Optimizing Digital Workflow in Upper-Limb Prosthetics: Validation of an Automated Limb-Socket Alignment Algorithm

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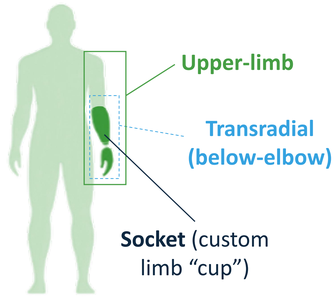
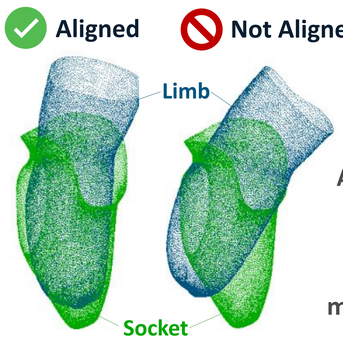
Background

For individuals with upper-limb absence, the **prosthetic socket** directly affects **device comfort, control, and adoption** [1-3].





Alignment between the residual limb and socket influences the overall device comfort and functionality, yet **no reliable method exists for assessment** [4].

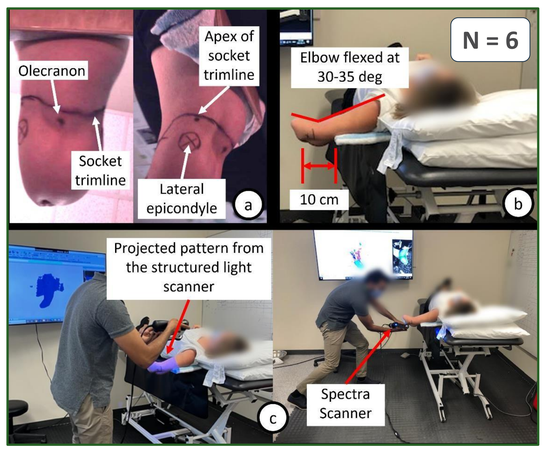
- An **automated algorithm** was developed to address gap
- This algorithm has yet to be **validated**

Research Question

*How does an **automated limb-socket alignment algorithm** compare **to real-world alignment by experienced clinicians (ground truth)**?*

