Balgrist
University Hospital

# Dynamic tracking of anterior tibiofibular distance during external rotation – A cadaveric syndesmotic injury model

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# DISCLOSURES

Nothing to disclose

# INTRODUCTION

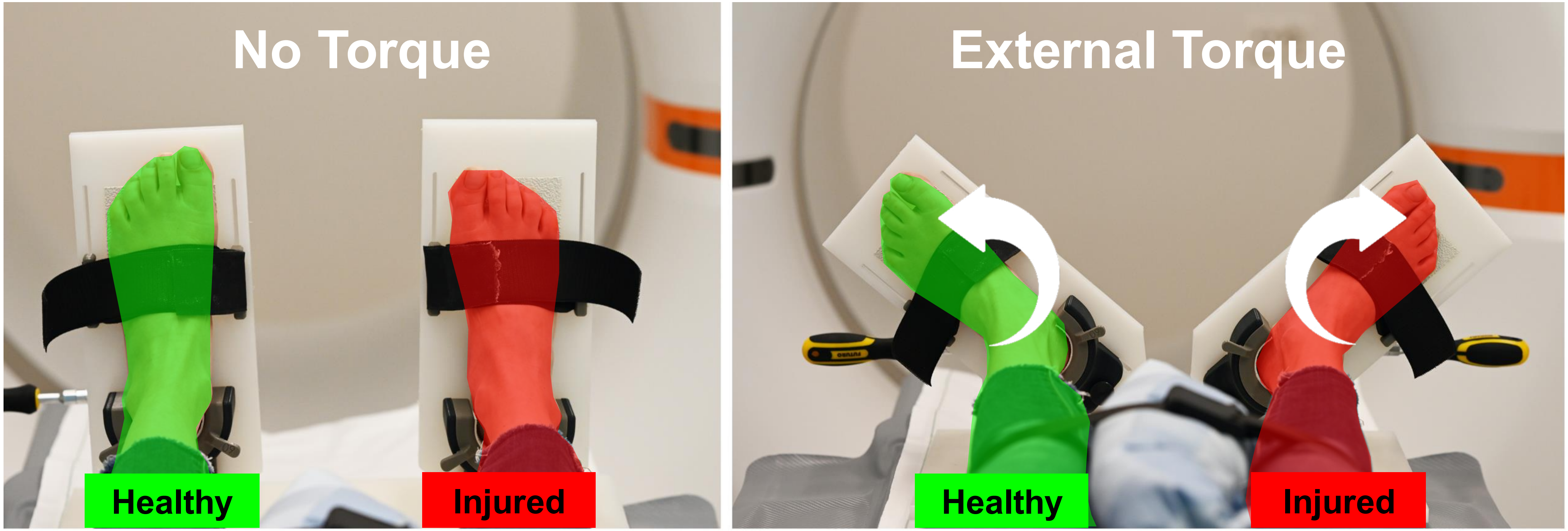
- Distal tibiofibular instability
- Pain and Osteoarthritis
- Diagnostic challenges

This is an AI generated Illustration. OpenAI 2026


1) Gribble PA, Br J Sports Med 2016

2) Lubberts B, Foot Ankle Int 2020

# INTRODUCTION




1) Beeler S, JBJS Am 2024

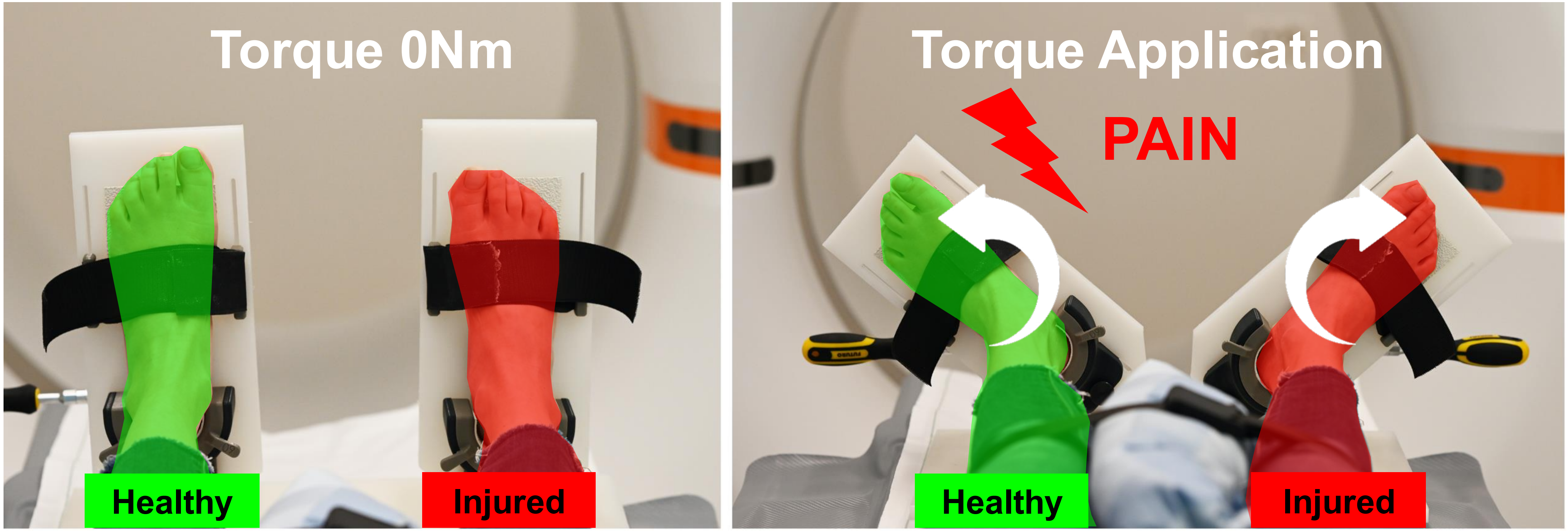
2) Calek A, Foot Ankle Int 2024

# INTRODUCTION

Delta
Anterior Distance
*(AD mm)*

1) Beeler S, JBJS Am 2024
2) Calek A, Foot Ankle Int 2024

# INTRODUCTION




1) Beeler S, JBJS Am 2024

2) Calek A, Foot Ankle Int 2024

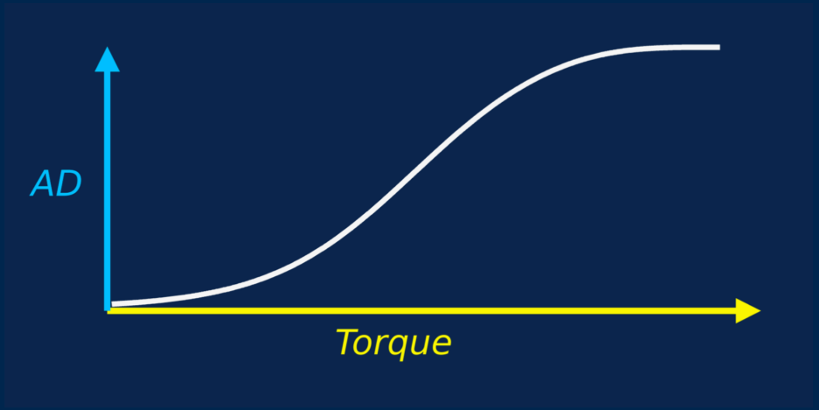
# STUDY AIM / HYPOTHESIS

## STUDY AIM

Dynamics of the Anterior Distance during continuous torque measurements

## HYPOTHESIS

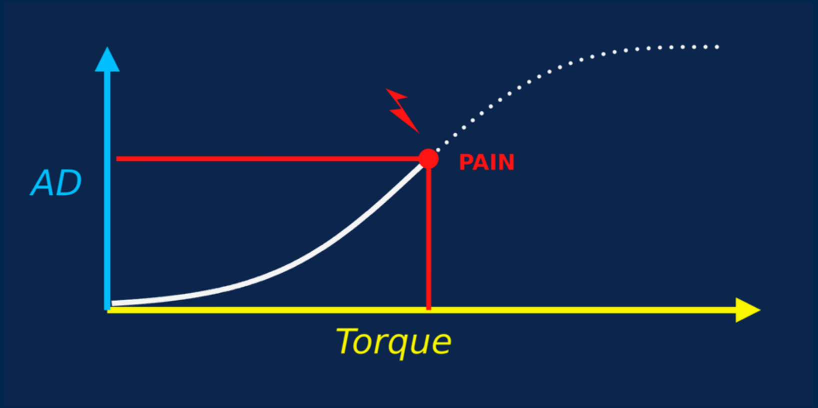
Expected “gompertz” curve for syndesmotic instability



