3D-PASS

(3D Patellar instability Anatomical Severity Score)

A novel metric using machine learning to predict treatment outcome in patellar instability using a subset of data in the JUPITER cohort

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- AAG reports equity ownership of NeuralSeg Ltd., NodeAI Diagnostics, and GeminiOV LLC
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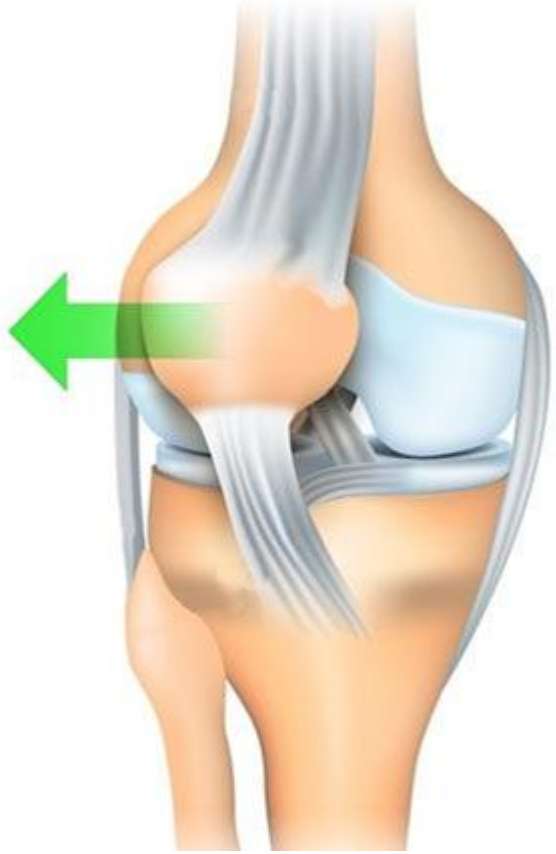
Patellar instability outcomes vary

Among non-operative patients:

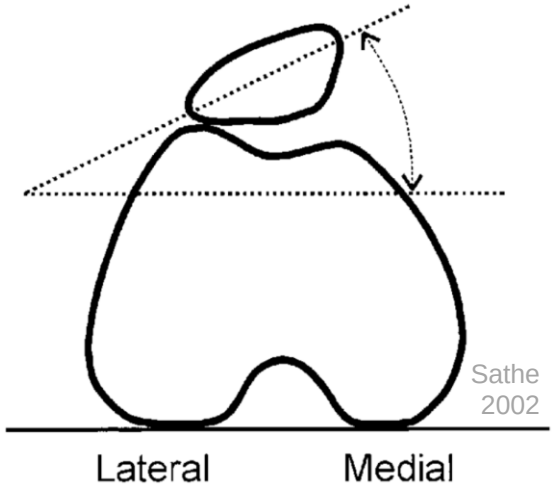
- 1/3 re-dislocate[1]
- 58% experience activity limitations after 6 months[2]

