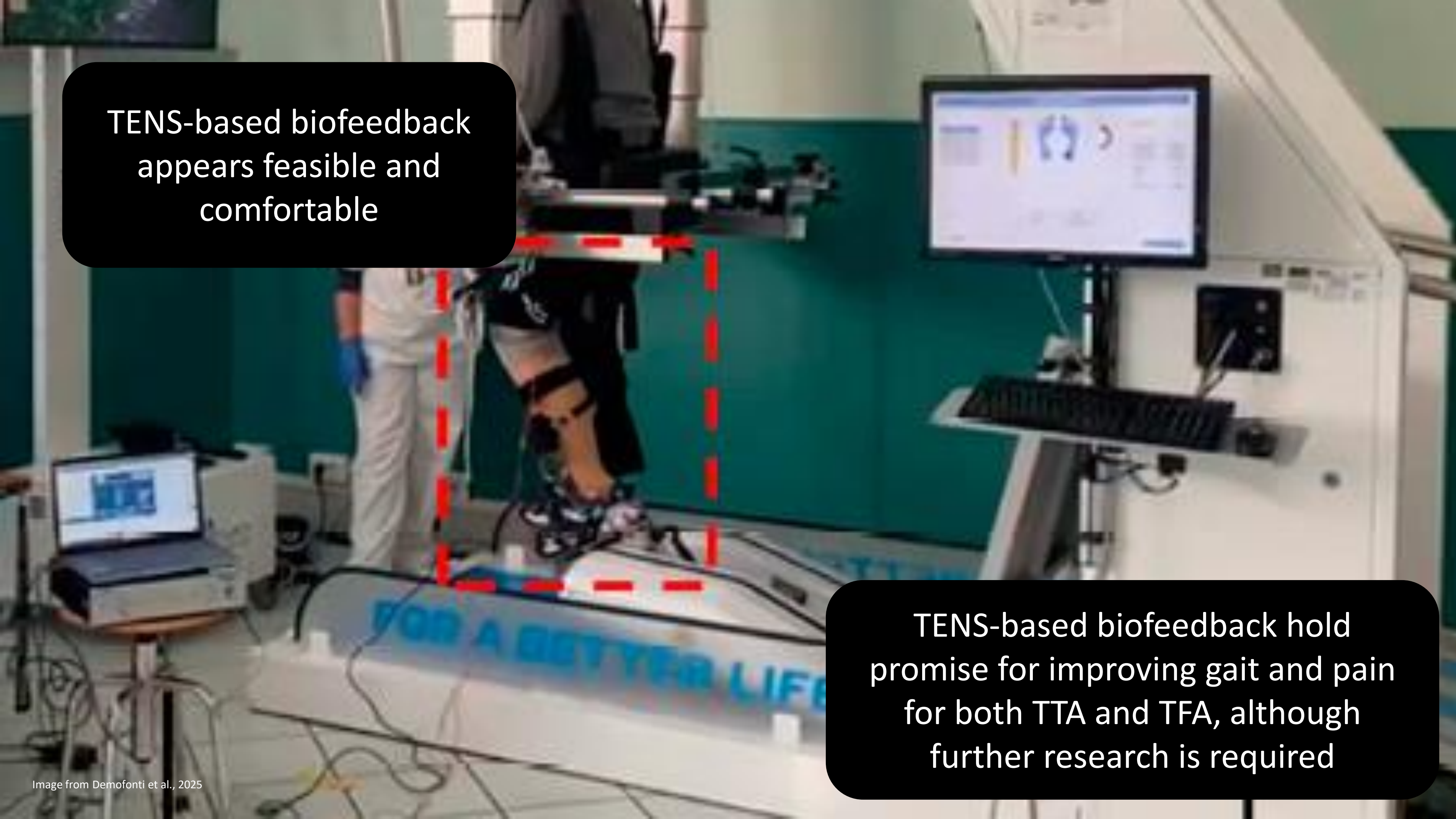


Image from Demofonti et al., 2025

TENS-based biofeedback hold promise for improving gait and pain for both TTA and TFA, although further research is required

Hybrid laminate feet (carbon, glass, linen) perform well[1]

Study design: mechanical testing and user testing (n=1) with foot fabricated from various laminates of perlon, carbon, glass, jute and linen

Level of evidence: emerging

Key take-home messages:

- Carbon-glass-linen laminates perform well across multiple parameters of strength, elasticity and fatiguability.

