Education in wrist arthroscopy
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Chapter 7
The use of navigation forces for assessment of wrist arthroscopy skills levels.

Miryam C. Obdeijn, Sophie J. van Baalen, Lisanne de Boer, Tim Horeman, Philippe Liverneaux, Gabrielle J.M. Tuijfhof

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ABSTRACT

Purpose
To provide an efficient learning process, feedback on performance is crucial. A prerequisite for a safe wrist arthroscopy is the gentle introduction and smooth handling of instruments. Thus, force related parameters could be valuable to assess arthroscopic skills. The research questions were:
- What are the forces used by novices during a wrist arthroscopy?
- What aspects of these navigation forces (e.g. in terms of magnitude or direction) are significantly different between novices and experts in wrist arthroscopy?
- What aspects of these navigation forces (e.g. in terms of magnitude or direction) show a distinct learning curve?

Methods
A cadaver wrist was mounted in a custom-made distraction device mounted in front of a force platform (ForceTrap). Eleven novices were invited to perform two tasks on a wrist:
- Insertion of the scope through the 3-4 portal and the hook through the 6R portal, and visualization of the hook in the center of the image.
- Navigation through the wrist from radial to ulnar with probing and visualization of 5 pre-defined landmarks.

Both tasks were repeated 10 times. Using the force signals in the x-, y- and z-directions, the absolute force ($F_{abs}$) per sample was calculated, as well as the force direction angle ($\alpha$) defined in the vertical plane, and the force direction angle ($\beta$) defined in the horizontal plane. The values of $F_{abs}$, $\alpha$ and $\beta$ were described by median and the 10th and 90th percentile, and were compared to those of experts using a MannWithney U test (p < 0.05).

Results
The median $F_{abs}$ was 2.1 N [0.7 – 6], $\alpha$ was 18° [-22° - 139°], and $\beta$ was -1° [-171° - 53°]. $F_{abs}$ was significantly lower compared to the expert data, and the mean force directions differed significantly from the expert data as well. There was no change in $F_{abs}$, $\alpha$ and $\beta$ after multiple trials.

Conclusion
Our results indicate that force parameters can discriminate between different skills levels, and that novices probably do not receive sufficient cues to improve their skills. This indicates that learning to navigate through a wrist and to use the tactile feedback for safe tissue manipulation could benefit from monitoring the force and the amount
of manipulation of the scope and instruments exerted during training. Although the experts used more force to navigate through the wrist, this allowed them an economy of movement and thus more precise instrument manipulation.

**INTRODUCTION**

In order to provide an efficient learning process, feedback on performance is crucial. In the clinical setting, tools like the Objective Structured Assessment of Technical Skills (OSATS) are used for assessment of skills (1-3). This type of assessment, by its nature, is subjective and time-consuming (4). Moreover they do not assess important elements that are related to safe tissue manipulation, which is mandatory in the beginning of a training process (4). In skills labs objective measurement of various aspects of surgical and endoscopic skills is possible, as well as monitoring trainees’ progression (5). A precondition is the identification of metrics that represent the learning curve of the trainees. The literature presents quite a variety of metrics of which time to task completion has been shown to be a strong predictor of task efficiency (3). Tracking of motion has also been investigated (6). Cut-off values for the scores of motion analysis devices have yet to be defined, making them only suitable for formative assessment (5). Oropesa et al. concluded that most training systems for laparoscopy assess performance using task time and motion-derived parameters like path length, speed, economy of movements and motion smoothness (3). These efficiency parameters are objective and reproducible and related to measurable physical metrics.

However, an effective performance of the task does not necessarily mean a safely performed task. A prerequisite for a safe wrist arthroscopy is the gentle introduction of the scope and secondary instruments, as well as a smooth and adequate manipulation of the instruments during the arthroscopic sweep through the wrist. Especially the cartilage needs to be respected during arthroscopy as it is a tissue with poor healing potential. Thus, force related parameters could be valuable to assess the technical skills of trainees in wrist arthroscopy.

