International Conference
CASA 2020
Computer Animation and Social Agents
Bournemouth, United Kingdom

Real-time suturing simulation for virtual reality medical training

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Background

- VR-based medical simulators are the trending in medical students' training.
- Suturing is a necessary basic training procedure in many surgeries.
- However, real-time simulating of suturing involves complex interactions and is not a well-settled problem.
    1. Separate simulation of the rigid needle, soft suture, and soft tissue.
    2. The different kinds of interaction (contacts, penetration, coupling) during the suturing procedure.

Contributions

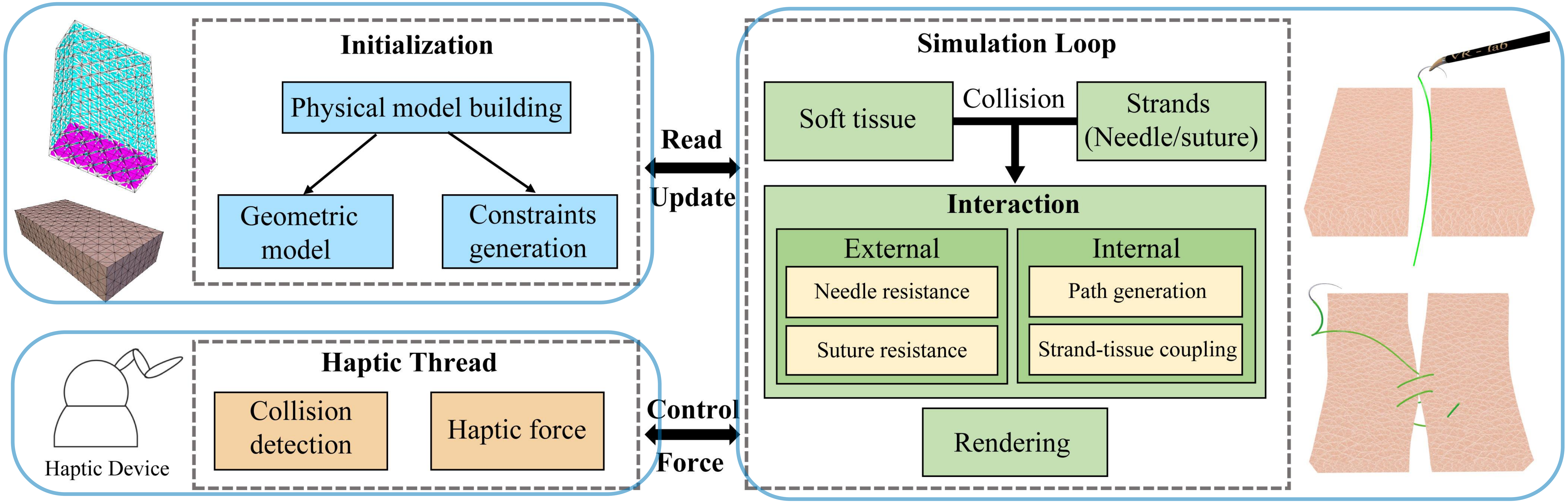
- A completed suturing simulation framework under the position based dynamics: external and internal stage

- A novel coupling method to ensure needle and suture passing through the puncturing path correctly.

- Our suturing methods are integrated into a VR laparoscopic surgery simulator with haptic feedback.