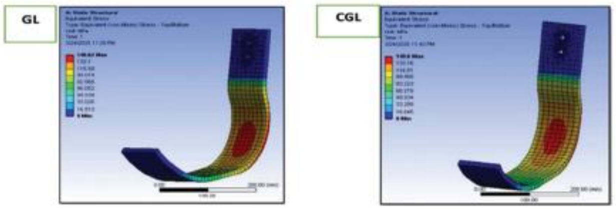
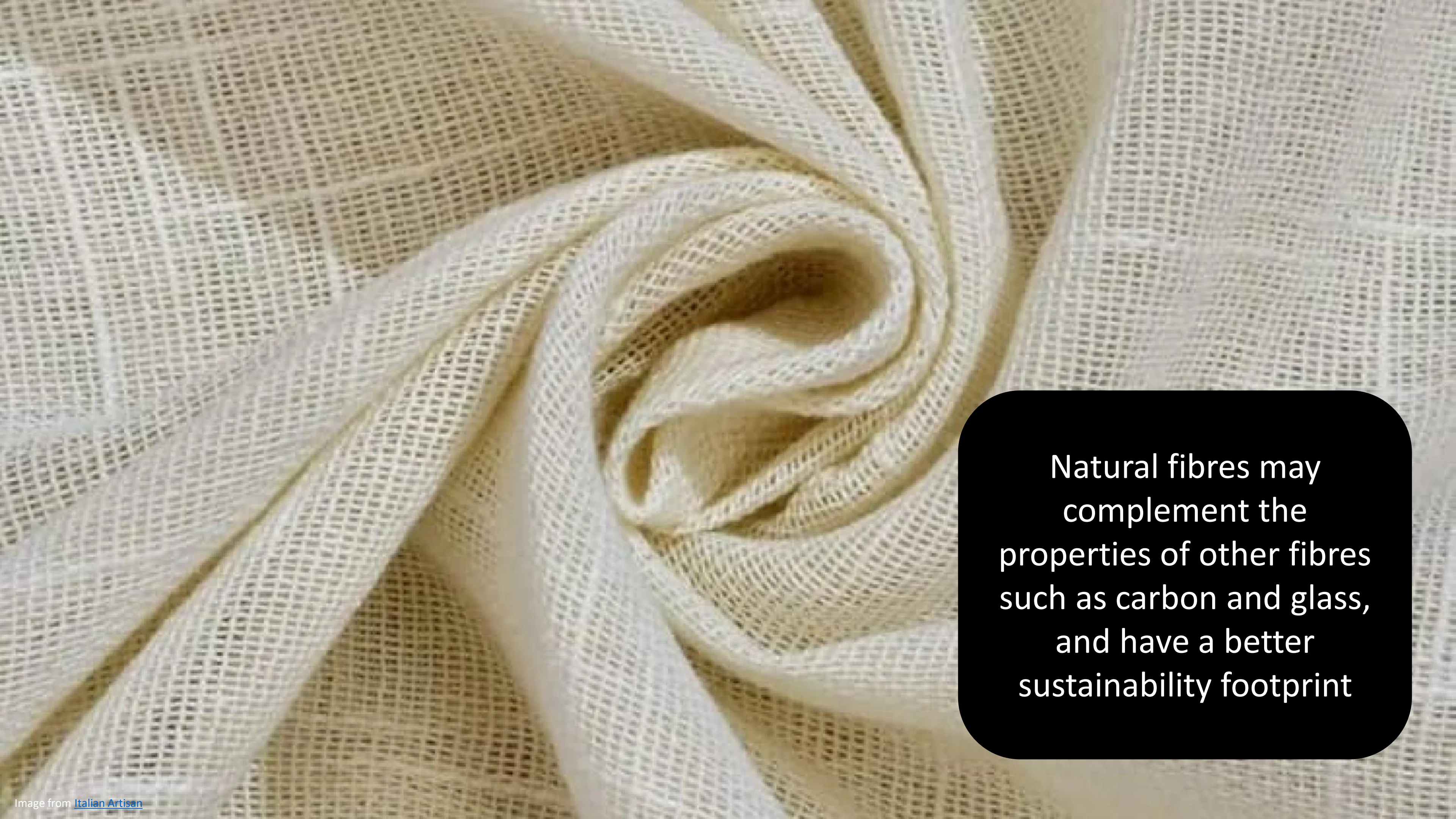