The literature presents a few studies on measurements of forces during arthroscopy. Tashiro et al. measured both motion and force data (7). The forces and torques were measured using a six degrees of freedom sensor attached to a dummy knee. The authors conclude that motion and force data were equally able to distinguish between levels of experience in a joint inspection and probing task. In a more complicated task (meniscectomy), all force parameters were similar for each group, suggesting that beginners take care to execute safe tissue manipulation. Chami et al. measured forces and torques
during knee arthroscopies in the operating room by fitting a six degrees of freedom force torque sensor to the arthroscopic hook (4,8). Their results on ‘efficiency of movement’ and ‘consistency of performance’ indicate that it is possible to assess experience objectively using force measurements (4).

Our purpose was to further investigate the usefulness of force parameters in monitoring safe tissue manipulation. To this end, we previously studied the forces used by experts during wrist arthroscopy in a cadaver with a custom-made force platform (Table 1, Figure 1). These data were used as reference for safe manipulation for this study where we investigated the following questions:

- What are the forces used by novices during a wrist arthroscopy?
- What aspects of these navigation forces (e.g. in terms of magnitude or direction) are significantly different between novices and experts in wrist arthroscopy?
- What aspects of these navigation forces (e.g. in terms of magnitude or direction) show a distinct learning curve?

**METHODS**

**Table 1: Demographic data of the experts**

<table>
<thead>
<tr>
<th>Experts</th>
<th>Age (Years)</th>
<th>Training</th>
<th>Expert Hand Surgery (Years)</th>
<th>Expert WA (Years)</th>
<th>Nr WA per month</th>
<th>Nr KA/SA per month</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>43</td>
<td>Ortho</td>
<td>14</td>
<td>8</td>
<td>5-10</td>
<td>5-10</td>
</tr>
<tr>
<td>2</td>
<td>47</td>
<td>Ortho</td>
<td>15</td>
<td>13</td>
<td>5-10</td>
<td>None</td>
</tr>
<tr>
<td>3</td>
<td>47</td>
<td>Ortho</td>
<td>20</td>
<td>15</td>
<td>5-10</td>
<td>None</td>
</tr>
<tr>
<td>4</td>
<td>55</td>
<td>Ortho</td>
<td>27</td>
<td>26</td>
<td>&gt;10</td>
<td>None</td>
</tr>
<tr>
<td>5</td>
<td>47</td>
<td>Plastic</td>
<td>15</td>
<td>15</td>
<td>5-10</td>
<td>None</td>
</tr>
<tr>
<td>6</td>
<td>43</td>
<td>Ortho</td>
<td>13</td>
<td>12</td>
<td>5-10</td>
<td>&gt;10</td>
</tr>
</tbody>
</table>

Expert WA = years of experience in wrist arthroscopy
WA = Wrist arthroscopy
KA = Knee arthroscopy, SA = Shoulder arthroscopy
Plast = Plastic Surgery
Ortho = Orthopaedic Surgery

**Experimental set-up**

Three left-handed cadavers were used in this experiment. In a session of measurements one left-handed cadaver wrist was mounted in a custom-made distraction device (Fig. 1)
that loaded the wrist via a set of ‘traction fingers’ and a spring to 5 kg. The cadaver wrist with the distraction device was mounted in front of a special force platform (ForceTRAP) (Fig. 1). A vertically oriented base platform was used to affix both the force platform and the mounted cadaver wrist in a vertical position to mimic the clinical setting closely. The ForceTRAP was developed to measure forces during surgical actions in training settings [9,10]. The ForceTRAP contains three parallelogram mechanisms each built from two stiff elements and two spring blades that decouple the applied forces from the moments [9]. This allows measurement solely of the applied forces, without measuring the moments. The ForceTRAP measures forces from 0 to 20 N in three dimensions, with an accuracy of 0.1 N and a sample frequency of 100 Hz. This set-up records the combined forces exerted on the cadaver wrist by the arthroscope and the hook. Thus the forces are a summation of direct (e.g. probing) and indirect (e.g. force on the portal) tissue manipulation.

