Planning Correction of Distal Radial Fractures Using ICP

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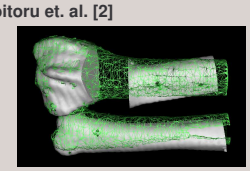
I. Introduction

Motivation

- A surgeon must manually align models of a damaged radius (white) and the mirrored radius of the opposite limb (green) in the Distal Radius Osteotomy (DRO) planner of Croitoru et. al. [2]

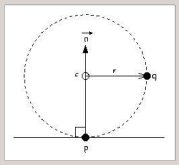


- Aligning models in 3D is time consuming and frustrating for the surgeon
- Assuming both arms are roughly symmetric, a shape-based registration algorithm such as ICP[1] might be used to speed up or even automate the alignment procedure
- We examine using ICP to align the damaged distal fragment (after corrective cut) with the mirrored radius of the opposite limb

Hypotheses

1. On average, ICP produces alignments with small angular and lengthening deviations from those planned by a surgeon
2. Using registration points of *high* curvature produces smaller deviations from surgeon-planned alignments than using all available points or points of *low* curvature

Minimal Local Curvature at a Point



The inverse of the radius (*r*, in mm) of the largest circle in the set of circles containing a point (*p*) and each neighbour (*q*) of *p*. Circle centers are located along the point normal (*n*) of *p*. Circles lie in the plane defined by *p*, *q*, and *c* [3].

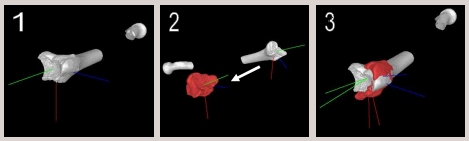
II. Methods and Materials

Ten Ground-Truth Test Scenes

From DRO plans previously executed by a single surgeon

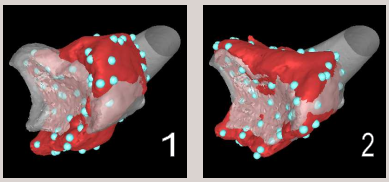
Ground-Truth Procedure

1. Axes placed manually on reflected unaffected radius (long (green), lateral (blue), palmar-dorsal (red) axes)
2. Axes mapped onto damaged distal fragment using inverse of corrective transformation in original surgical plan
3. Distal fragment manually translated roughly into place



Registration Point Selection Factors

1. Number of points (50 vs. 100)
2. Random selection vs. subsampling
3. Point set
   a. All points
   b. High curvature (min. local curv. ≥ 1/5)
   c. Low curvature (min. local curv < 1/5)
   d. Equal number of high and low curvature



Experimental Procedure

- Experimental Trials:
  1. Registration points selected from affected distal fragment
  2. ICP applied to align affected distal fragment with reflected undamaged radius
- For each test scene: one trial for subsampling conditions, 1000 trials for random selection conditions
- Factorial Design: all combinations of point selection factors above examined

Metrics Observed After Alignment:

1. Angle between long axes in anterior-posterior view (AP)
2. Angle between long axes in mediolateral view (ML)
3. Angle between palmar-dorsal axes in axial view (AX)
4. Distance between furthest affected and unaffected points along the long axis of the unaffected radius (Length)

III. Results

Table 1. Deviations of ICP Results from Original DRO Plan (10 Test Scenes, Subsampling Condition[5])

Number Points	AP[1] (degrees)	ML[2] (degrees)	AX[3] (degrees)	Length[4] (mm)
100 points				
mean, std	3.2, 2.6°	6.7, 5.9°	4.5, 5.0°	1.08, 1.06 mm
range	0.2 – 7.8°	1.7 – 19.2°	0.5 – 13.1°	0.01 - 3.24 mm
50 points				
mean, std	6.5, 4.8°	10.8, 9.1°	4.3, 4.8°	1.03, 0.78 mm
range	0.1 – 14.4°	1.5 – 27.1°	0.1 – 14.5°	0.18 - 2.75 mm

[1]AP: angular difference of long axes in anterior-posterior view
[2]ML: angular difference of long axes in mediolateral view
[3]AX: angular difference of palmar-dorsal axes in axial view
[4]Length: length difference along long axis of model bone
[5]Subsampling Condition: ICP using registration points subsampled from all affected distal fragment surface model points

ANOVA Results

- Two-way ANOVA performed for each metric (sampling, point set factors combined)
- Means of random results used to create a balanced design
- Main effect for number of points detected for the AP metric ($p < 0.05$). The mean AP value for the 100 points group (3.9°) was 1.1° smaller than the mean for 50 points (5.0°)

Qualitative Evaluation

- The surgeon that performed the original procedures visually inspected the ten results for the *subsampling 50 of all points* condition
- The surgeon classified six results as usable as-is, three as requiring minor alteration, and one as requiring 'major' alteration

Table 2. Sample ICP Distal Radius Alignment Results[1]

Informal Classification	Anterior-Posterior View	Mediolateral View	Axial View
Usable As-Is			
Minor Alteration			
Major Alteration			

[1]Using 50 registration points subsampled from the affected distal fragment

IV. Discussion

Points of High Curvature

- Likely include spurs and other artifacts on the affected distal fragment

Small Lengthening Deviations

- Possibly due to the initial translation of the affected distal fragment during test-scene creation

Experimental Design Limitations

- Used a very simple curvature metric; others may be worth studying
- Low power (only ten test scenes)

Using Multiple Initial Alignments

- Better to offer a surgeon a small set of initial alignments rather than a single one in practice

V. Conclusion

Hypotheses

1. Mean angular and lengthening deviations of ICP alignments from surgeon-planned alignments were small
2. Using registration points of high curvature *did not* reduce deviation from the surgeon-planned alignments

Visual inspection of results indicates that ICP is a useful addition to computer-assisted DRO planning

References

[1] Besl and McKay. IEEE TPAMI 1992; 14(2): 239-256.
[2] Croitoru, Ellis, Small and Pichora. LNCS 2000; 1935:1126-1135
[3] Schneider and Kobbelt. Computer-Aided Geometric Design 2001; 18:359-379.

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