Abstract
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Titel
Roboterassistierte Reposition von Femurschaftfrakturen auf Basis intraoperativer 3D Bildgebung

Title
Robot Assisted Reduction of Femur Shaft Fractures based on Intraoperative 3D Imaging

Keywords
Telemanipulation, Fracture Reduction, Femur, Force Feedback, Surgical Robotics

Purpose
Minimal-invasive intramedullary nailing is the treatment of choice for femoral shaft fractures because of its high union rates between 90-99% and low incidence of infection. However, several problems associated with this technique have been outlined in literature. E.g., the radiation exposure is quite high with average image intensifier usages between 158 and 316 seconds during reduction. Malreduction is another well-known problem with significant malalignments in sagittal and frontal plane between 2% and 18%. Correct rotation around the shaft axis is difficult to achieve intraoperatively, as only 2D fluoroscopy is used for assessment. Differences of more than 10° are recorded with an incidence of more than 40%. Malreduction leads to unphysiological conditions with consecutive reoperation in several cases. Both problems are related to difficulties in achieving and maintaining the correct reduction and are evident in the femur because of its tube-shaped bony anatomy and its counteracting muscle strength. Our hypothesis for this study is that robot assistance improves the quality of reduction while reducing the amount of radiation exposure.

Method
The process of 3D fracture reduction is separated into two steps: The acquisition and registration of a 3D data set and the reduction process itself.
First, a 3D DICOM data set is acquired with the Siemens Iso C 3D. The BrainLAB navigation system calibrates this data set by computing the transformation from the DICOM coordinate space to a DRB (dynamic reference base) which is mounted to the proximal (hip side) femur segment. With a threshold based segmentation method, the two major fracture segments are segmented and 3D surface models are reconstructed using the marching cube algorithm. A

second DRB is mounted to the distal (knee side) fracture segment. The calibration is finalized by computing the transformations between the two 3D models and the DRBs connected to each fracture segment.
During reduction, a 3D scene of the real-life situation, as measured by the navigation system, is displayed to the surgeon. The complex 3D reposition problem is reduced to simpler 2D repositions. Using a 2D input device, the surgeon can manipulated the fracture intuitively within a 2D projection of the 3D scene. This simplifies the spatial cognition required to reduce fractures. By interactively panning the viewing direction around the bone axis, the surgeon can examine and manipulate the fracture from every desired angle.

Results

In the case of bare bones, the users' learning curves are very steep. After a first introductory reposition, we found no learning effects regarding reposition time and accuracy. The achieved accuracies have been on a high level starting with the first reposition. Therefore, such a 3D telemanipulated reposition procedure can be considered as being very intuitive for the surgeons.
The experiments with bare bones achieved very good results with mean deviations of less than 2° for fractures of the AO type A, which is very satisfactory compared to clinical results. However, the achievable reposition accuracy decreases with increasing fracture complexity. Expectedly, the avoidance of axial displacements is very difficult for complex fractures without direct connection between the two major segments. But overall, even for complex fractures the achievable accuracy is very good with mean rotational deviations of less than 4°.

Conclusion

The user interface for telemanipulation proved to be very efficient and intuitive. All test persons could reduce fractures successfully after only very little training. The reposition results achieved during our tests are very promising and show the potential of robotized fracture reduction based on 3D imaging data.
Our next steps will be the evaluation of the 3D telemanipulator system on human specimens with intact soft tissues and an automated robotized fracture reduction.

Table 1: Results for fractures of AO type A (N=64)

Parameter	Mean	Std. dev.	Min	Max
Reduction time (min:sec)	4:34	2:31	2:00	12:57
Axial displacement (mm)	1.08	0.63	0.05	3.19
Lateral displacement (mm)	1.61	1.23	0.16	4.80
Varus/Valgus (axial torsion) (degrees)	1.37	1.39	0.02	5.82
Ante-/recurvature (front/back) (degrees)	1.42	0.84	0.19	4.04
External/internal rotation (degrees)	1.09	0.73	0.03	2.66

Table 2: Results for fractures of AO type B (N=40)