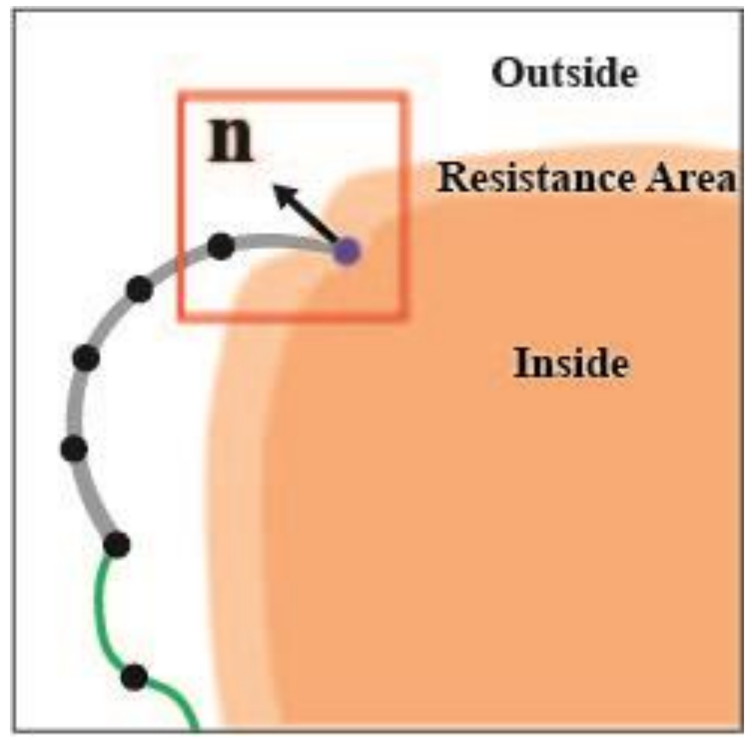
Method Overview

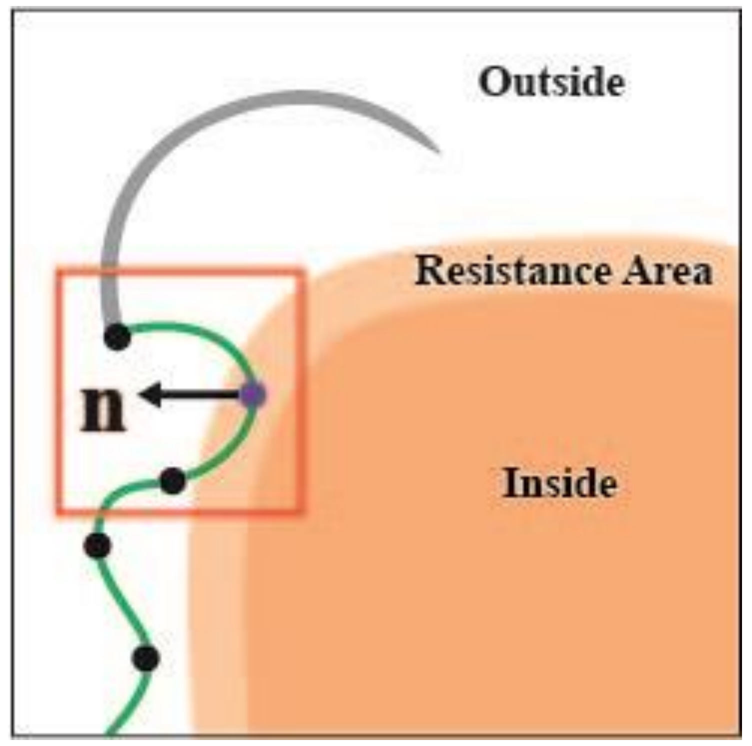
- The framework of suturing simulation



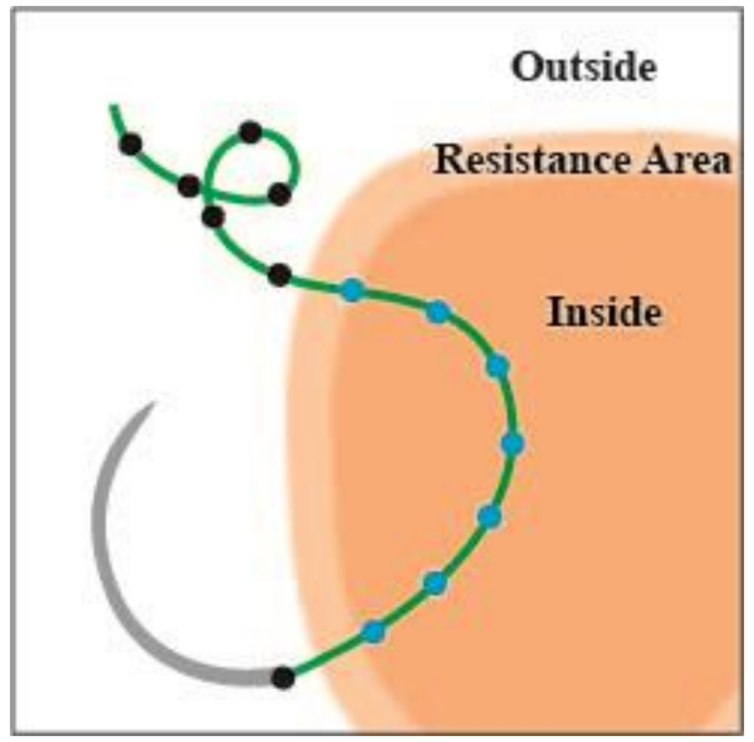
Technique 1

- Two-stage suturing simulation framework
  - External stage: no penetration is allowed





  - Internal stage: interactions with penetrations between surgical tools and soft tissue.