# STUDY AIM / HYPOTHESIS

**CLINICAL AIM**

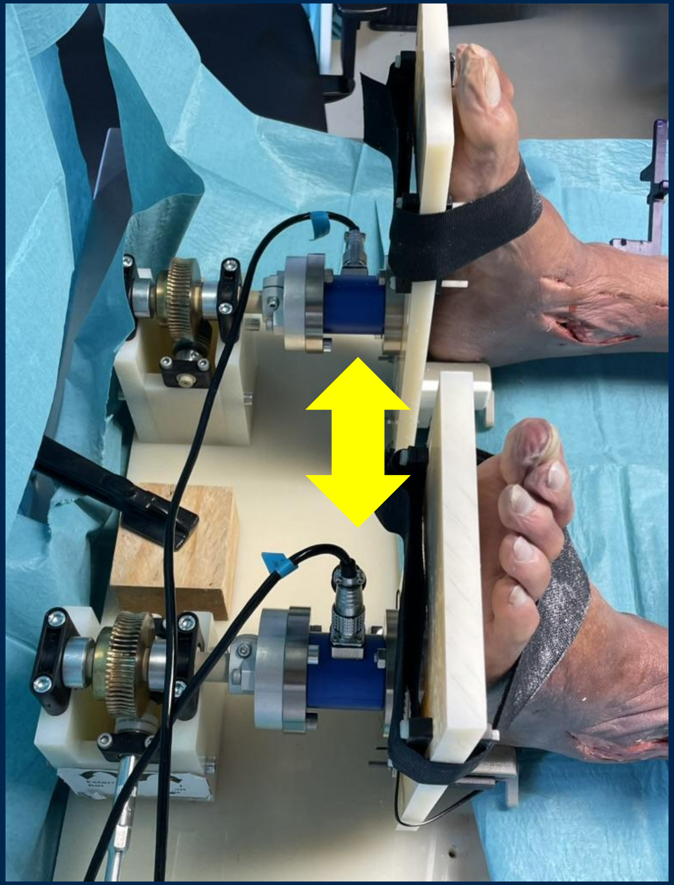
Detection of tibiofibular instability at low torque levels



# METHODS

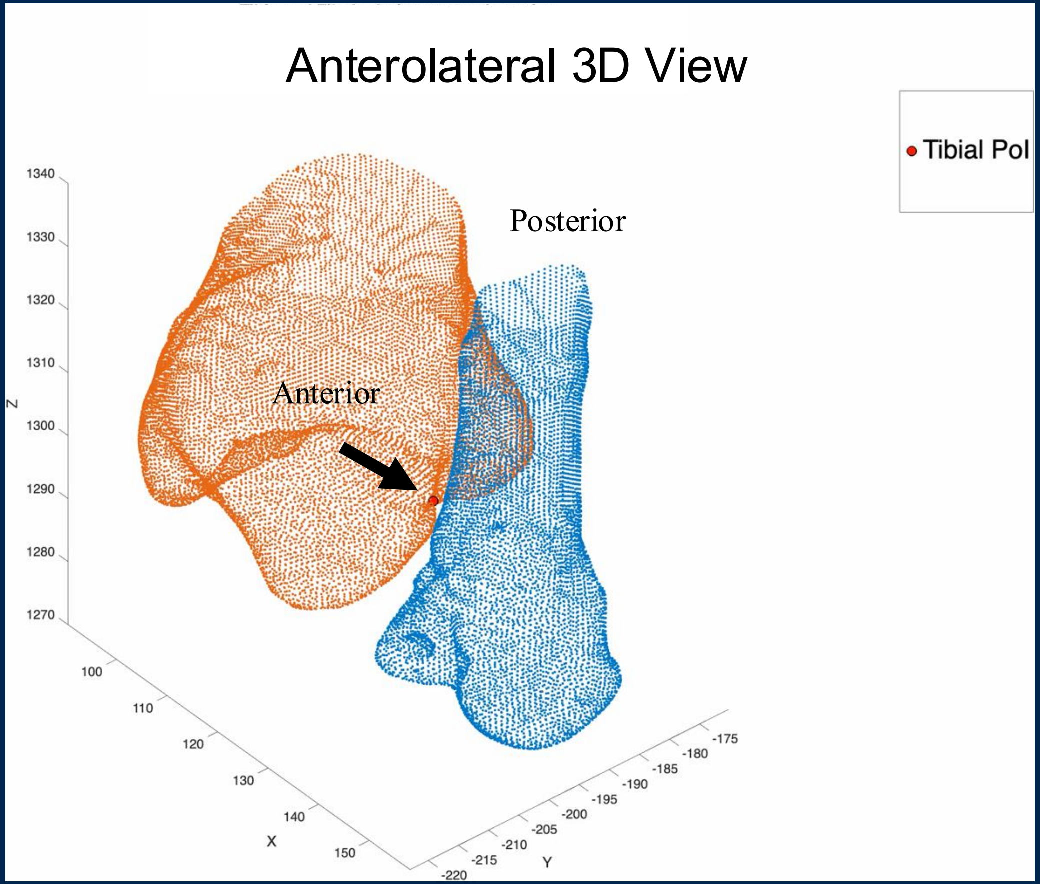
- n = 11
- Syndesmotic lesion
- AD measurement with CT
- AD measurement with Motion Tracking