Accurate prediction of outcomes could enhance personalized interventions

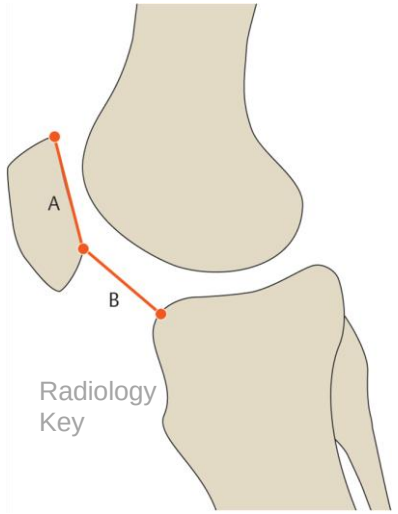


Treatment decisions rely on 2D imaging measures

patellar tilt

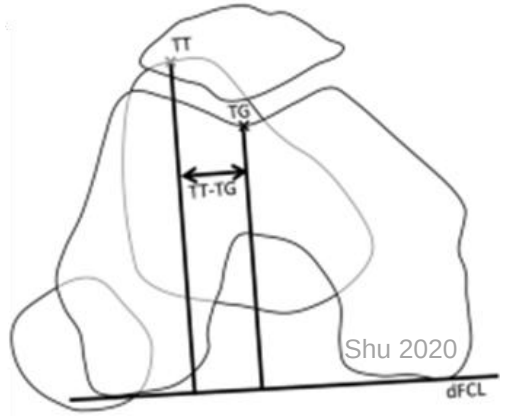


patellar height
e.g., Caton-Deschamps index



trochlear dysplasia
e.g., sulcus angle

tibial tubercle-trochlear groove distance



While informative, these 2D imaging measures do not fully leverage 3D MRI bone data

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Aim: Develop an anatomical score of patellar instability severity

3D Patellar instability Anatomical Severity Score (3D-PASS)

- Associated with instability history
- Associated with post-treatment patient-reported outcomes

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Participants

- Retrospective analysis
- 272 patients with patellar instability
  - Subset of the JUPITER (Justifying Patellar Instability Treatment by Results) cohort
  - First-time and recurrent
  - Non-operative and operative
- 26 age-matched ACL-injured controls

Measures

- Imaging at enrollment baseline
  - Patellar tilt
  - Caton-Deschamps Index (CDI)
  - Sulcus angle
  - TT-TG distance
- Patient-reported outcomes at baseline and 1-year follow-up
  - Kujala Anterior Knee Pain Scale (Kujala)
  - Banff Patellofemoral Instability Instrument 2.0 (BPII)

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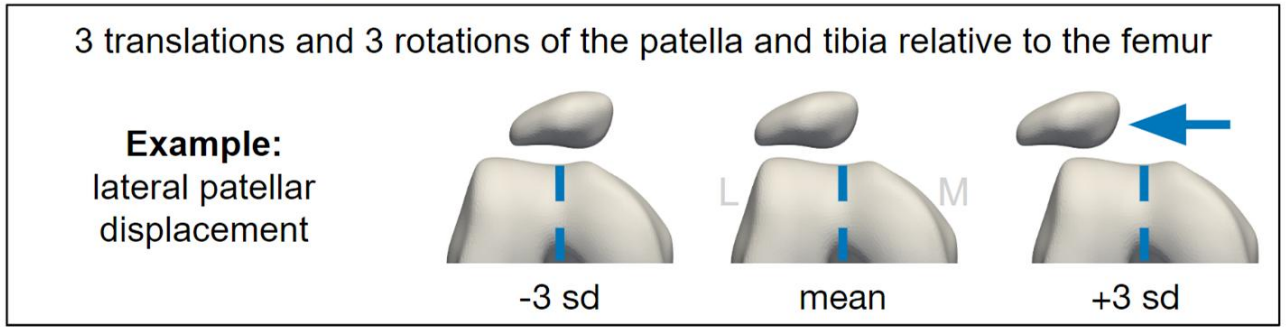
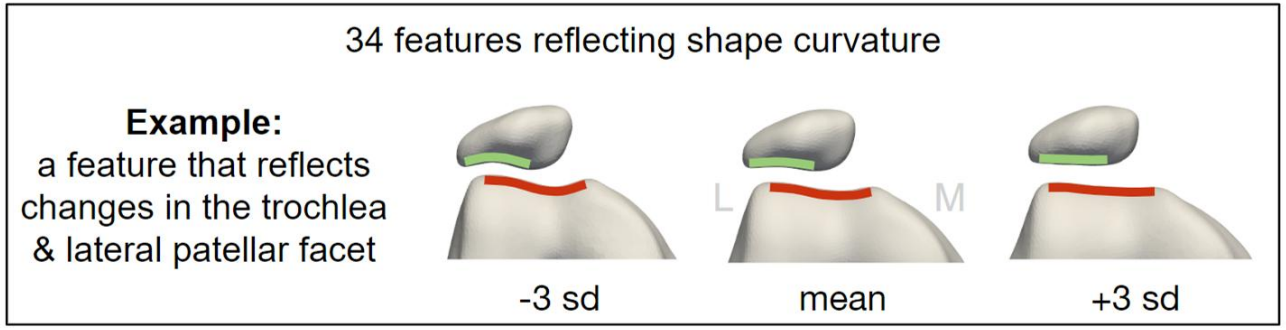
From 3D PD-weighted MRIs, we developed a statistical knee model[3] to quantify 3D relative bone positions and bone shape