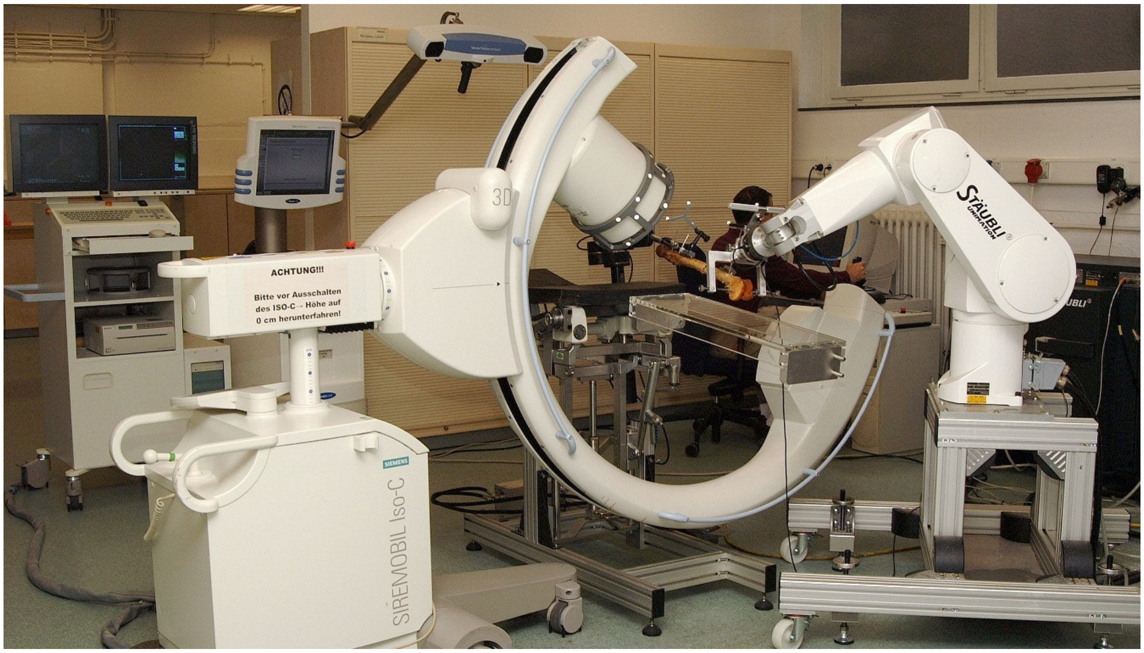
Parameter	Mean	Std. dev.	Min	Max
Reduction time (min:sec)	4:18	1:44	2:05	10:30
Axial displacement (mm)	2.35	1.48	0.06	5.71
Lateral displacement (mm)	2.03	1.13	0.45	4.86
Varus/Valgus (axial torsion) (degrees)	2.37	2.07	0.03	8.97
Ante-/recurvature (front/back) (degrees)	2.02	1.56	0.00	5.46
External/internal rotation (degrees)	2.18	1.36	0.01	5.52

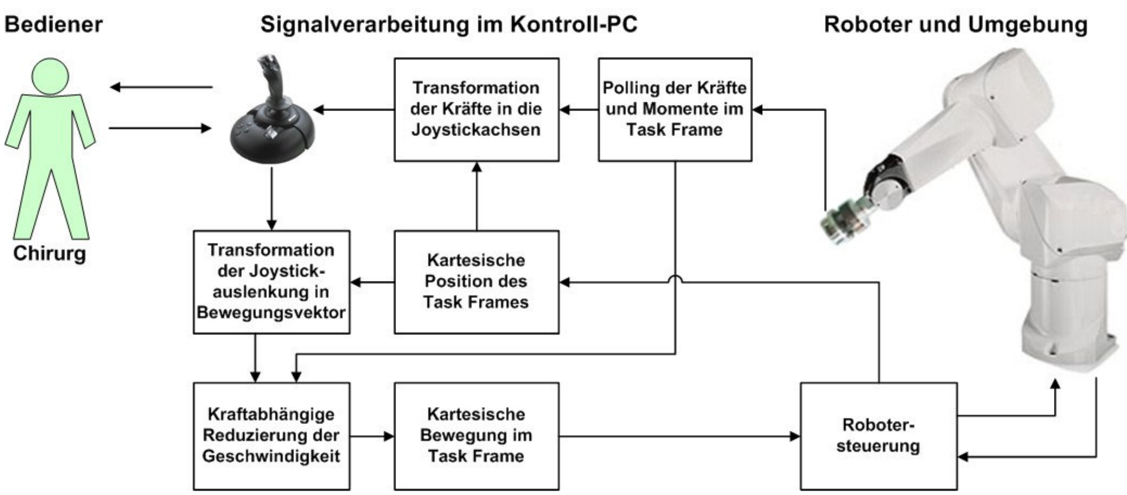
Table 3: Results for fractures of AO type C (N=16)