Torque Sensor

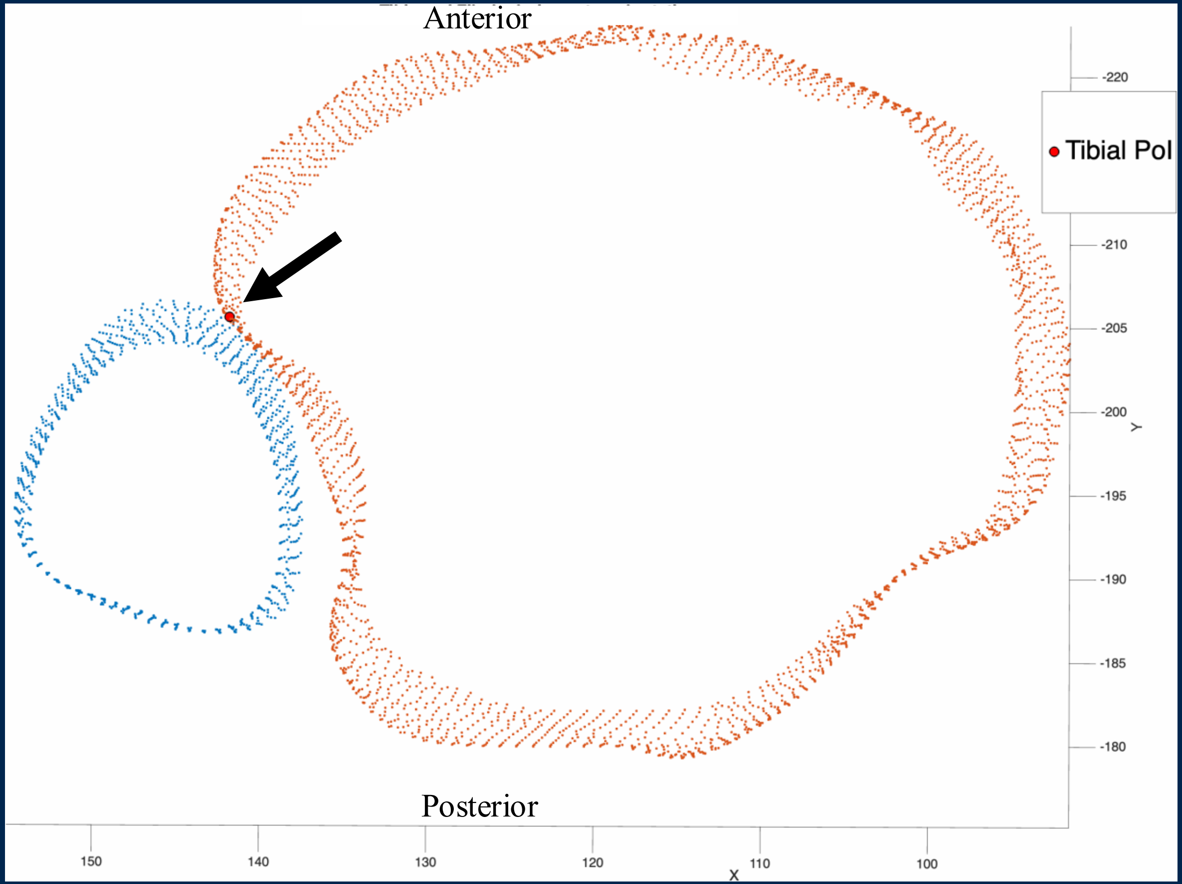


Motion Marker

# METHODS

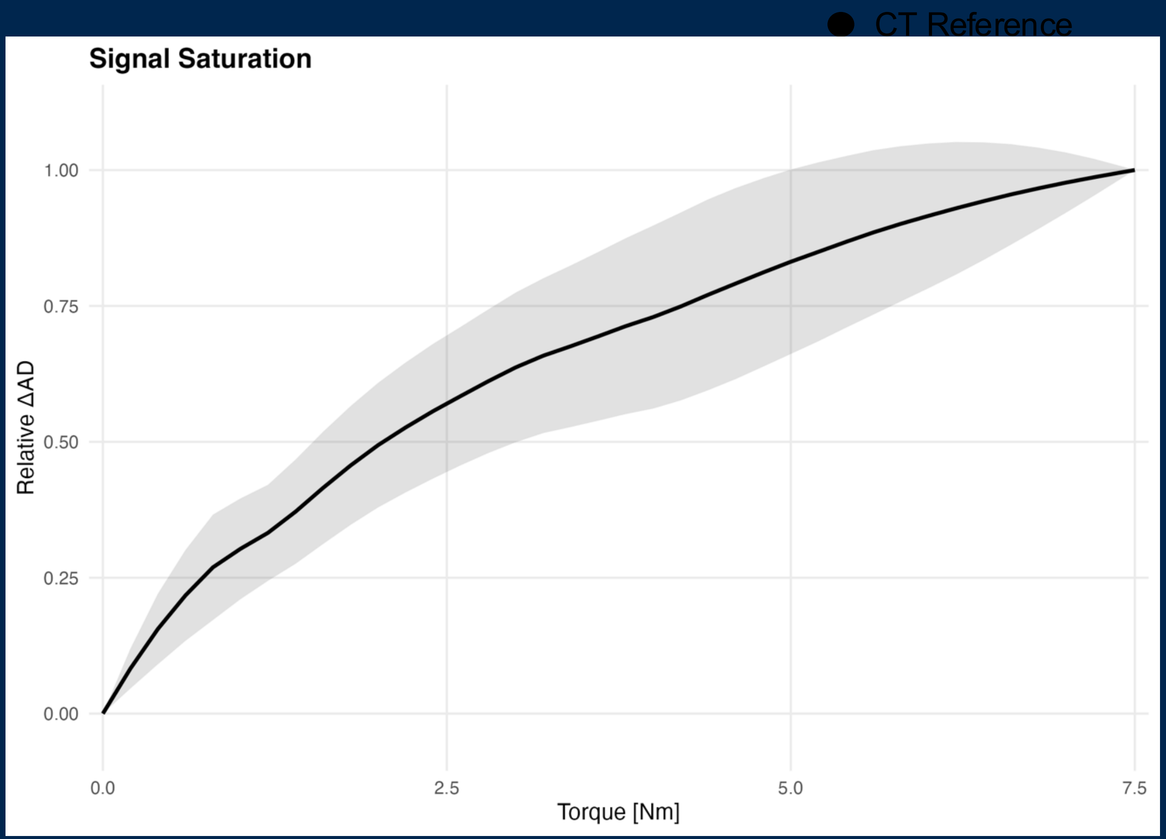



Axial View



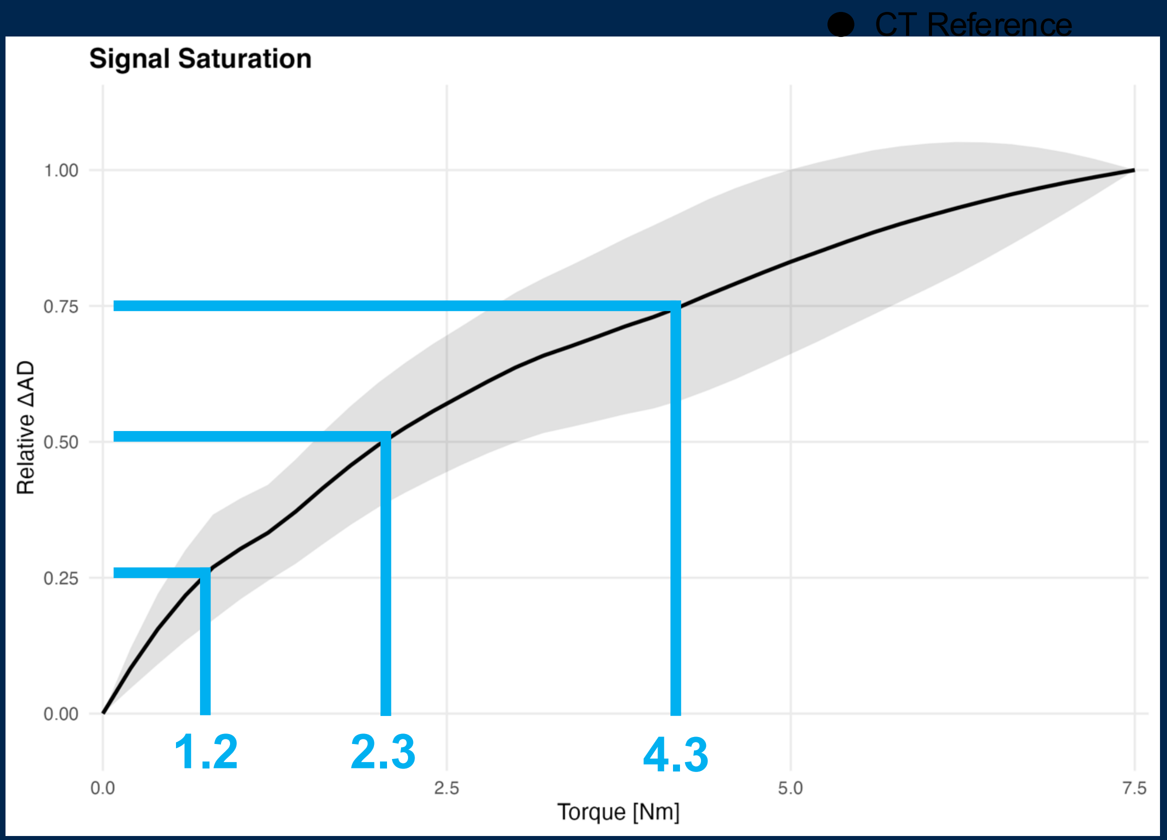
# RESULTS

No “gompertz” curve, but a digressive curve type.

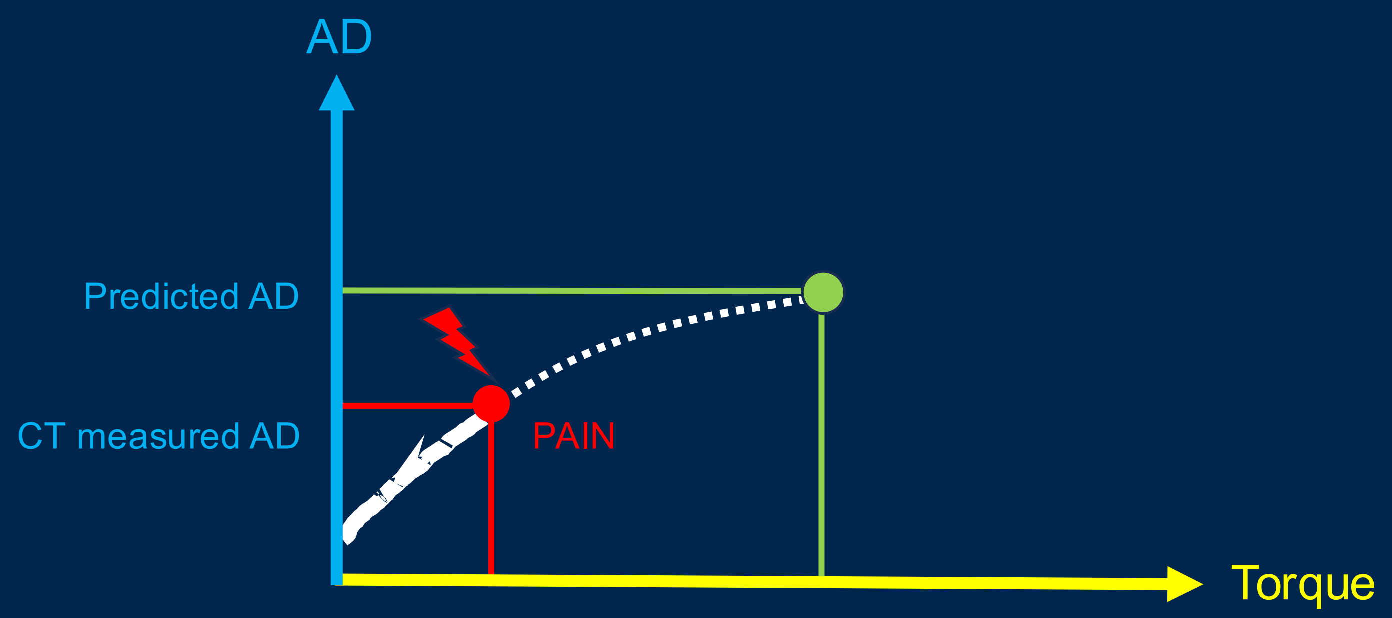


# RESULTS

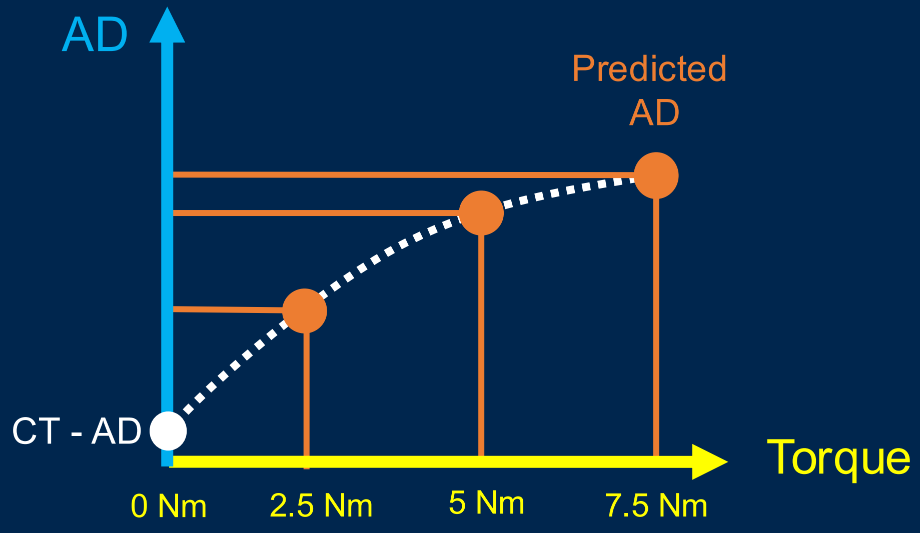
Low torque reveals a large portion of tibiofibular instability



