Enhancing Robot-Assisted Femur Fracture Surgery with Virtual Fixtures and Haptic Feedback: A Novel Integration Approach.

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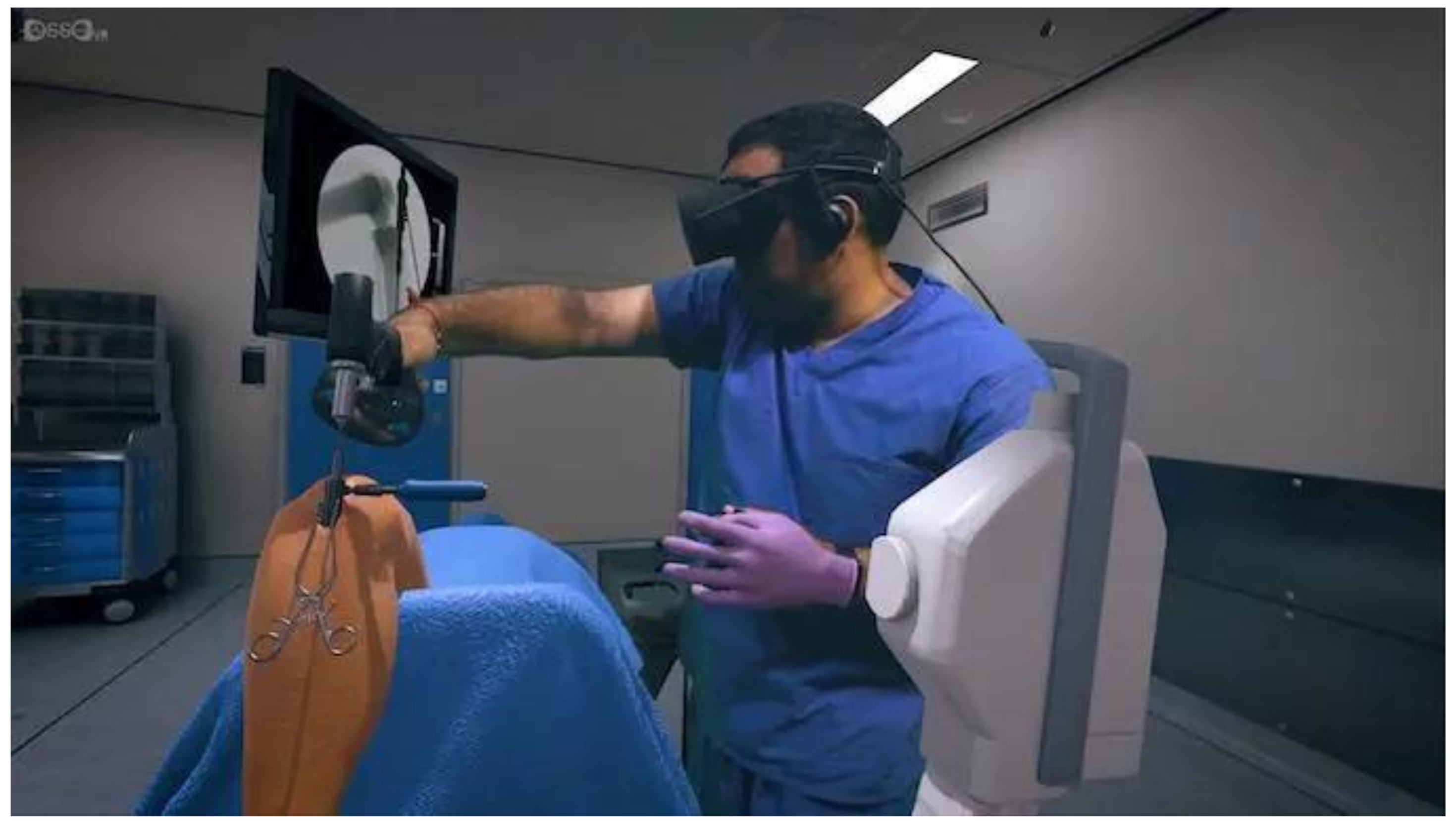
Background:

Enhancing Precision in Surgery: While robotic systems have advanced femur fracture surgeries by improving precision, they introduce new challenges:

- **Tactile Feedback Deficit:** A lack of somatic information hinders the surgeon's tactile connection to the procedure.
- **Navigation Complexities:** Surgeons face difficulties visualizing and navigating the path to reduce fractures accurately.
- **Intuitive Decision-Making Gap:** The absence of a surgeon's physical interaction with the tissues can diminish intuitive control during the operation.
- **Soft Tissue Risks:** There's an increased risk of inadvertently straining the tissues surrounding the fracture.