In addition to the recording of the forces, two CCD cameras (Bullet CCD Camera model DV-2301CW360, Shenzen D-Vitec Industrial Co. Ltd., Shenzhen Guangdong, China) and one digital video camera (GRD77, JVC, Kanawaga-ku Yokohama, Japan) were used to record the arthroscopic tasks from both sides and above the hand (Fig. 1). The images from the 3 cameras and the arthroscopic view were recorded simultaneously and represented in a split screen image using a colour quad processor (QC-904R, Przedsiębiorstwo

Figure 1: A = Cadaver wrist; B= Camera; C= tripod; D= Vertical traction device; E= Force Platform; F= Force Platform Holder; G= Laptop registering the data; Input = From the 3 camera’s and the scopic image
Wielobranzowe, Poznań, Poland) and an analogue-to-digital converter (Canopus® ADVC 110, GrassValley Thomson, San José, USA) (Fig. 1).

To perform the arthroscopic tasks, an instrument set and a 30° angled - Ø2.4 mm arthroscope from Karl Storz (Germany) were used. Before the start of the experiment the senior author (MO) established the 3-4 portal and the 6R portal in each of the cadaver wrists.

**Participants**

Eleven participants were recruited (Table 2). The participants were residents in training for plastic surgery or orthopaedic surgery. None of the participants had any experience in performing wrist arthroscopy. The residents in training for orthopaedic surgery had some experience in assisting during knee arthroscopies, but they had experience of less than 5 procedures in which they performed the procedure by themselves. We considered this experience negligible, as independent performance of 50 knee arthroscopies is considered needed to become competent [11].

**Table 2: Demographic data of the novices**

<table>
<thead>
<tr>
<th>Novices</th>
<th>Age (Years)</th>
<th>Training</th>
<th>Hand surgery experience (y)</th>
<th>Nr WA</th>
<th>Nr KA/ SA (total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>31</td>
<td>Plastic</td>
<td>3</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>2</td>
<td>29</td>
<td>Ortho</td>
<td>1</td>
<td>None</td>
<td>&lt;5</td>
</tr>
<tr>
<td>3</td>
<td>28</td>
<td>Ortho</td>
<td>1</td>
<td>None</td>
<td>&lt;5</td>
</tr>
<tr>
<td>4</td>
<td>27</td>
<td>Plast</td>
<td>0</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>5</td>
<td>27</td>
<td>Ortho</td>
<td>1</td>
<td>None</td>
<td>&lt;5</td>
</tr>
<tr>
<td>6</td>
<td>37</td>
<td>Plastic</td>
<td>3</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>7</td>
<td>33</td>
<td>Plastic</td>
<td>1</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>8</td>
<td>33</td>
<td>Plastic</td>
<td>2</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>9</td>
<td>33</td>
<td>Plastic</td>
<td>1</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>10</td>
<td>32</td>
<td>Surgery</td>
<td>0</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>11</td>
<td>31</td>
<td>Plastic</td>
<td>2</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

WA = Wrist arthroscopy  
KA = Knee arthroscopy, SA = Shoulder arthroscopy  
Plast = Plastic Surgery  
Ortho = Orthopaedic Surgery
Study design
Two tasks were defined that reflect important steps in learning wrist arthroscopy and require safe tissue manipulation. First, the creation of portals is an important step during arthroscopy. As we used cadavers, only one set of portals could be created per cadaver that would not reveal sufficient data to draw any conclusions. Therefore, we focused on insertion of the arthroscope and hook, which could be repeated multiple times. Similar to portal localisation, the insertion of the arthroscope is also primarily guided by haptic feedback. Second, safe navigation and orientation in the wrist is difficult due to the confined complex shapes in the wrist and the 30° oriented arthroscope. To be able to compare all data, the tasks were more specifically defined as follows:

Task 1 Insertion
This task consisted of two separate steps. The participants were required to insert the arthroscope through the 3-4 portal and visualize the central part of the radiocarpal joint. Subsequently, they were required to insert the arthroscopic hook through the 6R portal and visualize the tip of the hook in the centre of the arthroscopic image.