Figure17. Equivalentstressanalysis:(A)EquivalentvonMisesstressresults and (B) contour maps illustrating the distribution of von Mises stresses, including the expected locations and magnitudes of stress concentrations Abbreviations: C: Carbon; G: Glass; J: Jute; L: Linen.

1. Faheed, N.K., Issa, R.A-H., Hamad, Q.A., Jaafar, M.J., & Mahmood, M.S. (2025). Design and evaluation of a novel bioinspired prosthetic foot for running applications in lower limb amputees. *Biomaterials Translational*, doi: 10.12336/bmt.25.00016



Natural fibres may complement the properties of other fibres such as carbon and glass, and have a better sustainability footprint

Image from Italian Artisan

Ramie-fibre & polylactic-acid composites are worth exploring[1]

Study design: simulation using finite element analysis

Level of evidence: emerging

Key take-home messages:

- Ramie fibrr-reinforced polylactic-acid may be a future component material
- Ramie nearly twice as strong as linen
- Lower-cost, higher-biodegradability
- Simulation suggests performance within acceptable parameters.

1. Perkasa, M., Soemardi, T.P., Karmiadji, D., et al. (2025). Composite mechanics simulation for design of lower limb prosthetic using ramie fiber-reinforced polylactic-acid. *International Journal of Technology, 16*(2), 470-482.

Image from Non-conventional Fibre Association

Scanning & 3D printing sockets[1]

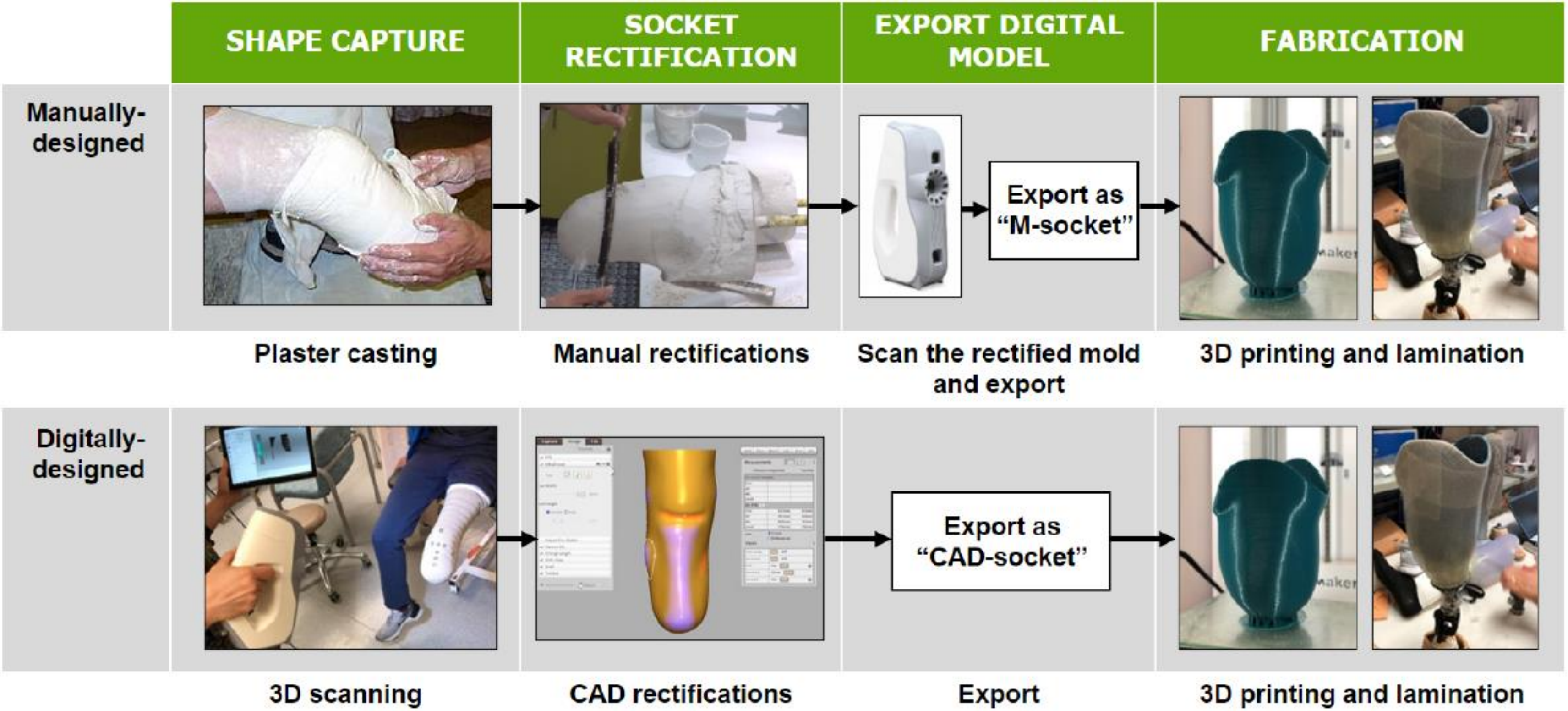
Study design: feasibility study (n=9 TTA) comparing manual casting & rectification vs digital scanning and rectification for 3D printed socket that is reinforced with fibreglass & resign