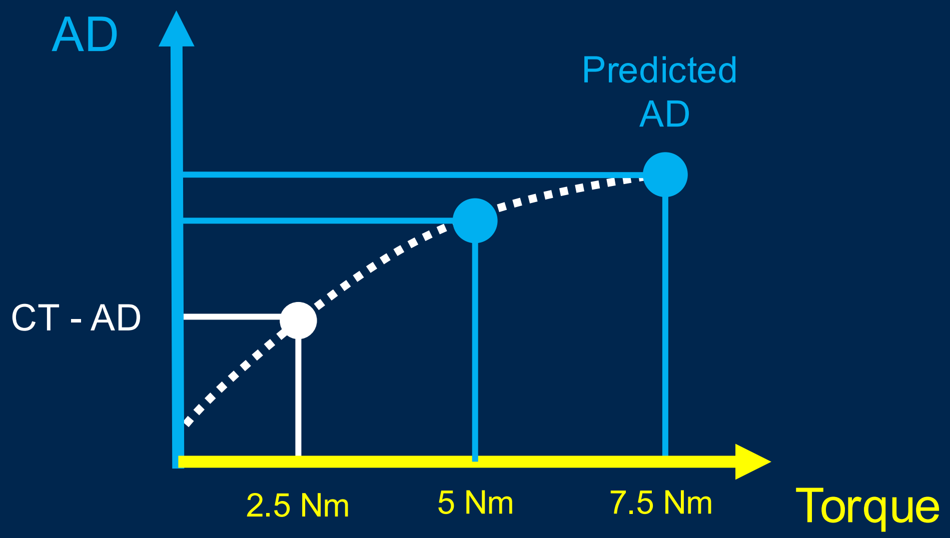
# Results



# RESULTS

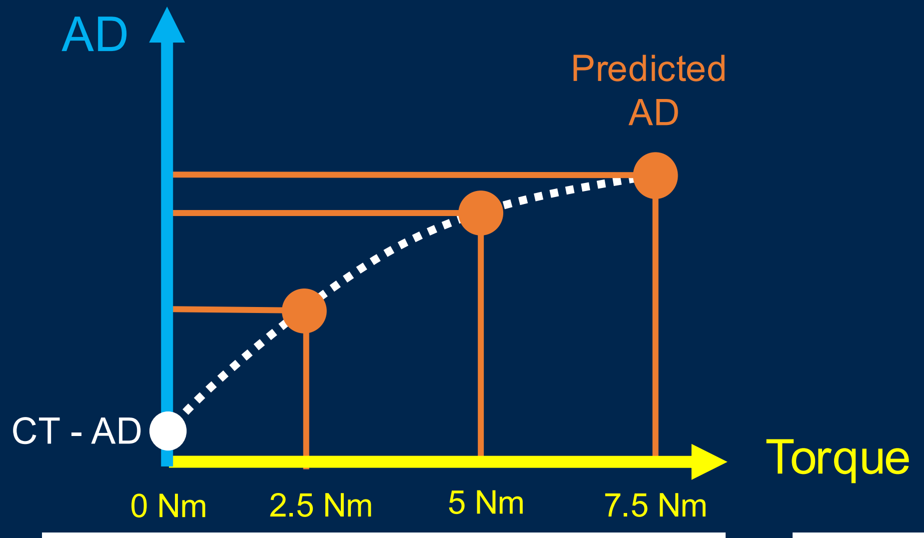


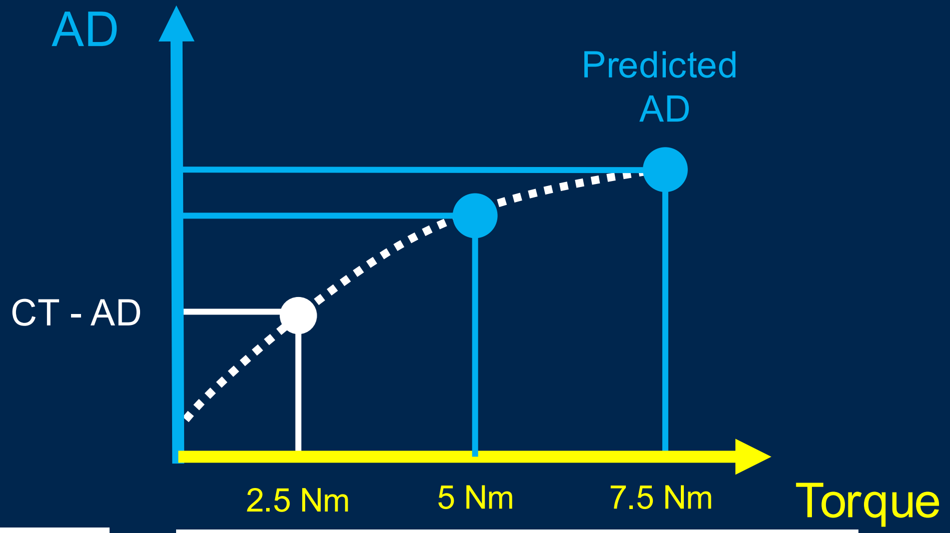
AD
Predicted
AD
CT - AD
Torque
0 Nm
2.5 Nm
5 Nm
7.5 Nm

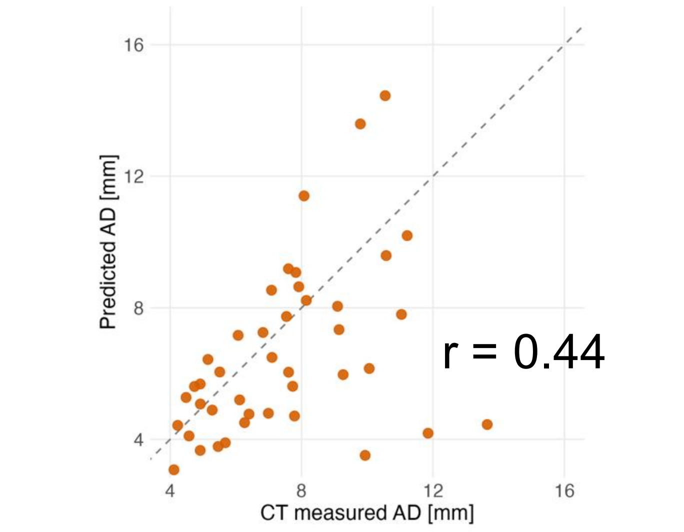



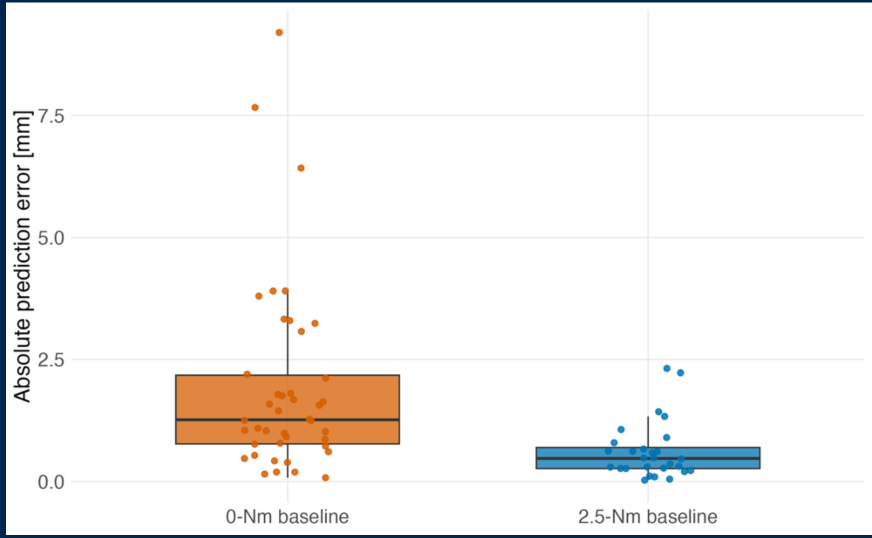
AD
Predicted
AD
CT - AD
2.5 Nm
5 Nm
7.5 Nm
Torque

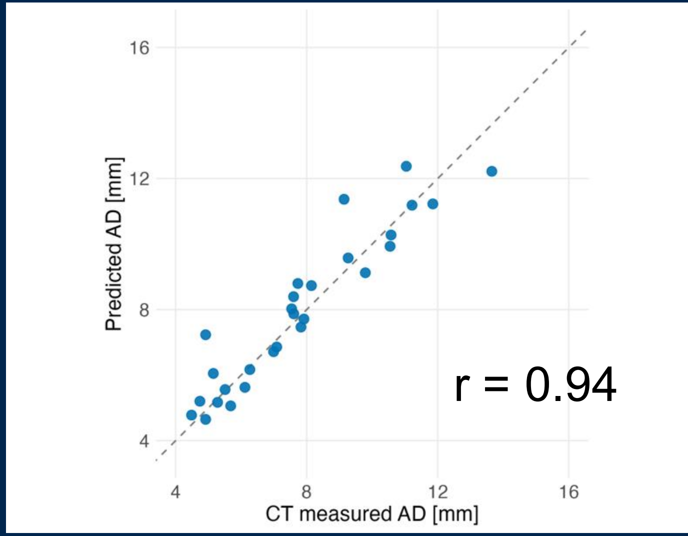
# RESULTS


AD
Predicted
AD
CT - AD
Torque
0 Nm
2.5 Nm
5 Nm
7.5 Nm


AD
Predicted
AD
CT - AD
2.5 Nm
5 Nm
7.5 Nm
Torque


16
12
8
4
Predicted AD [mm]
4
8
12
16
CT measured AD [mm]
r = 0.44


Absolute prediction error [mm]
7.5
5.0
2.5
0.0
0-Nm baseline
2.5-Nm baseline


16
12
8
4
Predicted AD [mm]
4
8
12
16
CT measured AD [mm]
r = 0.94

# LIMITATIONS

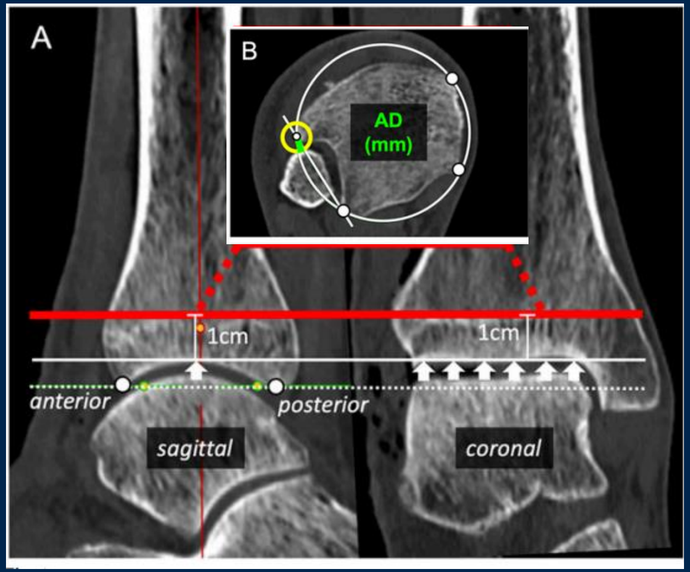
- Small sample size (n=11)
- No continuous measurement of intact contralateral side
- No muscle tension