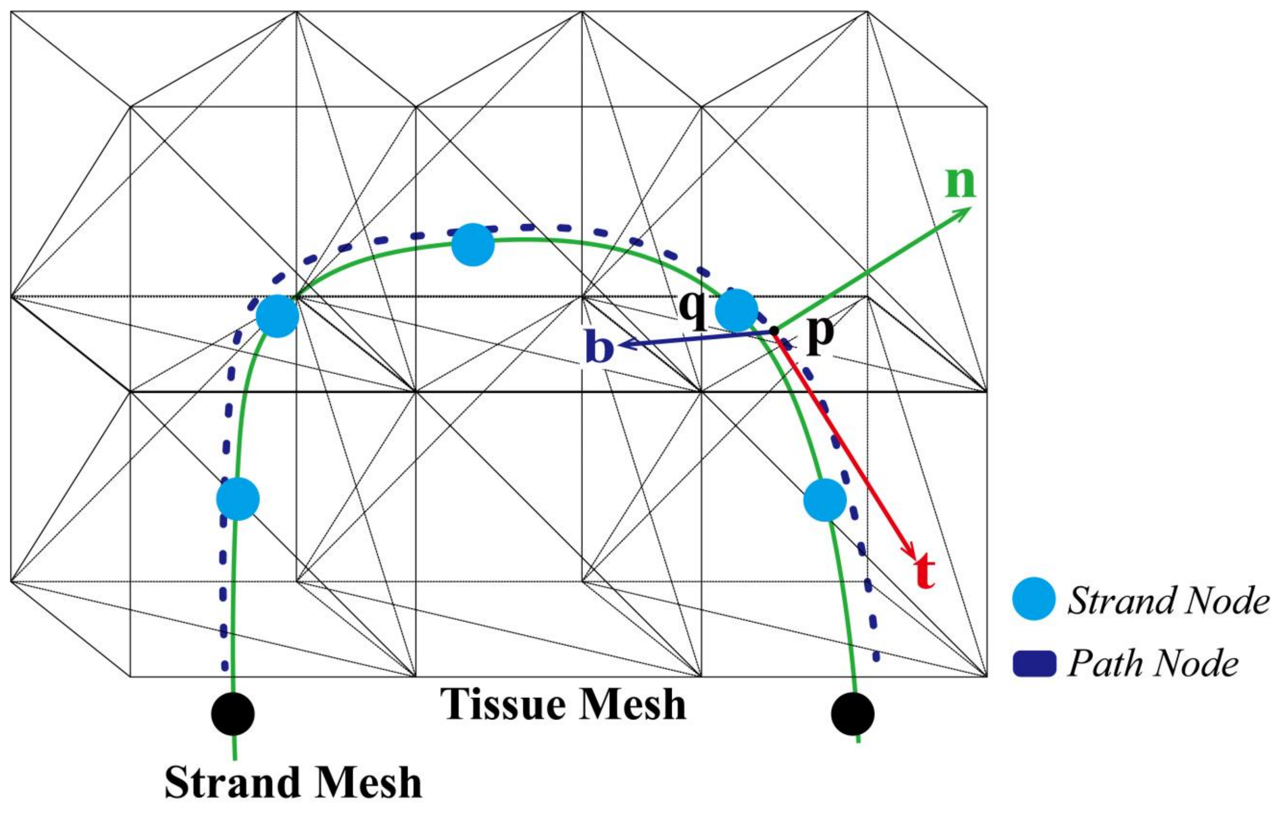


Technique 2

- Interactions between strands and soft tissue

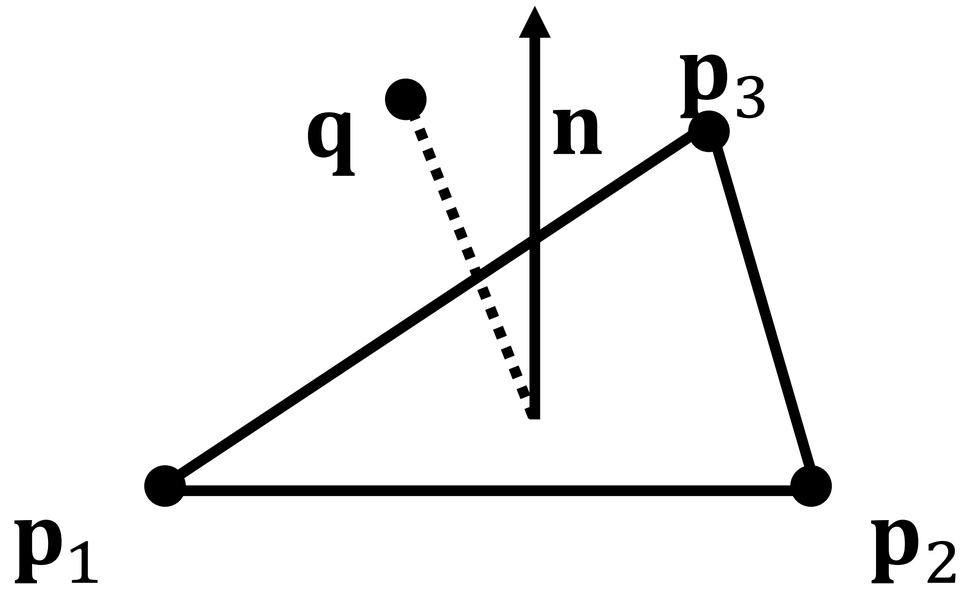
1. Node-path constraint

$$C(\mathbf{q},\mathbf{p}_1,\mathbf{p}_2,\mathbf{p}_3,\mathbf{p}_4)=(\sum_{i=1}^{4} w_i\mathbf{p}_i-\mathbf{q}\times\mathbf{t}=(\mathbf{p}-\mathbf{q})\times\mathbf{t}$$



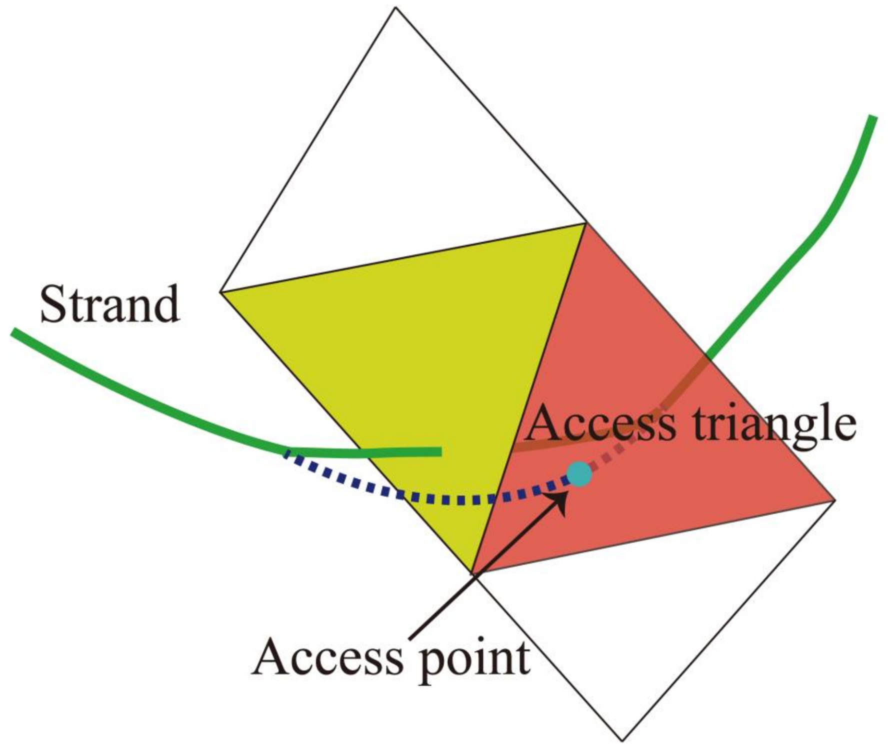
2. Node-triangle (non-penetration) constraint