- A statistical knee model describes major modes of variation in relative bone translations, rotations, and shape curvature
- One example relative bone position feature and one example bone shape feature are depicted at right

a) relative bone positions



b) bone shape

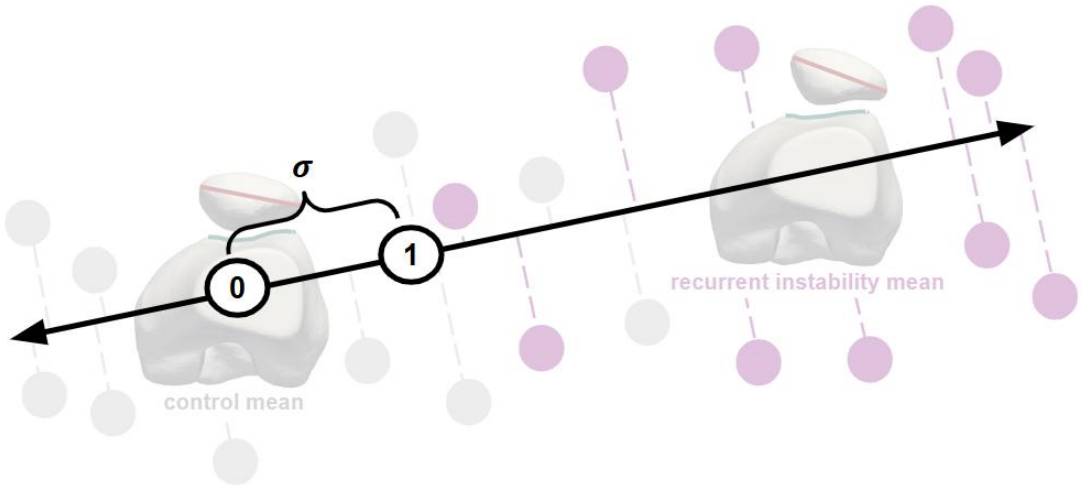


Using these features, we developed instability severity scores to reflect differences between control and recurrent instability cohort means

Four scores of instability severity

complexity ↓

1. 2D imaging measures
2. 3D relative bone positions
3. 3D bone shape
4. 3D relative bone positions & bone shape