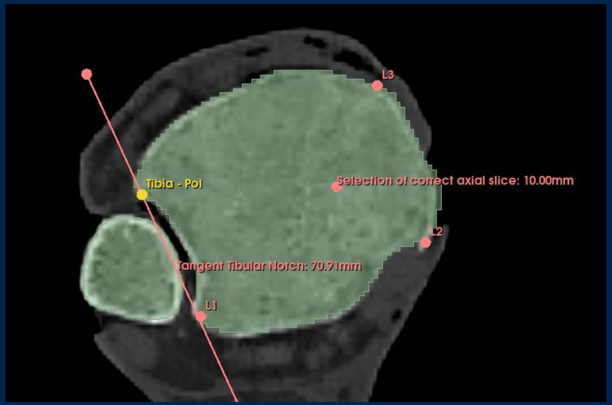
# CONCLUSION

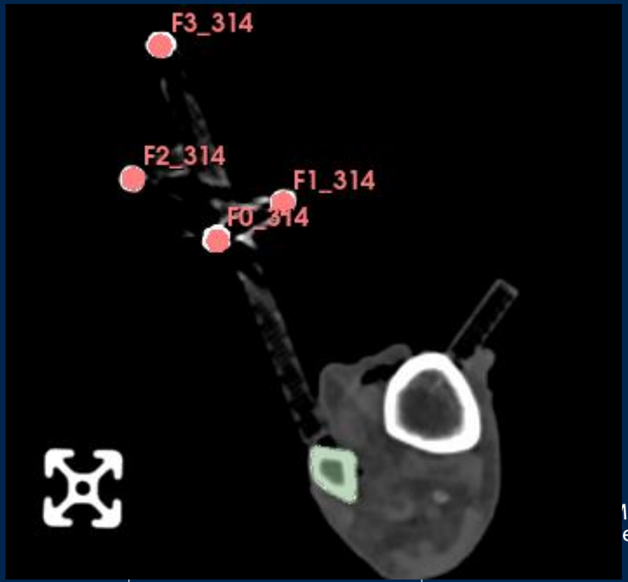
- Degressive curve type
- 50% of the maximum tibiofibular divergence is already reached at only 2.3Nm
- No need for high torque examinations in complete syndesmotic lesions

# APPENDIX

# ANALYSIS WORKFLOW

# Analysis workflow | High level

## Segmentation on CT

- Relevant **'objects' are segmented** on the CT
- This includes this **Fibula, the motion markers** and the landmarks to obtain the point of interest on the Tibia (circle + tangent tibular notch)
- The **point of interest is then calculated** by solving for the intersection between the circle around the tibia and the tangent along the tibular notch)

## CT registration

- **Three coordinate** systems are used in the calculations:
  - CT system
  - Camera system
  - Intrinsic marker system
- To 'apply' the obtained motion to the CT, a **coordinate transformation from CT to marker and/ or camera system** is required
- This registration is **based on singular value decomposition**

## Model of motion

- **Premise:** Motion markers and the bone they are screwed on form a rigid object
- The **measured orientation and translation** of the motion marker can therefore be applied to the connected bone

# Motion modelling (1/2) | Two mathematically sound options to model motion using motion marker data

Multiple coordinate systems exist in the motion tracking framework

- Camera coordinate system
- Intrinsic marker coordinate systen, where the Fiducial FO is located at the origin

With the motion tracking systen we measure for each marker m its orientation $\mathbf{R}^m_{\mathrm{Cam}}(t)$ and position $\vec{T}^m_{\mathrm{Cam}}(t)$ at a given time $t$. This yields the coordinate transformations between the representation in the intrinsic marker coordinate system $\vec{p}_m(t)$ and the corresponding representation in the camera system $\vec{p}_{\mathrm{Cam}}(t)$ as

$$\vec{p}_{\mathrm{Cam}}(t) = \mathbf{R}^m_{\mathrm{Cam}}(t) \cdot \vec{p}_m(t) + \vec{T}^m_{\mathrm{Cam}}(t) \tag{1}$$

Under the assumption that $\vec{p}_m(t) = \vec{p}_m$ remains fixed in the intrinsic marker system (e.g., any point rigidly connected to the marker) we can choose any fixed timestamp $t_0$, to write:

$$\vec{p}_m = \mathbf{R}^m_{\mathrm{Cam}}(t_0)^T \left[\vec{p}_{\mathrm{Cam}}(t_0) - \vec{T}^m_{\mathrm{Cam}}(t_0)\right]$$

This leads to:

$$\begin{aligned}\vec{p}_{\mathrm{Cam}}(t) &= \mathbf{R}^m_{\mathrm{Cam}}(t) \cdot \mathbf{R}^m_{\mathrm{Cam}}(t_0)^T \left[\vec{p}_{\mathrm{Cam}}(t_0) - \vec{T}^m_{\mathrm{Cam}}(t_0)\right] + \vec{T}^m_{\mathrm{Cam}}(t) \\ &= \mathbf{R}^m_{\mathrm{Cam}}(t) \cdot \mathbf{R}^m_{\mathrm{Cam}}(t_0)^T \left[\vec{p}_{\mathrm{Cam}}(t_0) - \vec{T}^m_{\mathrm{Cam}}(t_0)\right] + \vec{T}^m_{\mathrm{Cam}}(t_0) + \vec{T}^m_{\mathrm{Cam}}(t) - \vec{T}^m_{\mathrm{Cam}}(t_0)\end{aligned} \tag{2}$$

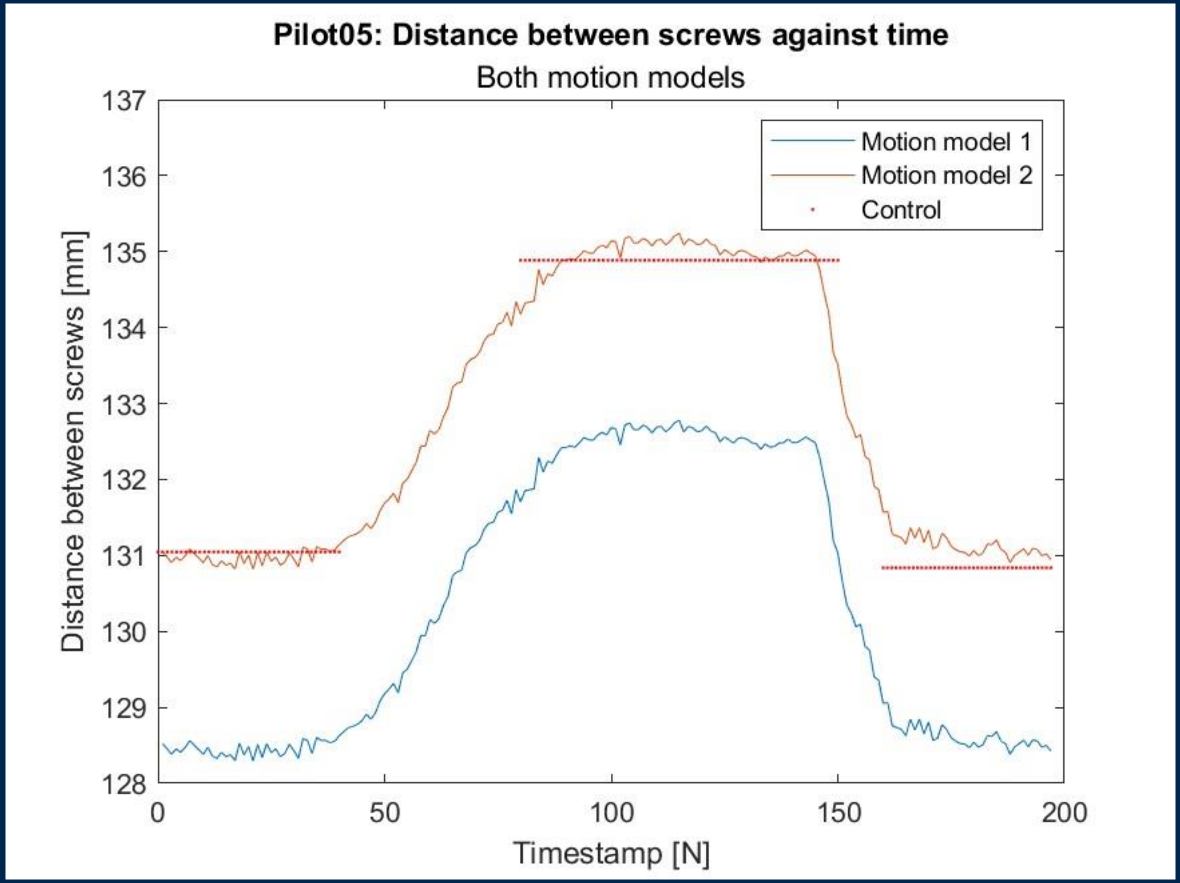
which can be understood applying motion to the initial position through a residual rotation and a residual translation:

- **Rotation** of $\mathbf{R}^m_{\mathrm{Cam}}(t) \cdot \mathbf{R}^m_{\mathrm{Cam}}(t_0)^T$ around the marker position $\vec{T}^m_{\mathrm{Cam}}(t_0)$ at $t_0$
- **Translation** of $\vec{T}^m_{\mathrm{Cam}}(t) - \vec{T}^m_{\mathrm{Cam}}(t_0)$

- If the CT is registered to the marker or camera system (meaning, the CT coordinates can be expressed in the marker/ camera coordinates) **formula 1** (marker system) or **formula 2** (camera system) can be applied to anatomical points visible in the CT
- **Note:** Inaccuracies can arise due to **noise in the selection of points for registration** via SVD

# Motion modelling (2/2) | The motion require ‘different’ registration between coordinate systems

# CONTROL MEASUREMENT




**Description of the measurement:**

Two screws are fixated onto Tibula resp. Fibula and used as control measurement

At the end points of the applied foot rotation the distance between the screws is measured

The measured distance is compared to the reconstruction using the motion marker frameworks

**Qualitative findings:**

**Overall good match** between the reconstructed distances and the control measurement

**Differences** between the two calculation methods:

- Constant offset, however, evolution/ behavior over time is almost identical
- Most likely driven by uncertainties in the registration process

High **sensitivity to initial CT segmentation**

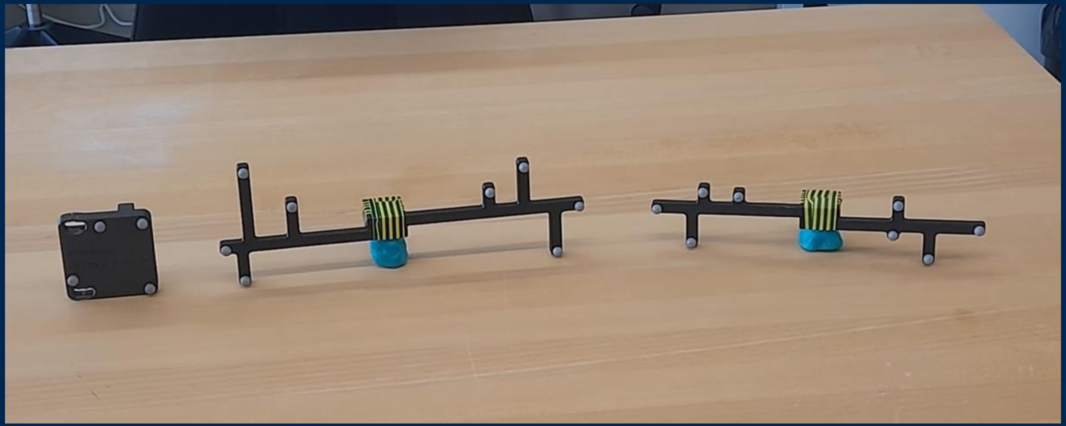
# APPENDIX A – UNCERTAINTIES OF MARKER FRAMEWORK

# PTENTIAL “ERROR” SOURCES

| | **Root cause** | **“Size” of error** | **Comments** |
|---|---|---|---|
| **Calculation** | Wrong calculation logic | n/a | Unlikely, results match too well |
| | Mistakes in code calc | n/a | Unlikely, results match too well |
| | Inaccurate matrix inversion | n/a | Almost identical results for three Matlab methods (incl. transpose) |
| **Intrinsic “errors” (no motion)** | Inaccurate translation measurement | +/- 0.1 mm | |
| | Inaccurate translation measurement | +/- xx ° | Can propagate to larger “errors” with increasing distance from rot center, e.g., xxmm for r = 100mm |
| **Differences in residual rotation & translation** | Issues in geometry | **Obtained exp. error of +/-1mm** | |
| | Influence of motion speed (e.g., due to time delays of measurement) | | |
| | Distance from camera | | |

# Uncertainties in Motion Tracker Measurements | Description of setup and experiments

### Description of Setup and approach

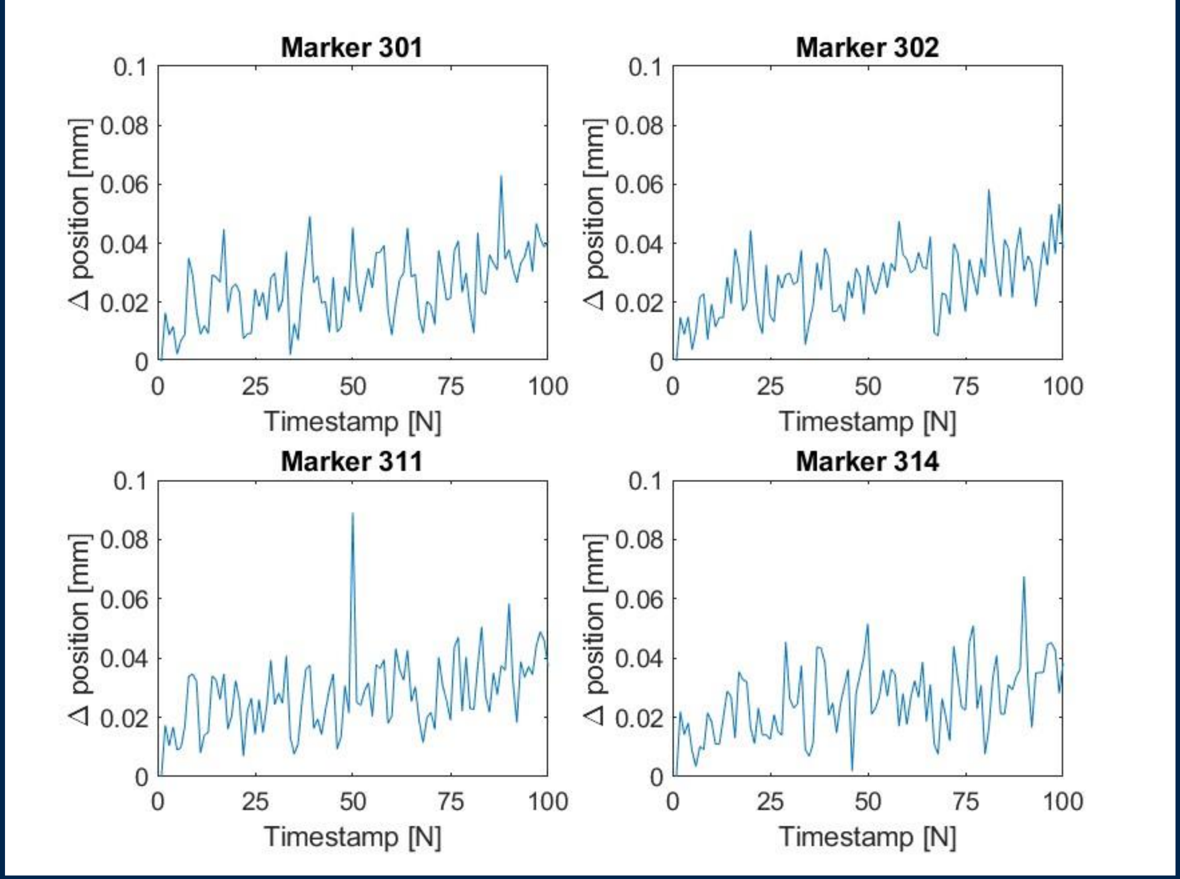


### Experiments

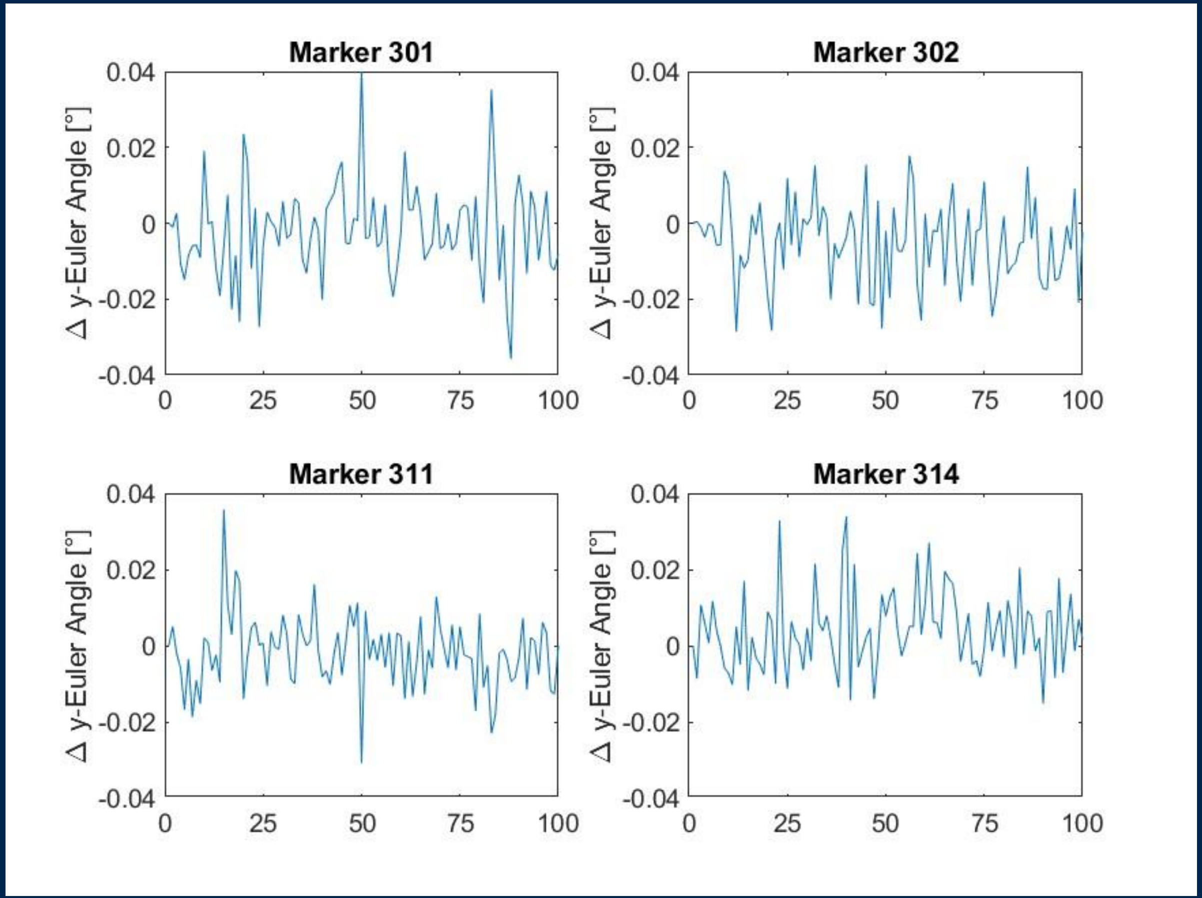
- **No motion** applied for 5 min:
  - Measure intrinsic uncertainty in residual translation and rotation of a marker itself
  - Compare measured and calculated trajectory in 2-marker system
- **Motion** applied to **2-marker system**:
  - Trajectory in x-z plane (table)
  - Evaluate difference between measured and calculated point for different motion patterns