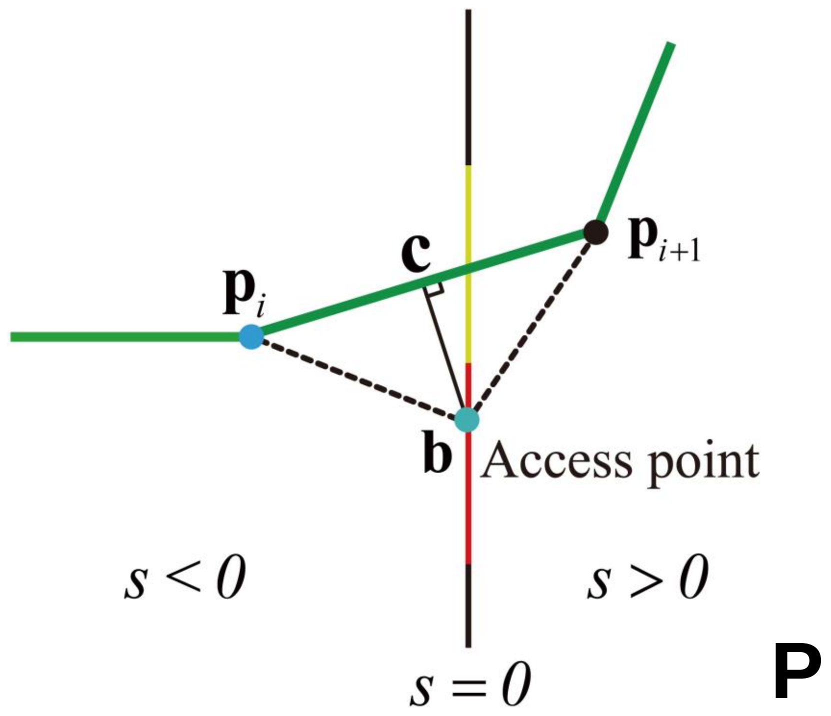
$$C(\mathbf{q},\mathbf{p}_1,\mathbf{p}_2,\mathbf{p}_3)=(\mathbf{q}-\mathbf{p}_1)\cdot\frac{\mathbf{p}_{21}\times\mathbf{p}_{31}}{\parallel \mathbf{p}_{21}\times\mathbf{p}_{31}\parallel}-\varepsilon$$



3. Node-access constraint

$$C(\mathbf{p}_i,\mathbf{p}_{i+1})=\parallel \mathbf{b}-\mathbf{p}_i\parallel+\parallel \mathbf{b}-\mathbf{p}_{i+1}\parallel-l=0$$





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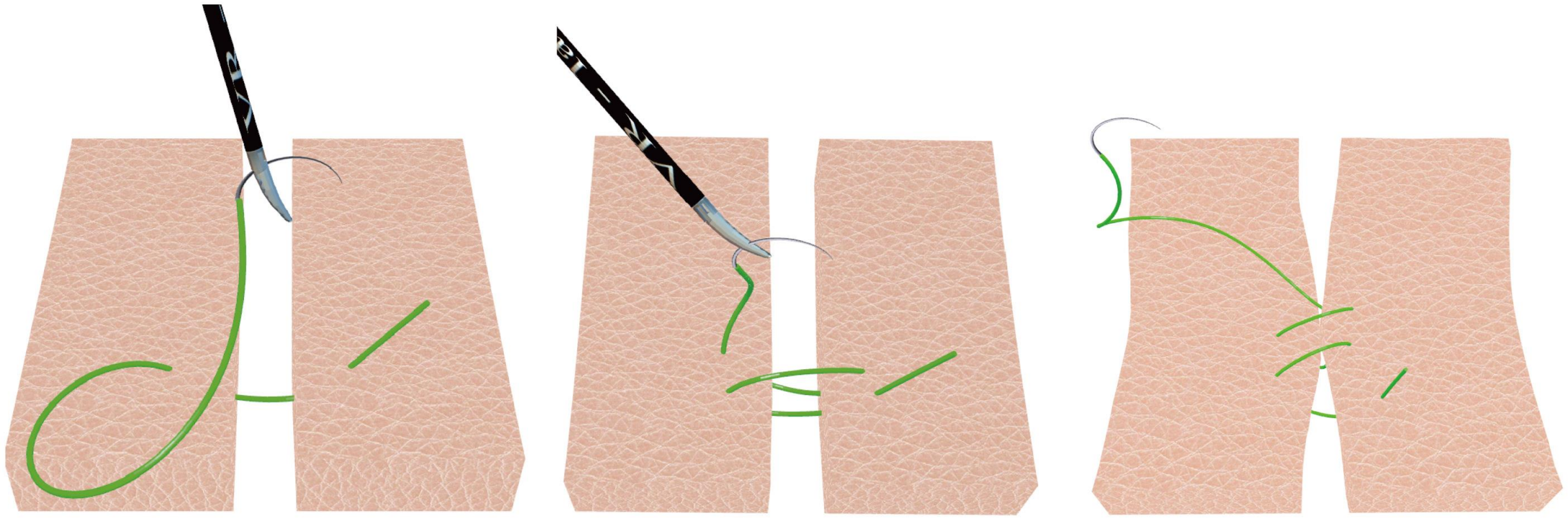
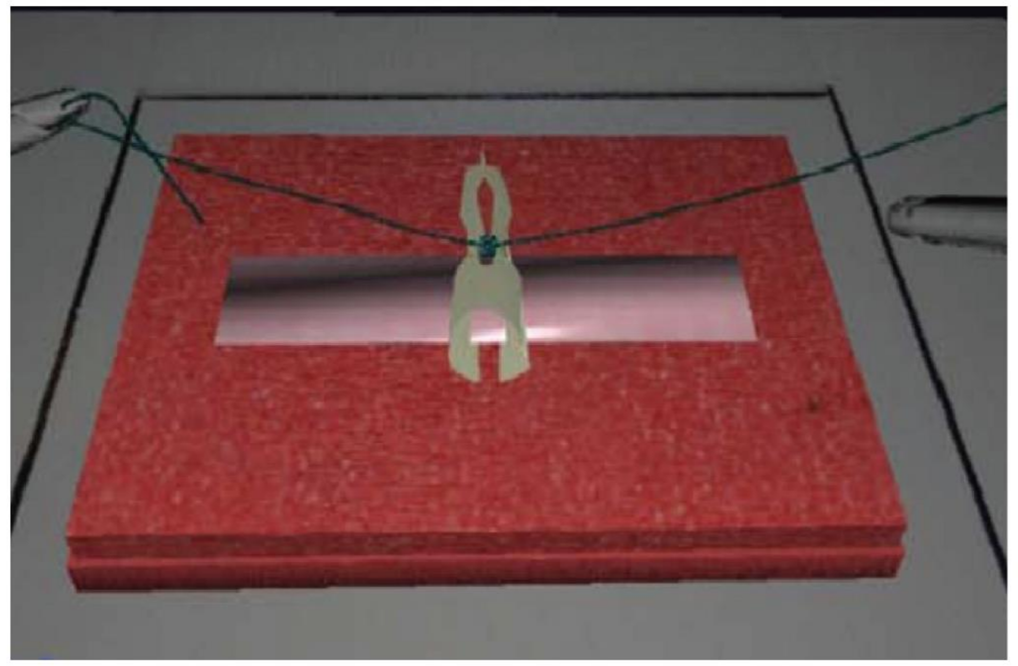
Result 1