Task 2 Navigation and probe
This task consisted of five separate steps. With the instruments in the above-mentioned portals, navigation had to be performed through the wrist from the radial to the ulnar PSR while probing five predefined anatomic landmarks consecutively: radial styloid process (PSR), scaphoid (SC), scapholunate ligament (SL), lunate (LU) and triquetrum (TR)(12). Each structure had to be touched by the hook and visualized in the centre of the arthroscopic image (Fig. 2). For this purpose, a circle with a diameter of 18 cm was glued to the screen.

Each participant performed the insertion task. The time needed to insert the arthroscope and the time needed to visualize the hook in the centre of the arthroscopic image were documented separately. Subsequently, each participant performed the navigation
task. The first author stood next to the participants, verifying visually whether each of the structures had been visualized according to the protocol. Once the structure had been visualized correctly, the participant was allowed to proceed to the next anatomic landmark. There was no urging to perform the tasks as fast as possible. The participants were asked to perform the tasks as if they would be operating on a real patient. The total task time was defined as the summation of all time periods to identify and probe each of the five landmarks of Task 2. Both tasks were repeated 10 times. The participants were randomly allocated to the different wrists, so as to use each wrist a maximum of 4 times. Only the forces that were exerted within the indicated timeframes were used for further analysis.

**Data processing and statistical analysis**

The data were processed using *Matlab* (version R2011b, The Mathworks Inc., Natick MA, USA) and *IBM SPSS Statistics* (version 19, SPSS Inc., Chicago, IL, USA). The task times for all seven steps were determined and used to select the force trajectories for further processing. Using the force signals in the x-, y- and z-directions the absolute force (*Fabs*) per sample was calculated from the square root of *Fx*, *Fy* and *Fz* force components. The angle (α) is defined in the vertical plane, which is aligned with the cadaver wrist mounted in the set-up (Fig. 1). A positive angle implies upward distal rotation and a negative angle implies downward proximal rotation. The angle (β) is defined in the horizontal plane, where a positive angle implies rotation to the ulnar side and a negative angle implies rotation to the radial side. The experts performed the same two tasks on a different specimen and their data were processed identically as described for the novices.

The presence of normal distributions for the parameters (*Fabs*, α and β) was assessed with the Kolmogorov-Smirnov test for the seven individual landmarks and both tasks combined. As the data were not normally distributed, they were expressed as median. Normally, the median is complement with the minimum and maximum values, but as we processed the raw data without filtering we propose to use the 10th and 90th percentile of the datasets for visualisation. The raw datasets of the novices for *Fabs*, α and β were compared to those of the experts as previously measured using a Mann-Whitney U test (p < 0.05) to highlight any significant differences. For illustration purposes, the descriptive values of *Fabs*, α and β of both tasks combined as executed by the novices are graphically presented per trial together with the proposed safe threshold values for *Fabs*, α and β that were previously determined from expert data. These thresholds are proposed to consist of the 10th and 90th percentile as indicated in Table 3. As these experts all had more than 8 years of experience in wrist arthroscopy (Table 1), we assumed that they are at the end of the learning curve for wrist arthroscopy. Therefore, we considered the forces they use to be safe for wrist arthroscopy. Inherent to the navigation task angle
The use of navigation forces for assessment of wrist arthroscopy skills levels.