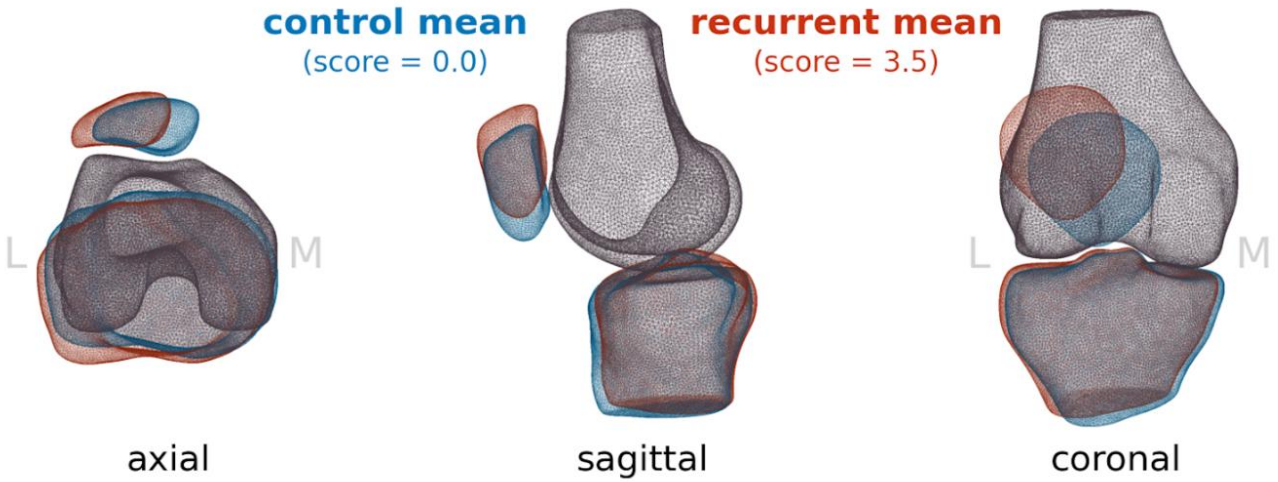


Developed such that:

- Score of 0 corresponds to mean control
- 1 unit corresponds to 1 control standard deviation
- Higher score corresponds to recurrent instability

Instability severity position and shape score visualizations

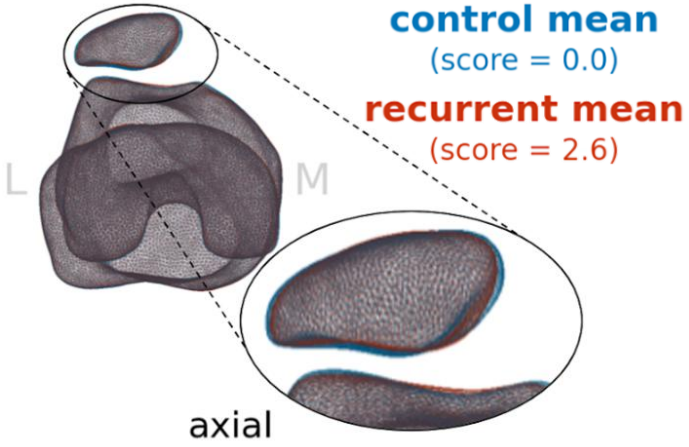
3D relative bone positions severity score



Recurrent instability was associated with large differences:

- Greater patellar tilt, height, and lateral displacement
- More external rotation of the tibia relative to the femur
- More knee valgus

3D bone shape severity score



Recurrent instability was associated with slight differences:

- Greater trochlear dysplasia
- Greater lateral patellar facet concavity
- A more medial trochlear groove
- Less patellar width