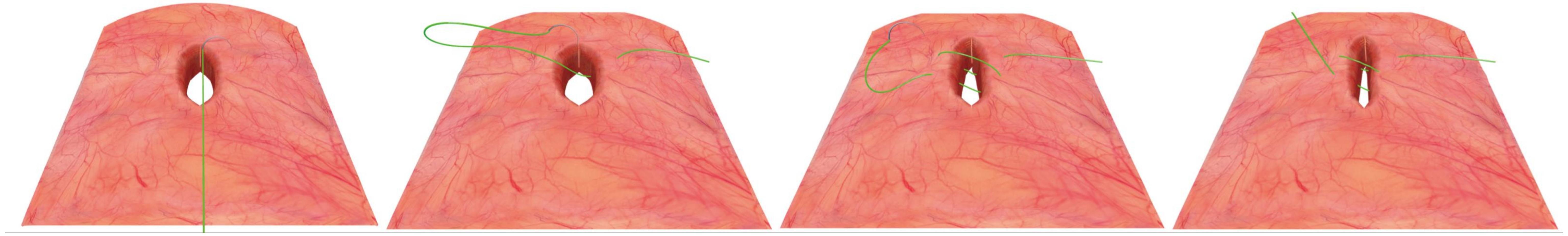


Ours
Tetrahedra: 6840; Tet vertices: 2000;
Triangles: 2264; Tri vertices: 6792;
fps:35

Qi et. al, 2017 [13]

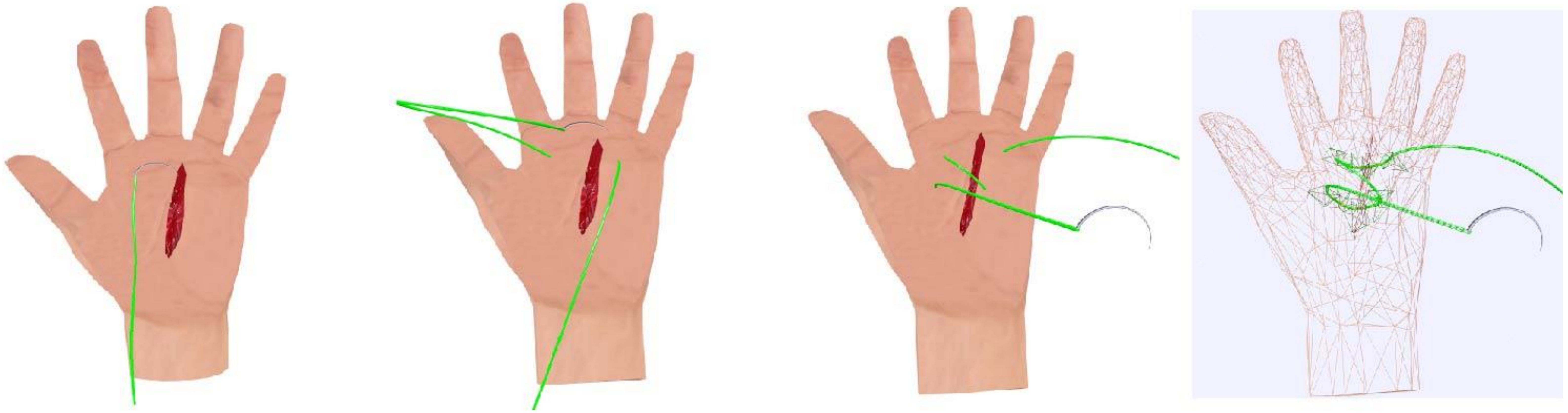
Result 2

- Suturing simulation of abdominal wall



Tetrahedra: 4333; Tet vertices: 1261;
Triangles: 2308; Tri vertices: 5814;
fps: 38