Methods

1 3D- scanned limb & socket models



2 Aligned limbs and sockets using 2 methods

Clinician-based (real-world) | Algorithm-based

3 Computed alignment error using transformation matrices

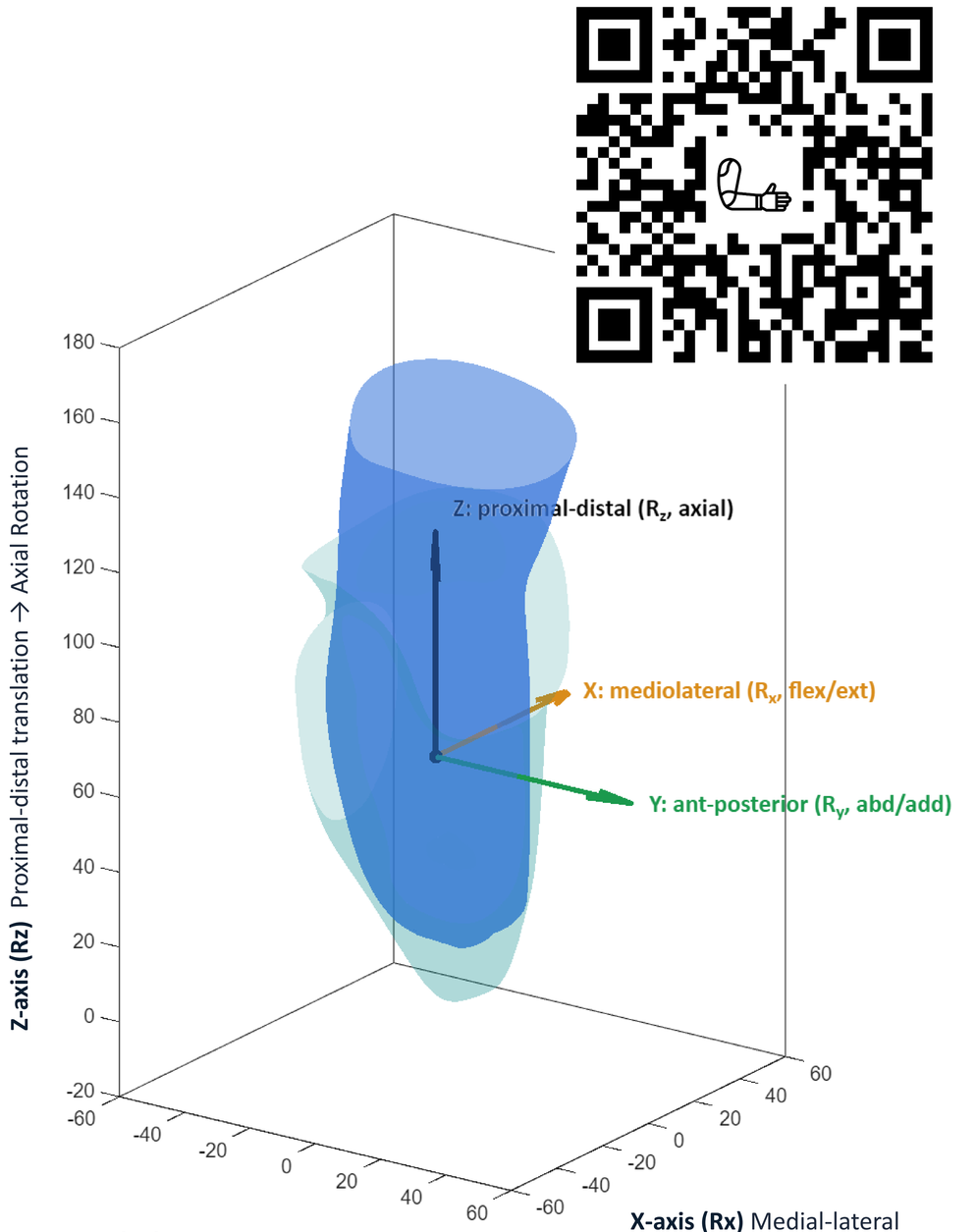
$$A_{Global} = A_1 * A_2 * A_3 * A_4$$

Rotation Matrix; Vector (Origin to Origin); Scale

$$A_{Global} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & O_x \\ r_{21} & r_{22} & r_{23} & O_y \\ r_{31} & r_{32} & r_{33} & O_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

4 Determined descriptive statistics per axis

An automatic way to correctly position the residual limb into a prosthetic device, optimizing patient comfort.

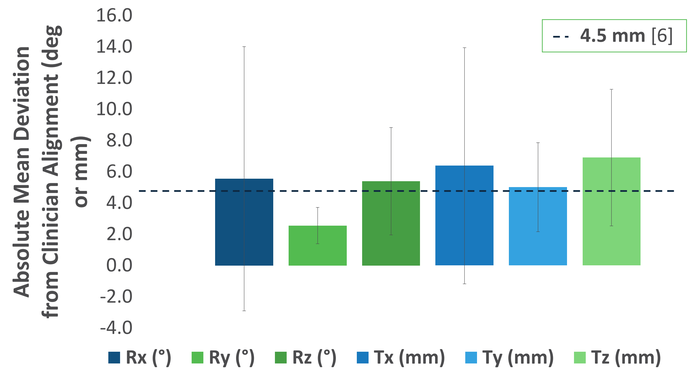


Y-axis (Ry) Anterior-posterior translation → Abduction/Adduction

X-axis (Rx) Medial-lateral translation → Flexion/Extension

Results

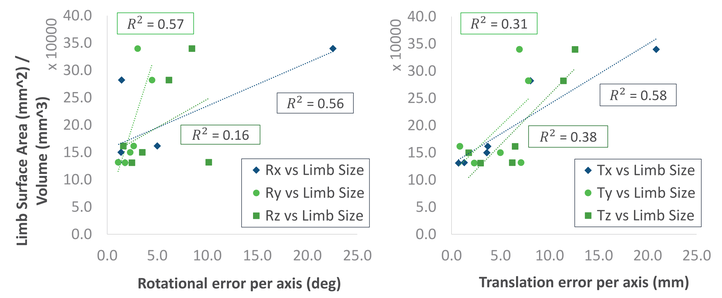
Descriptive Statistics: Absolute Mean + Standard Deviation



Alignment errors outside clinical threshold of **< 4.5 mm** [6].

Flexion/extension (Rx) exhibited the largest deviations in rotation ($5.5 \pm 7.8°$).

Correlation Analysis: Alignment Errors vs Limb Size



Correlation observed between alignment errors + limb size varies across axes (R^2 **= 0.16 to 0.58**).

Findings suggest algorithm performance is mostly **independent** from limb size.

Discussion & Next Steps

Alignment errors outside clinical threshold	**Expand alignment landmarks to entire surfaces to improve accuracy of placement.**
Largest errors in Flexion/extension	**Resolving the worst performing angular alignment (Rx) may also improve YZ-positioning.**
Current sample size limitations	**Retest with a larger sample size to confirm statistical patterns.**

Clinical Impact

Good limb-socket alignment for patients leads to **better fit and device adoption**.

More consistent care by initializing a **data-driven approach** for socket alignment.

Supports **Holland Bloorview's digital workflow** adoption to improve **access** and **efficiency** [7-9].

Acknowledgements

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[1] Asokan & Saber 2023 [2] Lake 2008 [3] Biddiss & Chau 2007 [4] Paterno et al. 2018 [5] Ngan et al. 2022 [6] Dickinson et al. 2022 [7] Olsen et al. 2022 [8] Won et al. 2022 [9] Ngan et al. 2022