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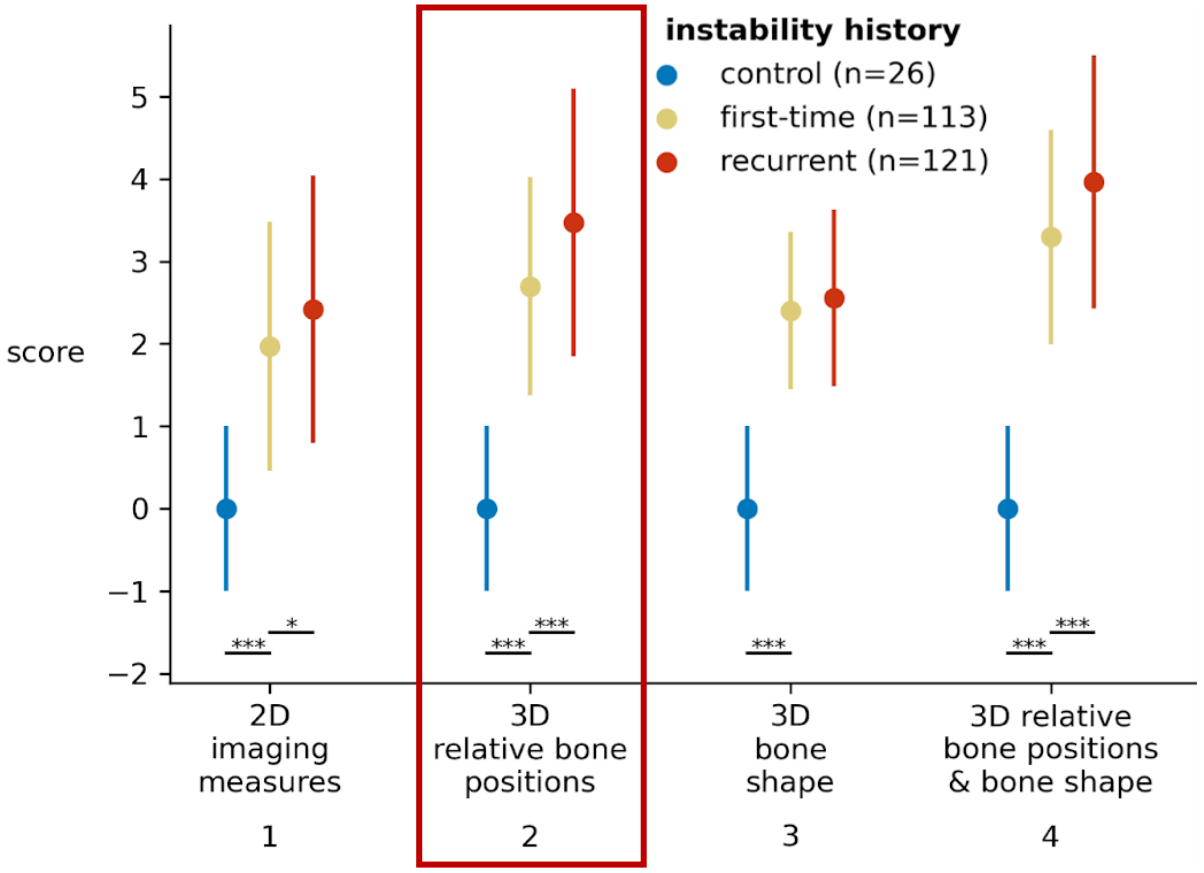
3D relative bone positions best distinguished between first-time and recurrent instability cohorts



- All four scores increased with recurrence
  - The 3D relative bone positions score best distinguished between the first-time and recurrent instability cohorts
- The 3D relative bone positions score was the only score to correlate with one-year non-operative patient-reported outcomes:
  - $r_{Kujala} = -0.42$
  - $r_{BPII} = -0.49$