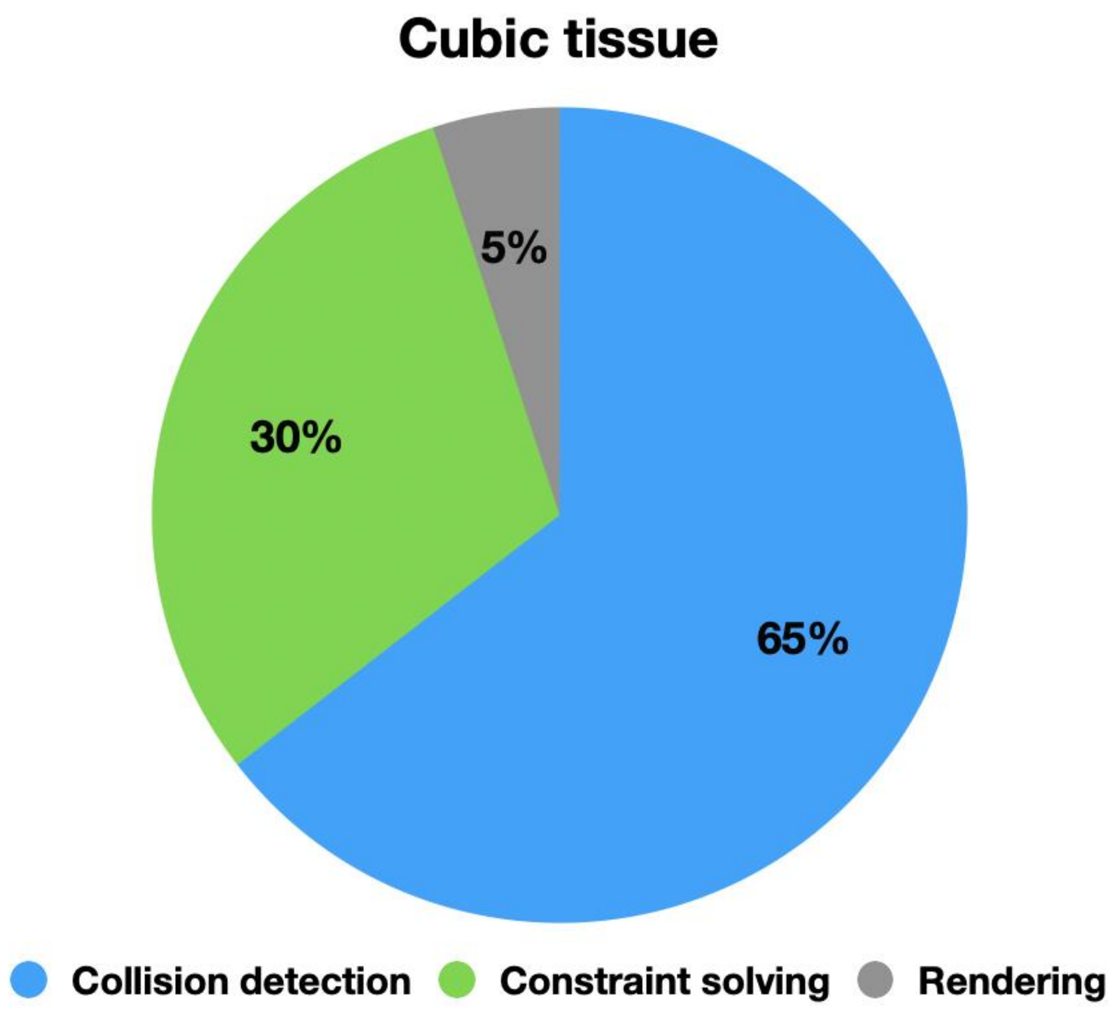
- Suturing simulation of a hand

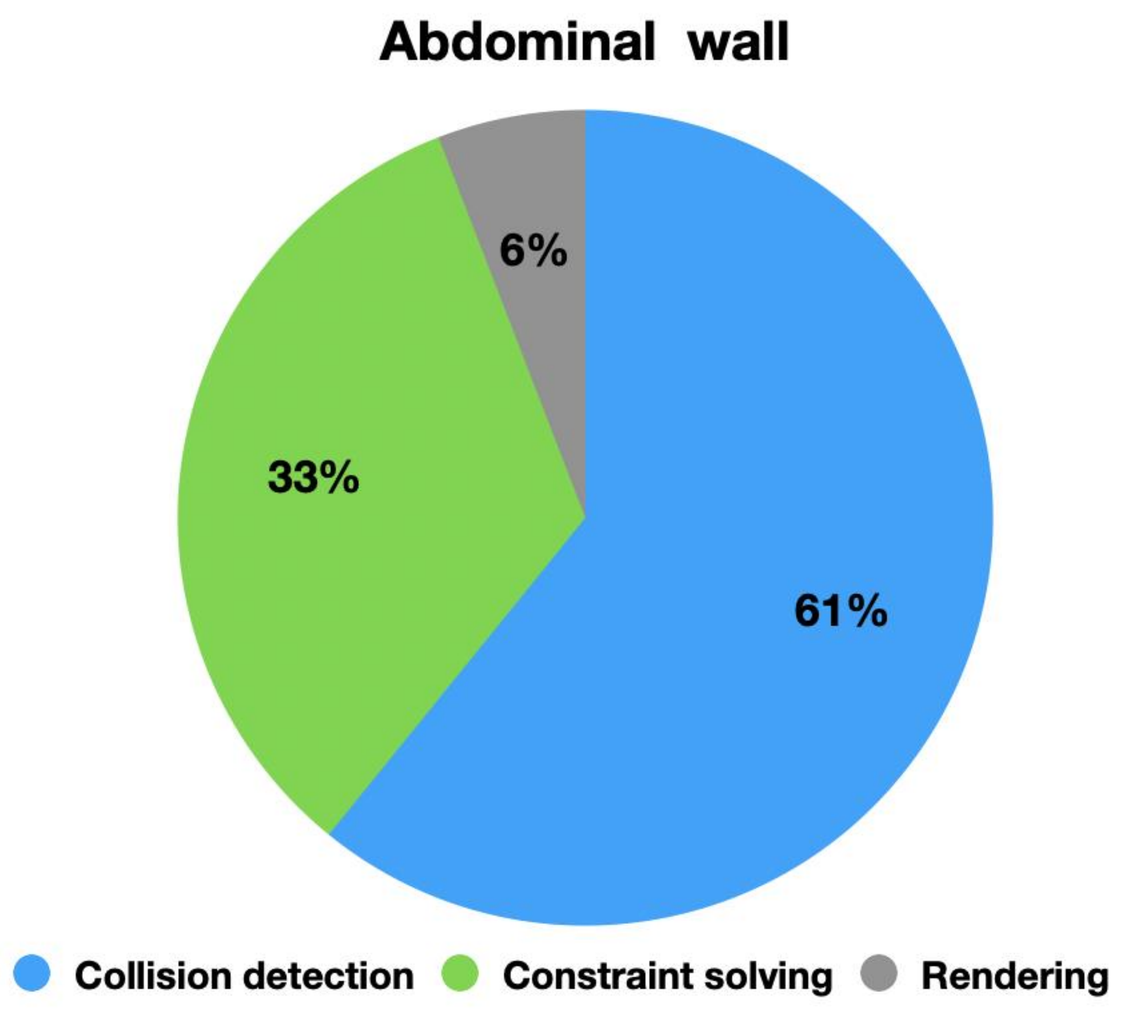