Level of evidence: emerging

Key take-home messages:

- 3D-printed, laminated prosthetics appear feasible
- A future full study is feasible
- Initial results show minimal difference in socket geometry and comfort
- 8 of 9 preferred 3D scanning to plaster casting

1. Eshragi, A., Phillips, C., MacKay, C., et al. (2024). Comparison of socket geometry, socket comfort, and patient experience between manually- and digitally-designed prosthetic sockets for lower-limb amputees: a feasibility study. *Prosthesis, 6*, 672-682.


SHAPE CAPTURE
SOCKET RECTIFICATION
EXPORT DIGITAL MODEL
FABRICATION
Manually-designed
Export as "M-socket"
Plaster casting
Manual rectifications
Scan the rectified mold and export
3D printing and lamination
Digitally-designed
Export as "CAD-socket"
3D scanning
CAD rectifications
Export
3D printing and lamination

Sockets made from Single Polymer PET meet ISO10328[1]

Study design: mechanical testing (comparative to single polymer PLA and dual polymer carbon & fibreglass) and user testing (n=7 of SPET)

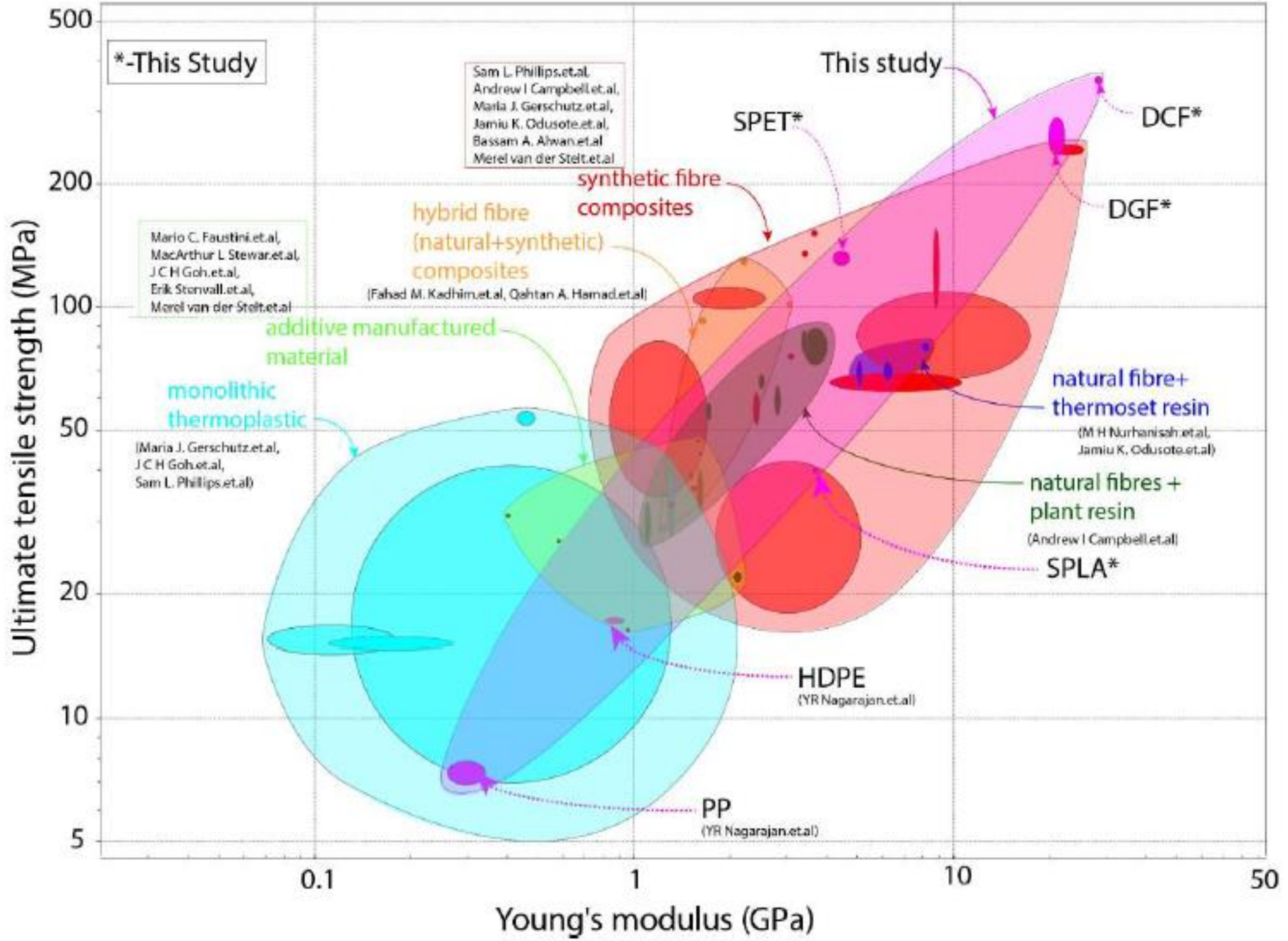
Level of evidence: emerging

Key take-home messages:

Compared to dual polymer fibreglass/carbon or carbon-fibre-braided-carbon-fibre lamination;

- Self-reinforced polyethelene terephthalate (SPET) sockets have similar strength
- SPET is heavier
- SPET is significantly cheaper, recyclable and mouldable after fabrication
- SPET failure was plastic (not brittle)
- Single polymer PLA is inferior

1. Nagarajan, Y.R>, Furukh, F., Buis, A., & Kandan, K. (2024). Single polymer composites: an innovative solution for lower limb prosthetic sockets. *Prosthesis, 6*, 457-477.



Young's modulus is a measure of stiffness

Watch this space for further development

Outcome measures for prosthetic intervention health economic evaluations[1]

Study design: Review of outcome measures that reflect the PI-COS (outcomes of importance to prosthetic users)

Level of evidence: moderate

Key take-home messages:

- A wide range of outcome measures were identified that can be used for economic evaluations linked to prosthetic interventions
- EQ-5D and PROMIS provide both broad and relevant coverage

1. Clarke, L., Ridgewell, E. & Dillon, M.P. (2025). Content comparison of utility and effectiveness instruments to the Prosthetic Inventions Core Outcome Set: a step to inform the benefits measured in lower-limb prosthetic health economic evaluations. *Disability & Rehabilitation, 47*(7), 1861-1871.

If looking to conduct an economic evaluation, use this study to help guide selection of outcome measures

Image generated using AI

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