# Results | Intrinsic uncertainty +/-0.1mm and 0.05°

## Translation Uncertainty

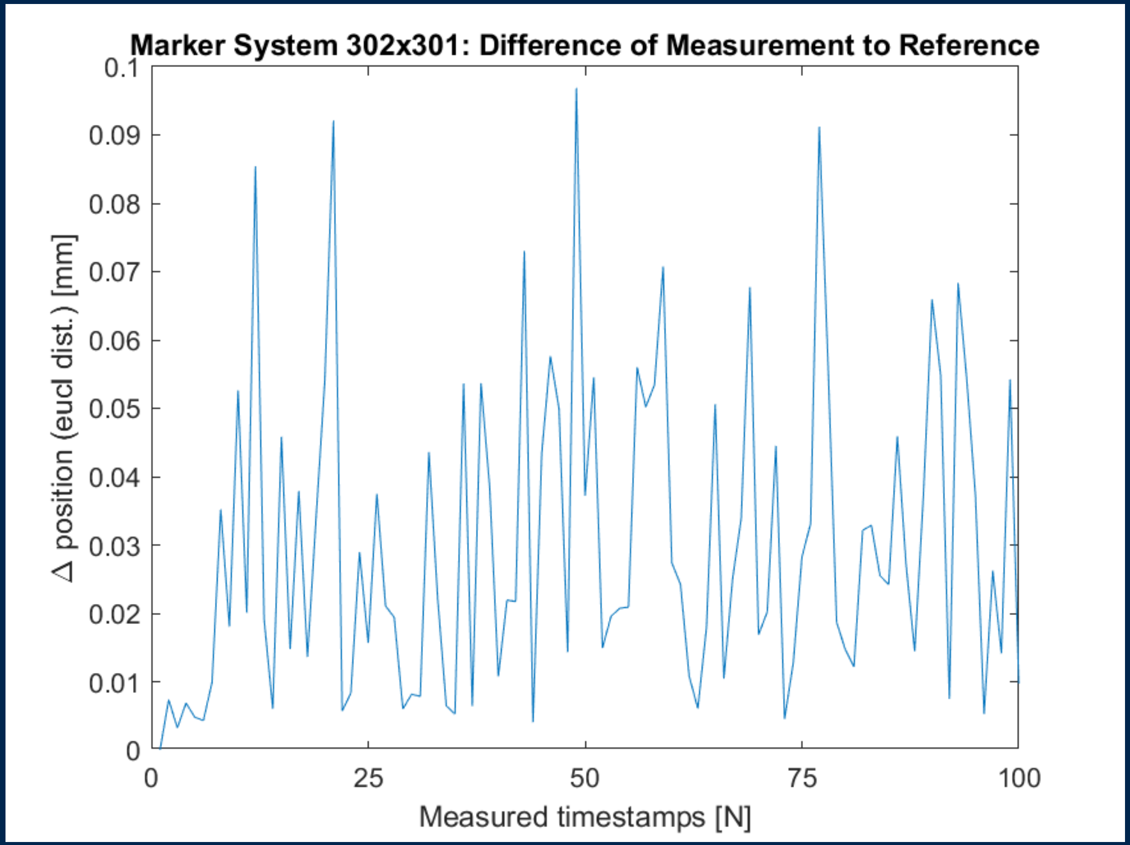



## Rotation Uncertainty

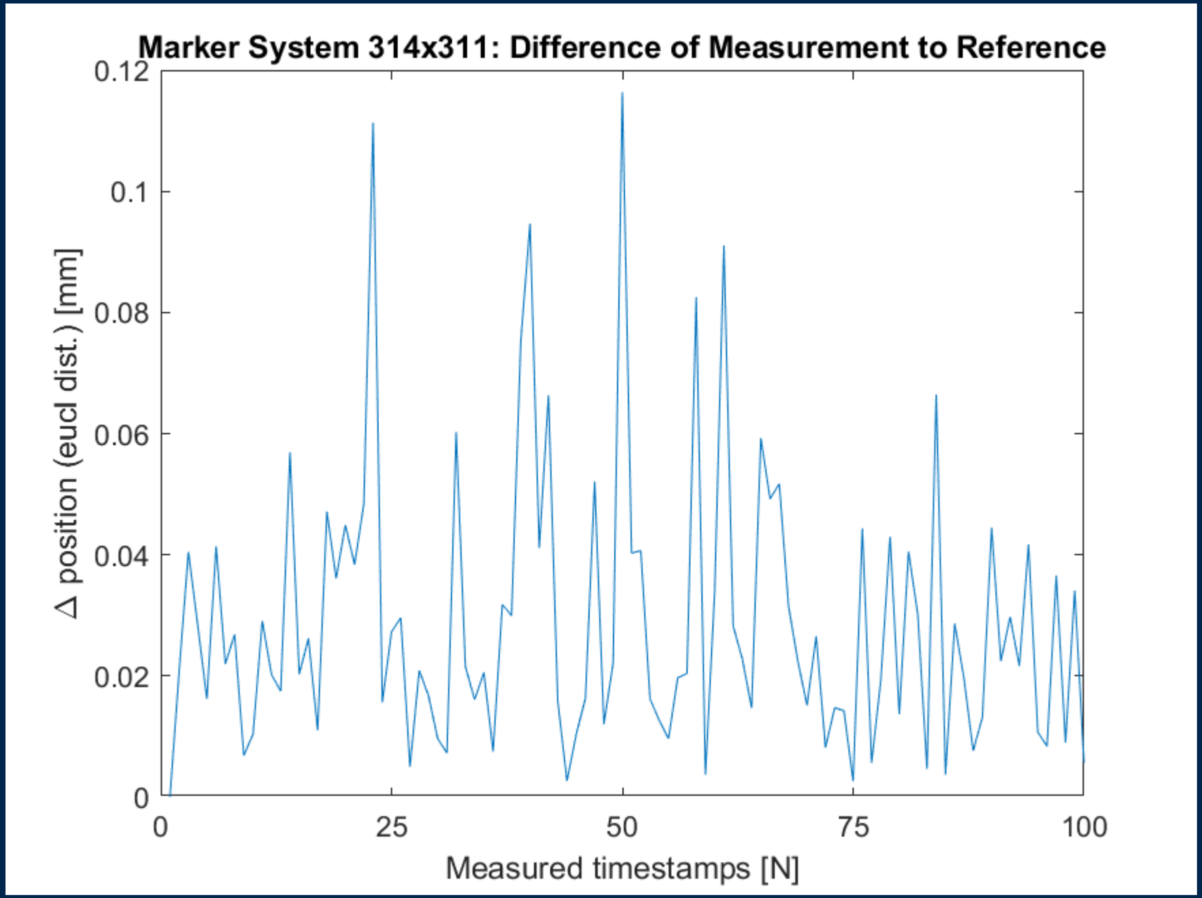


# Results | No Motion two marker system: uncertainty of +/- 0.1mm

## Marker System 302 (measurement)x301 (control)

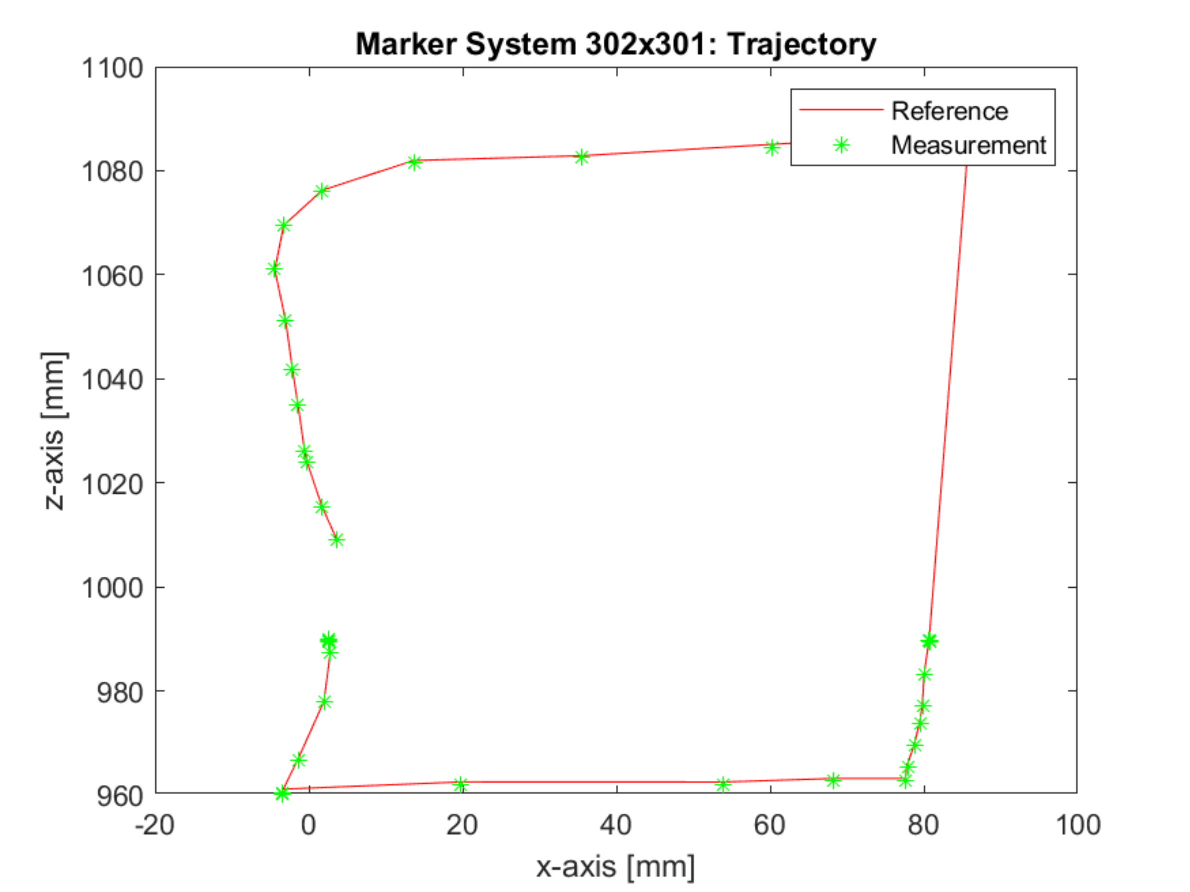