β shifts from radial (negative) to ulnar (positive) when navigating through the wrist. Therefore, angle β is presented per landmark for all novices. The presence of a learning curve for the median of \( F_{\text{abs}} \), the minimum of \( F_{\text{abs}} \), the maximum of \( F_{\text{abs}} \), the median of \( \alpha \) and \( \beta \) were determined per landmark and total task using a Friedman test. The Friedman test is similar to the parametric repeated measures ANOVA, and it is used to detect differences in treatments across multiple test attempts. Only the results of the 1st, 5th and 10th trial were used, therefore the significance level was set at 0.05.

\[ \text{RESULTS} \]

The overall magnitude and force directions \( (F_{\text{abs}}, \alpha \) and \( \beta) \) for both tasks are summarized in Table 3. Noticeable are the substantial larger ranges of the 10th and 90th percentiles of the novices compared to the experts. All three parameters \( (F_{\text{abs}}, \alpha \) and \( \beta) \) show significant differences between novices and experts with the force magnitude applied by novices being lower, the angle in the vertical plane being lower and the angle in the horizontal plane being shifted to the radial side (Table 3). The lower angle \( \alpha \) indicates that the novices keep their scope in a more horizontal plane, failing to follow the natural inclination of the radius.

![Table 3](image)

<table>
<thead>
<tr>
<th></th>
<th>Novices (n= 11)</th>
<th>Experts (n= 6)</th>
<th>Mann Withney</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median [10th – 90th perc.]</td>
<td>Median [10th – 90th perc.]</td>
<td>U</td>
</tr>
<tr>
<td>( F_{\text{abs}} ) [N]</td>
<td>2.1 [0.7 – 6]</td>
<td>3.8 [1.8 – 7.3]</td>
<td>p &lt; 0.05</td>
</tr>
<tr>
<td>( \alpha ) [deg.]</td>
<td>18 [-22 - 139]</td>
<td>26 [0 - 72]</td>
<td>p &lt; 0.05</td>
</tr>
<tr>
<td>( \beta ) [deg.]</td>
<td>-1 [-171 - 53]</td>
<td>4 [-54 - 44]</td>
<td>p &lt; 0.05</td>
</tr>
</tbody>
</table>

Similar values are given for the angles \( \alpha \) and \( \beta \), which indicate the direction of \( F_{\text{abs}} \) in vertical and horizontal plane, respectively. 10th percentile for \( \alpha \) is defined as rotation to the dorsal side and the 90th percentile is defined as rotation to the volar for a left wrist. 10th percentile for \( \beta \) is defined as rotation to the radial side for a left wrist and the 90th percentile is defined as rotation to the ulnar side for a left wrist. All three parameters are significantly different between novices and experts.

Figure 4, shows the graphical presentation of the magnitude of forces per trial as applied by the novices. More specifically, the median values (bars) and the 10th and 90th percentiles (error bars) of \( F_{\text{abs}} \) for all novices and landmarks together are plotted per trial. The horizontal lines indicate the 10th and 90th percentile of \( F_{\text{abs}} \) of the experts (Table 3). The median \( F_{\text{abs}} \) of the novices remains the same and is located at the 10th percentile threshold of the experts. The range of \( F_{\text{abs}} \) formed by the 10th and 90th percentiles remains similar by repeated trials executed by the novices. Figure 5, has an identical structure,
but shows the results of angle $\alpha$, the direction of the force in the vertical plane as defined in Figure 1. The range of angle $\alpha$ as indicated by the error bars is consequently larger than the threshold lines. Figure 6, shows angle $\beta$ per landmark per trial for all novices. The direction of force in the horizontal plane is quite similar to those of the experts for probing the radial styloid process. Also the shift from radial to ulnar can be identified from the radial styloid towards the lunate when viewing the median values. Again a noticeable difference is shown between the ranges of angle $\beta$ and the threshold ranges as measured with the experts. The experts also use quite a large range of force direction in the horizontal plane to insert the scope.

As already suggested by Figures 4-6, but confirmed by the Friedman tests, no significant differences were found between the 1st, 5th and 10th trial of the novices for all parameters (median, minimum and maximum of $F_{abs}$ and median of $\alpha$ and $\beta$). Consequently, there was no improvement of skills for any of the tested parameters.