Advantages Of Virtual Fixtures & Haptic Feedback

- **Precision Alignment:** Decreases the likelihood of misalignment in bone fragments.
- **Sensory Enhancement:** Improves tactile feedback, enhancing surgical intuition.
- **Tissue Protection:** Lowers the risk of damage to adjacent soft tissues.
- **Navigational Efficiency:** Streamlines the process of fracture reduction.



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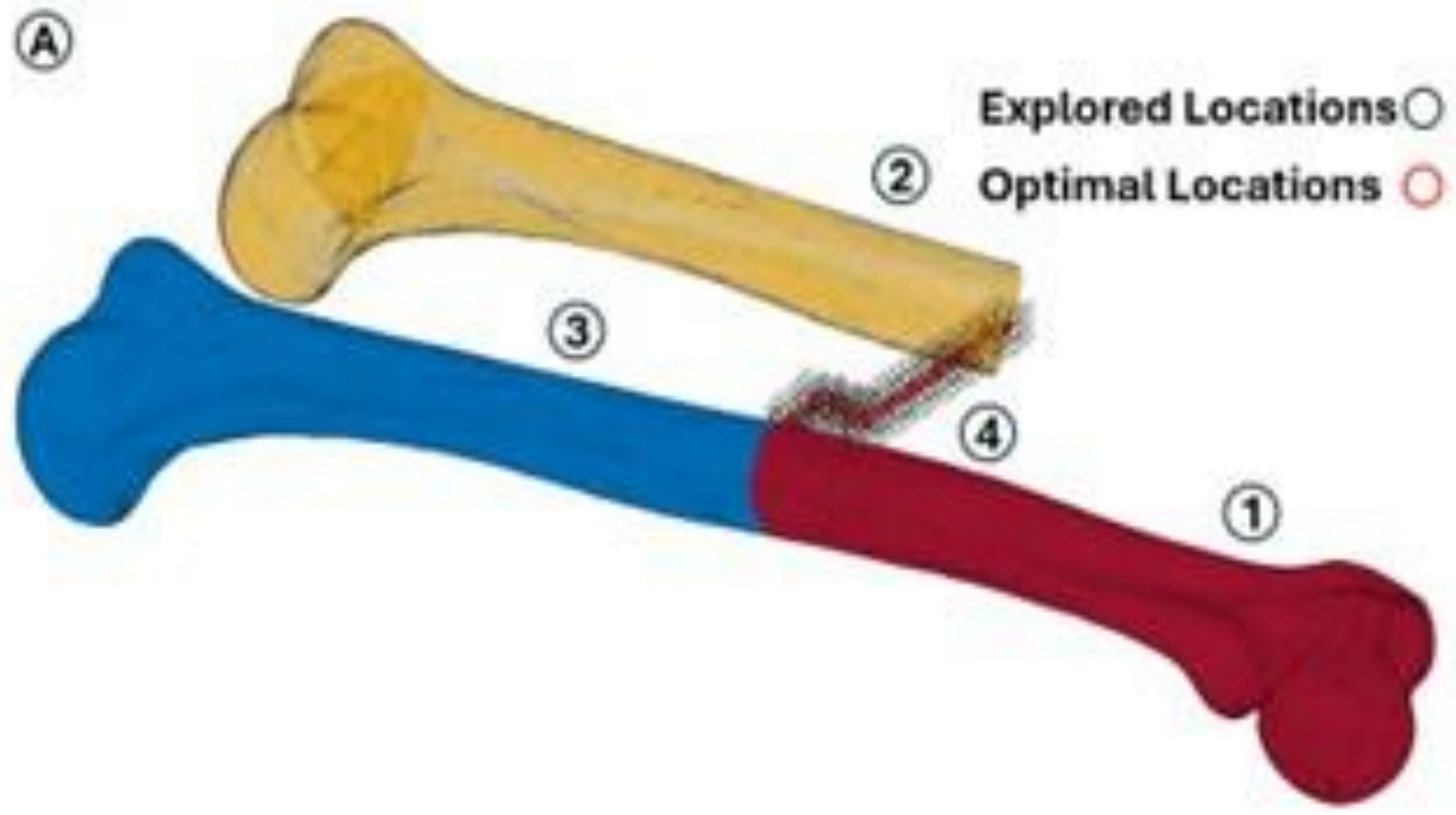
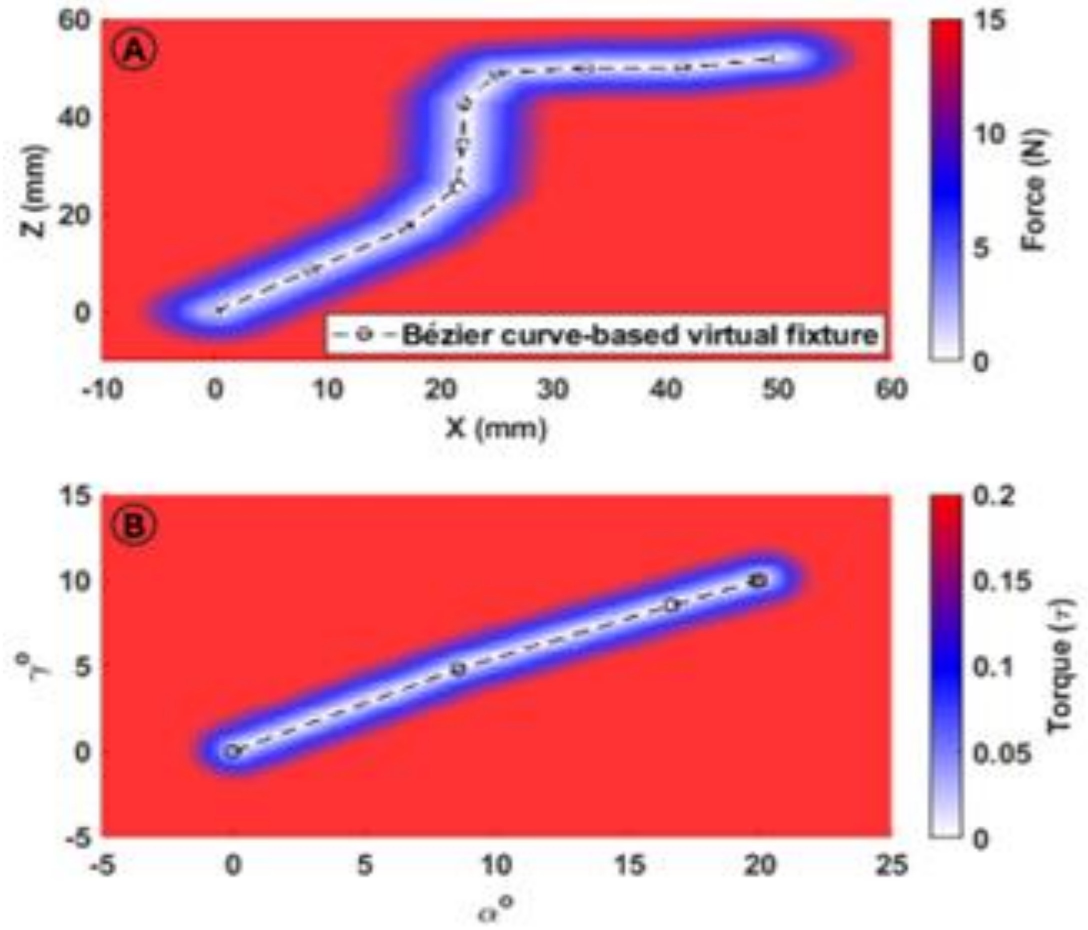
Methods & Results