## Marker System 314 (measurement)x311 (control)

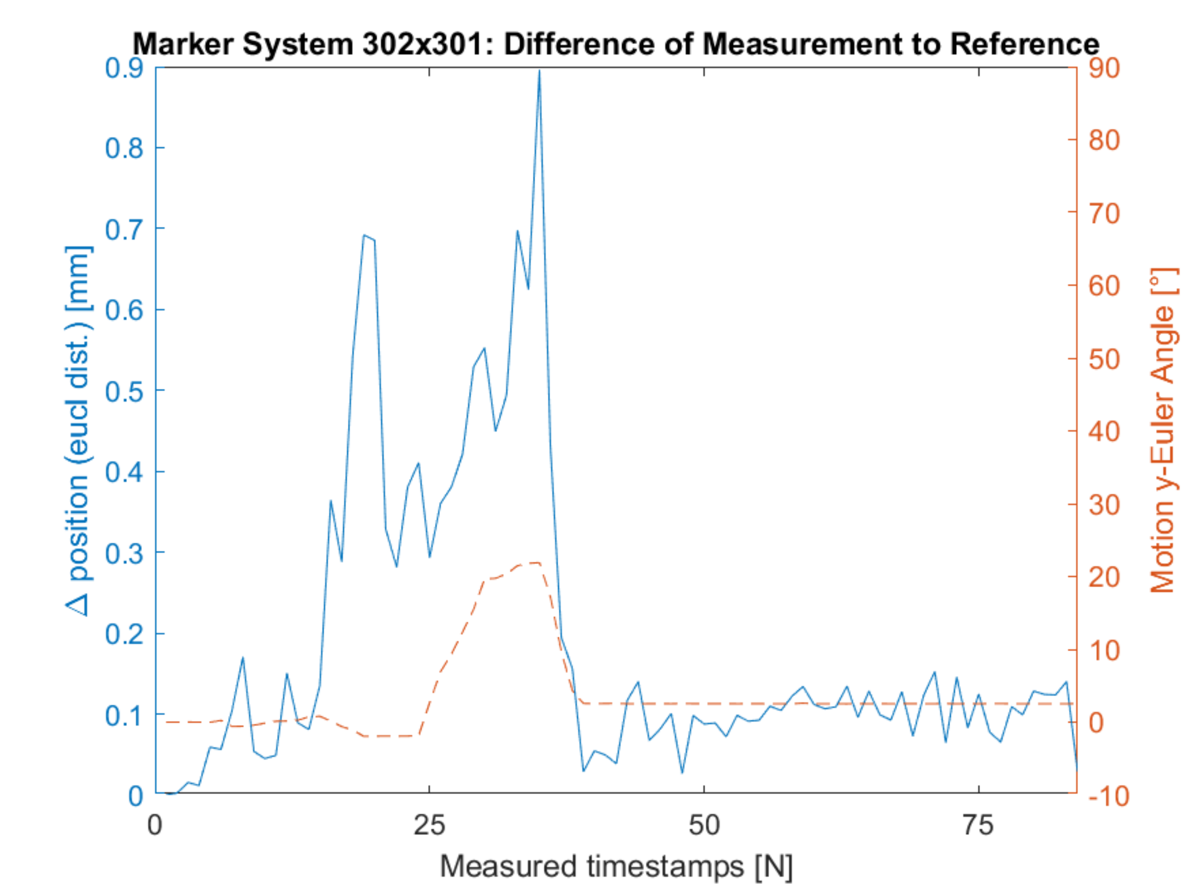


# Results | Motion in Marker System 302x301: Uncertainty up to +/-1mm

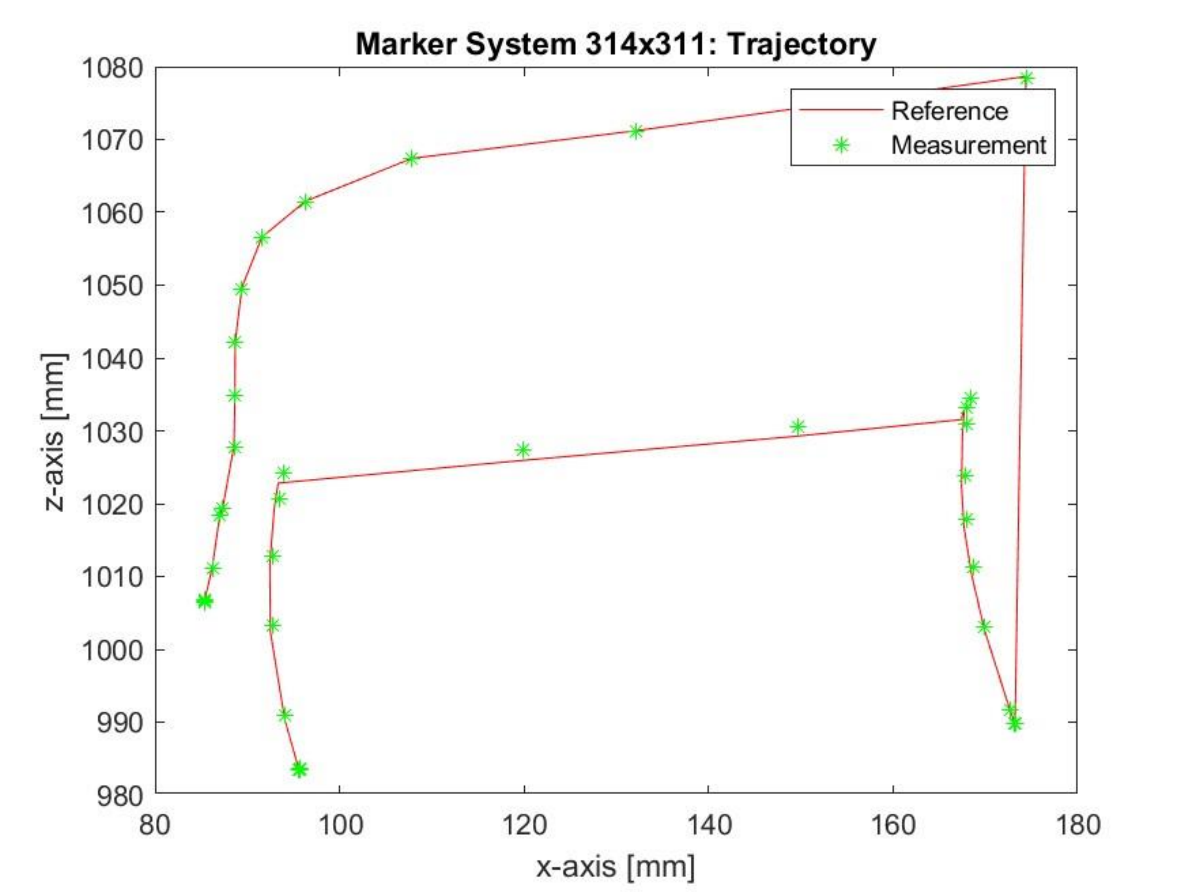
## Trajectory




## Difference between measurement and control



## Trajectory




## Difference between measurement and control