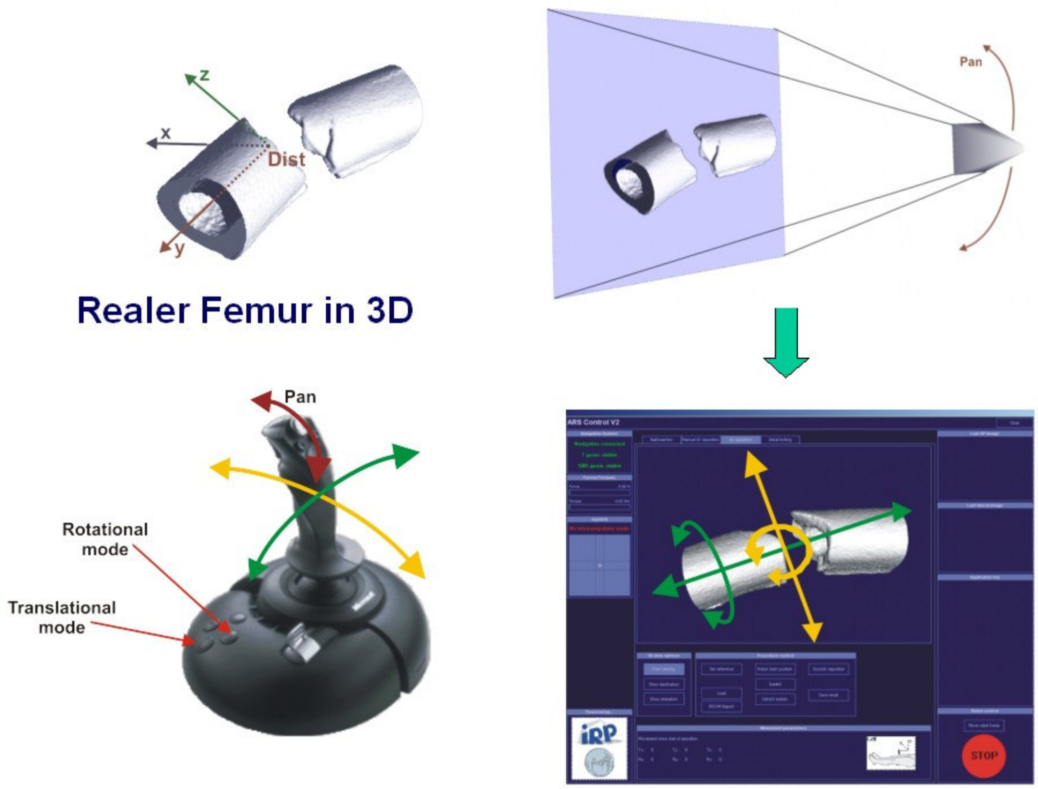
Parameter	Mean	Std. dev.	Min	Max
Reduction time (min:sec)	2:48	1:18	1:36	6:29
Axial displacement (mm)	5.55	3.10	0.70	11.30
Lateral displacement (mm)	0.96	0.48	0.26	1.69
Varus/Valgus (axial torsion) (degrees)	3.89	2.40	0.28	7.79
Ante-/recurvature (front/back) (degrees)	2.28	1.77	0.16	5.27
External/internal rotation (degrees)	1.32	0.86	0.07	2.95

Table 4: Mean values for all AO fracture types

Parameter	A	B	C
Reduction time (min:sec)	4:34	4:18	2:48
Axial displacement (mm)	1.08	2.35	5.55
Lateral displacement (mm)	1.61	2.03	0.96
Varus/Valgus (axial torsion) (degrees)	1.37	2.37	3.89
Ante-/recurvature (front/back) (degrees)	1.42	2.02	2.28
External/internal rotation (degrees)	1.09	2.18	1.32


ACHTUNG!!!
Bitte vor Ausschalten des ISO-C→ Höhe auf 0 cm herunterfahren!
3D
SIREMOBIL Iso-C
SIEMENS
STÄUBLI


Bediener
Signalverarbeitung im Kontroll-PC
Roboter und Umgebung
Chirurg
Transformation der Kräfte in die Joystickachsen
Polling der Kräfte und Momente im Task Frame
Transformation der Joystick-auslenkung in Bewegungsvektor
Kartesische Position des Task Frames
Kraftabhängige Reduzierung der Geschwindigkeit
Kartesische Bewegung im Task Frame
Roboter-steuerung


z
x
y
Dist
Realer Femur in 3D
Pan
Pan
Rotational mode
Translational mode
ARS Control V2
STOP