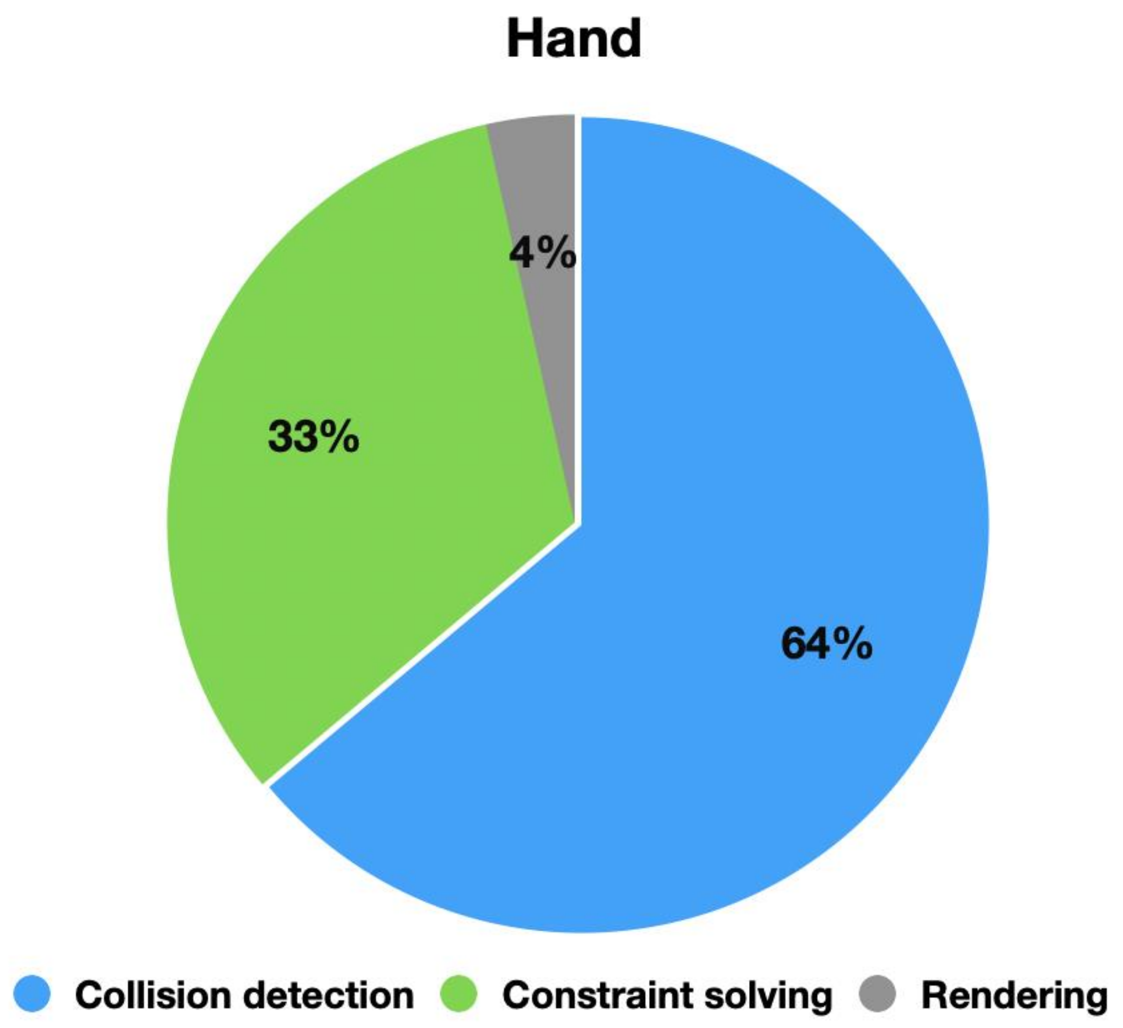
Tetrahedra: 8656; Tet vertices: 2357;
Triangles: 908; Tri vertices: 2724;
fps: 21