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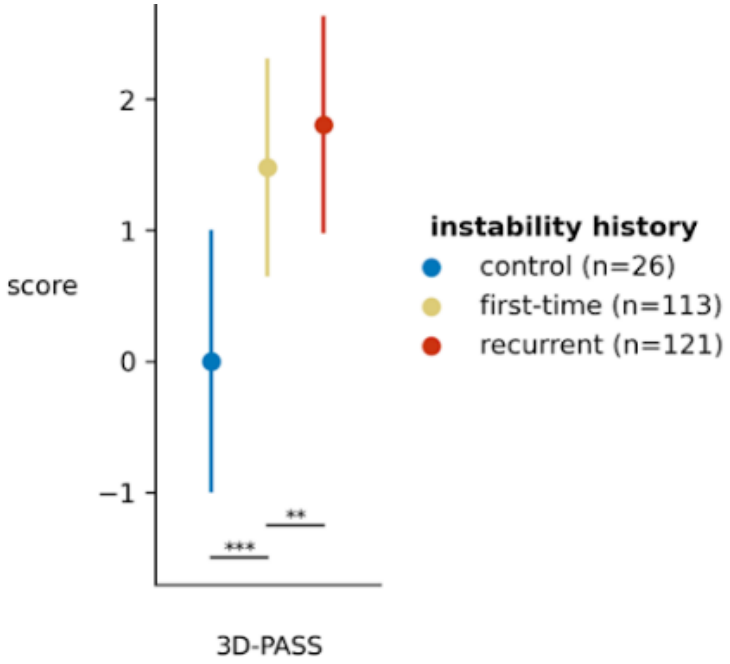
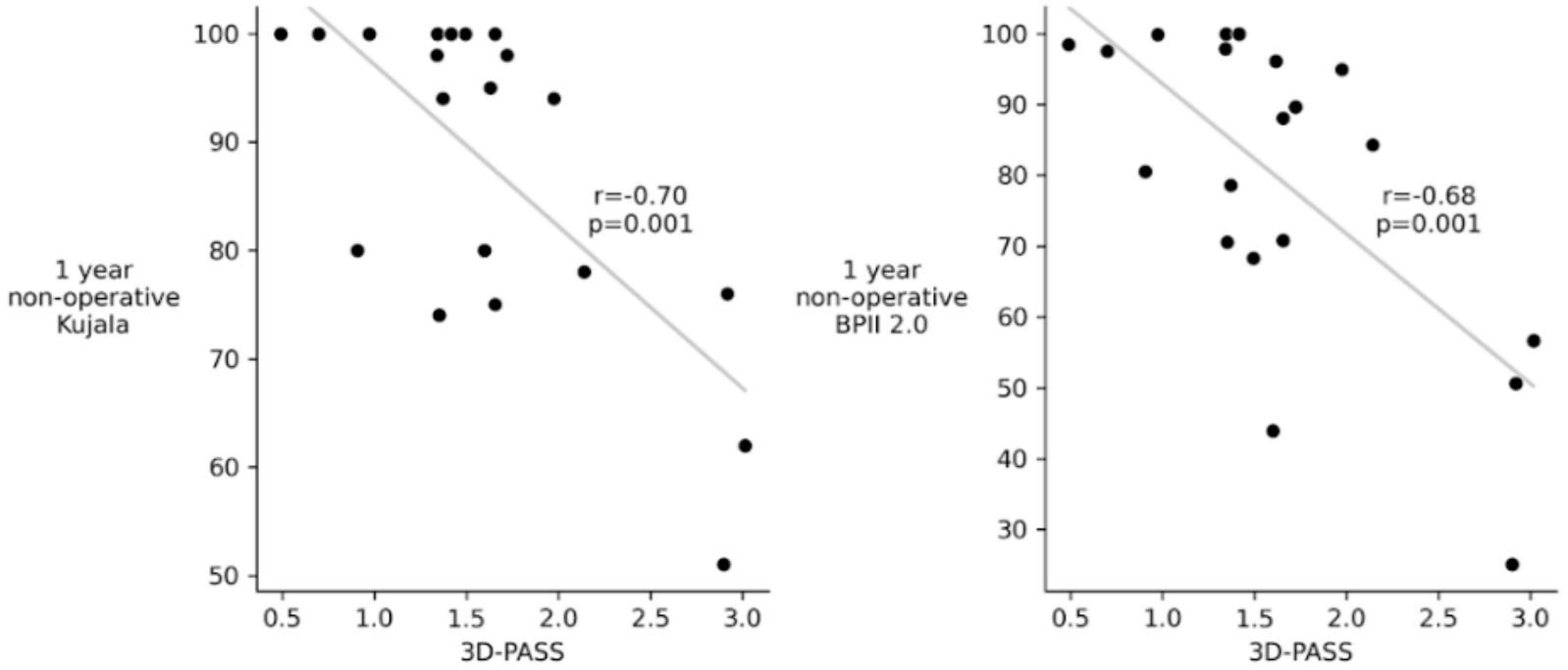
3D-PASS was developed using a subset of the 3D bone relative bone positions that maximized correlations with patient-reported outcomes

3D-PASS is associated with instability history



3D-PASS is strongly correlated with patient-reported outcomes



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Summary: 3D-PASS (3D Patellar instability Anatomical Severity Score)

- Novel metric using machine learning associated with:
  - Instability history
  - One-year non-operative patient-reported outcomes
- Can be computed automatically from CTs & MRIs
- Demonstrates that 3D relative bone positions are more important than 3D bone shape
- Provides potential to help identify patients at risk of poor outcomes and guide earlier surgical intervention to improve prognosis

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References

1. Dixit 2017. 10.1097/JSA.0000000000000149
2. Atkin 2000. 10.1177/0363546500280040601
3. Cootes 1999. 10.1093/oso/9780199637010.003.0007

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