Navigating the reduction path with the RSR can be a challenging task. Based on the patients CT scans a 3D model of the fracture fragments can be created. We develop a modified A* path search algorithm to find the optimal reduction path to align these fragments. The A* is a path finding method, that is typically used for navigation in robotics. We demonstrate our method and its path search in Fig 1. The path calculated by the algorithm can then be used to generate virtual fixtures. Our virtual fixtures are generated by implementing a bezier curves on both the translation and rotational vector spaces Fig 2. The virtual fixtures help guide the user and are used to calculate the haptic feedback.



Here we demonstrate the path finding capabilities of our modified A* algorithm. The figure demonstrates the distal fragment to be reattached (2). The proximal fragment it needs to be reattached with (1), and the desired position of the distal fragment in blue (3). The green circles represents all the explored positions near the fragment. The Algorithm then chooses the best position factoring in distance and collision. Which generates the path composed of red circles (4).

Fig 1.



The A* determines the path in 2 spaces; The Translational (A) & Rotational vector space (B). The Bezier curve transforms the discretized steps generated by the A* into a smooth continuous path along which we can guide the users end effector. Based on this we calculate haptic feedback and torque for both spaces. With the feedback gradually increasing the further the user deviates from the path. Along the path, with feedback reaching a maximum of 0.2 N

Fig 2.

Discussion & Conclusion

- ***Bezier & A Algorithm:**** We've developed a novel approach using Bezier curves for intuitive haptic feedback and an optimized A* algorithm for precise fracture alignment.
- **Intuitive Surgical Experience:** Our system enhances the surgeon's tactile perception, promoting accuracy and maintaining the optimal path during surgery.
- **Forthcoming Advancements:** Future enhancements include a hill-based muscle model for more accurate force feedback and path calculation, enhancing the procedure's realism.
- **Validation Aims:** Plans are underway to validate our methods with cadaveric experiments to confirm their practical benefits and effectiveness.

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