Performance

Model	Collision detection	Constraint solving	Rendering	Avg. sum time (ms)
Cubic tissue	61.68%	29.12%	4.81%	28.57
Abdominal wall	59.38%	32.49%	5.73%	26.32
Hand	62.14%	31.70%	3.41%	47.62

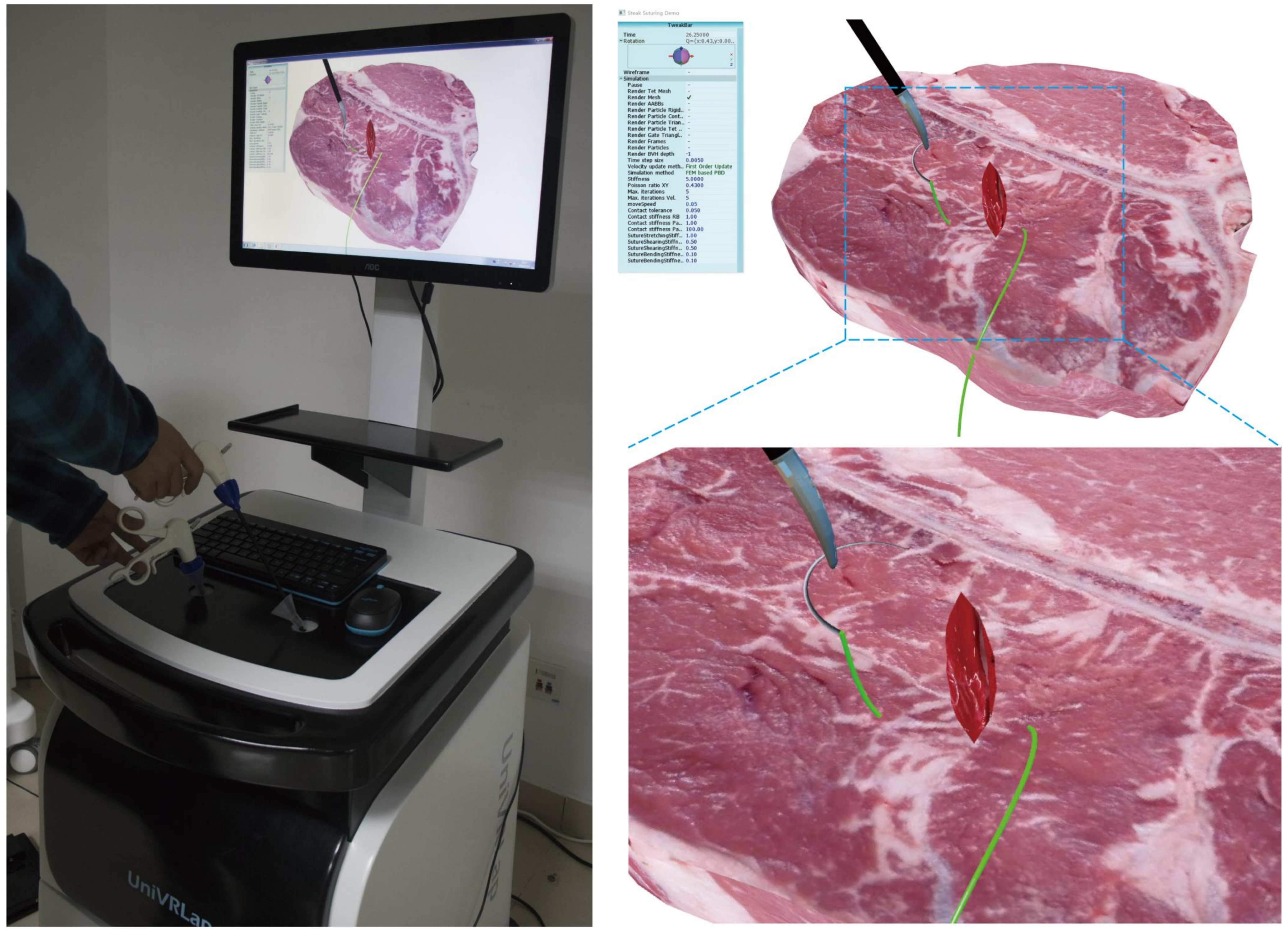






Application

- Interface of our prototyped virtual-reality laparoscopic surgery simulator



Conclusion

- We presented a real-time simulation framework to handle the complex interactions between strands and soft tissue in suturing.
- The whole suturing procedure is divided into two stages: external stages and internal stages which are handled by different constraints to deal with the coupling between surgical tools and soft tissue.
- We apply our suturing approach into a virtual-reality based laparoscopic medical training simulator with haptic feedback.

Limitation and future work

- Position-based dynamics is not a physical accurate method and the material parameters are related to timestep and iteration numbers.

- The collision detection method is the bottleneck of our simulation. We should design a more efficient collision detection algorithm.

- Our suturing simulation has not achieved all the suturing procedure like knot-tying and self-collision detection.

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Thanks for your listening