**DISCUSSION**

Objective, reliable and reproducible evaluation of skills is important in training of arthroscopic procedures, not only to monitor skills progression but also safe tissue handling (13,14,15). The findings of this study indicate that force information during...
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Figure 5: The median values of the angle $\alpha$ of all novices for both Task 1 and 2 per trial. The error bars indicate the 10th and 90th percentiles of $\alpha$. The two horizontal dotted lines indicate the 10th and 90th percentile of $\alpha$ of the experts.

Figure 6: The median values of angle $\beta$ of all novices for 6 landmarks per trial. The error bars indicate the 10th and 90th percentile of $\beta$. The two horizontal dotted lines indicate the 10th and 90th percentile of $\beta$ of the experts.
training in wrist arthroscopy can be recorded and that there is a significant difference between novices and experts.

Furthermore, the ranges of the force directions in both planes remain consistently large compared to the smaller ranges of the experts. A smaller range of force directions indicates a smoother movement.

Since the forces exerted on the wrist cannot be seen or felt by the supervisor, it is difficult to give adequate directions. As we demonstrated in accordance with other studies that objective force measurement is possible in a skills training setting, the next step can be taken to provide and implement proper feedback as determined from the measurements. For example Horeman et al. studied force feedback by providing a coloured arrow visualized in the arthroscopic view with augmented reality. The colour of the arrow indicates proper (green) or improper (red) tissue contact and the direction of the arrow indicates the direction of the force. (16). Other cues are also feasible such as audible signals.

This study has limitations. All of the testing was done on cadaver specimens, which may not approximate the clinical situation. Furthermore, the establishment of the portals was not assessed, which is a major difficulty for most novice arthroscopists. The numbers were too small to perform a statistical analysis to determine if the force parameter and angle $\alpha$ and $\beta$ differences between the novices and the experts was statistically significant. Measurements were performed on only three cadaver wrists and 11 participants. After repetitions the portals will widen and tissue inside the wrist can deteriorate. We took measures to minimize this by using several wrists and creation of the portals by ourselves to make sure they were at the proper location. This was a trade-off, since using more than one cadaver introduces a bias in terms of complexity. Different wrists could have been more tight or present scar tissue. To minimize the differences, M.O. performed the navigation task after the creation of the portals and removed fibrous tissue to allow normal navigation.

The tasks were repeated 10 times. Compared to the numbers of repetitions needed to become proficient in wrist arthroscopy, these repetitions are few. However, this study is not about acquiring proficiency, but investigates the possible contribution of force parameters to reflect skill improvement in two specifically defined tasks. Based upon other studies, where for example task time has been known to decrease quite rapidly after up to ten times of task repetition (17,18,19), we expected to see changes in the magnitude of the studied parameters.
Lastly, as we used the cadaver wrist more than one time, no dissection of the wrist was performed to assess the amount of damage to the cartilage.

As Howells et al. eloquently described: Arthroscopy has some notable differences in techniques compared to other operative procedures. One hand is often used for camera manipulation, the instruments are shorter, the operating field is a more confined space and there is greater degree of tactile feedback from the cartilaginous surfaces (14). Our results indicate that learning to navigate through a wrist and to use the tactile feedback for safe tissue manipulation could benefit from monitoring the force and the amount of manipulation of the scope and instruments exerted during training. Although the experts used more force to navigate through the wrist, this allowed economic motion and possibly prevented cartilage injury by more precise instrument manipulation. This is in concordance with the findings of Tashiro et al. who showed that compared to experienced surgeons trainees had more unnecessary movements. Probably the magnitude of the force might not be as important. This could be due to the fact that the articular injury does not occur by “pushing” the cartilage with the probe but rather by improper positioning of the instruments. This could be further investigated in future research.

Acknowledgment: We would like to thank Juul Alewijnse for her assistance during the measurements and during the preparation of this manuscript.
REFERENCES


