Education in wrist arthroscopy
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Chapter 5
Design and preliminary validation of a new wrist arthroscopy simulator


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ABSTRACT

Purpose
Wrist arthroscopy is taking up an important place in hand surgery. The purpose of this study was to build a wrist arthroscopy simulator to train the key navigation and probing skills required for a diagnostic wrist arthroscopy.

Methods
Our starting point was to keep the simulated environment as close as possible to the real-life situation by using normal equipment and replacing the joint by a physical anatomical model that can be mounted on a force platform to track performance.

The specific requirements for the simulator were determined by questioning a panel of experts. These were translated in technical demands regarding the intra-articular structures and the skin. Especially the skin substitute was tested to provide the same elastic and resistance properties as human skin. A prototype was built and tested for face validity by asking the opinion of 14 experts.

Results
All 14 participants found the simulator a good tool to teach wrist arthroscopy. The aspects that were paid most attention to in the design demonstrated face validity: realism of the lubricated top layer (mean 7.7 / SD 1.6), realistic size of the joint structures (mean 7.7 / SD 1.6) and realistic arthroscopic image (mean 7.9 / SD 1.2). The flexibility of the prototype (mean 6.0 / SD 2.3) and the color of the structures (mean 5.4 / SD 1.9) were rated lower. The structures that the experts missed most were the TFCC and the volar ligaments.

Conclusions
The concept to use a physical model for wrist arthroscopy training is well perceived, and indicates the potential for continued development

Clinical relevance
Training of skills is a prerequisite for good clinical care and should start outside the operating room for patient safety reasons. By introducing a validated wrist arthroscopy simulator, we have added a necessary and relevant training tool.
INTRODUCTION

Clinical medicine is becoming more focused on patient safety and quality than on bedside teaching and education (1). To ensure adequate education, new methods have been introduced to shift the training of certain psychomotor skills away from the operating room into the skills lab environment (2).

Over the last decades, a number of simulators have been developed for the training of basic laparoscopic skills (3-5). By training the elementary endoscopic skills in a simulated setting, such as eye-hand coordination, unnecessary errors during the learning phase of the live operation can be reduced (6-8). Furthermore, the progress of training in the operating room can be accelerated after such basic psychomotor skills training (6). For general surgery and gynecology, this has led to simulator training becoming part of residents’ curricula (9), although this is not yet the case for the training of arthroscopic skills. However, several authors have stressed the fact that teaching of arthroscopic skills lends itself well to training on a simulator (10-12). Arthroscopy is performed in a 3-dimensional environment, yet surgeons have to rely on a 2-dimensional camera image for visual feedback. Compared to laparoscopy, arthroscopy poses the additional challenge of maneuvering in a small space.

Arthroscopic simulators have been developed and are being validated for knee and shoulder arthroscopy (12-14). Recently in a review, Slade Shantz et al. compared the internal validity of arthroscopic simulators and their effectiveness in arthroscopic education. They concluded that the currently available simulators appear to demonstrate the ability to discriminate between participants at both ends of the skills spectrum (novices and experts), but not yet between novices and intermediates, which is paramount in surgical education (15). Furthermore, standardized methods of simulator validation are required to demonstrate the utility of arthroscopic simulators in arthroscopic education (15).

Compared to knee and shoulder arthroscopy, the wrist poses the additional challenge of a very narrow joint space with an inclination in the dorsal to volar direction and a curvature in the radial to ulnar direction (Fig. 1). Furthermore, many structures, such as tendons and nerves, cross the dorsal surface of the wrist making the placement of the entry portals a challenge. Correct portal placement is crucial for the safe and efficient execution of a wrist arthroscopy. Orthopedic residents indicate it as one of the skills residents should possess before continuing their training in the operating room (16-17).
Currently, only three wrist arthroscopy simulators can be found on the Internet. The first is a virtual reality simulator presented by Yaacoub et al. in 2008 (18). No proof of concept or validation was found, nor signs of further development. The other two are physical anatomical bench models, marketed by CLA webs-ref1 and Sawbones webs-ref2. No papers on the validation of these training models could be found either (18). Wrist arthroscopy is not yet as widespread as knee and shoulder arthroscopy, but it is becoming more important in the hand surgery practice (19). As the number of specialists performing wrist arthroscopy is increasing (19), there will also be an increasing need for proper training modalities. Consequently, there is room for a validated wrist arthroscopy simulator dedicated to the training of hand surgery residents.

The purpose of this paper is to present the design and preliminary validation of a new concept of a wrist arthroscopy simulator. The design requirements were defined on a theoretical basis and expert opinion. The production of this simulator should also be affordable to allow its introduction into every teaching hospital. For this reason, we applied the theoretical design requirements for a simulator focused on training psychomotor skills as described by Motola et al. (20). In summary, the simulator should: (a) represent reality by providing natural, visual and haptic sensory feedback (face validity); (b) train what is important to train (internal validity); (c) be able to discriminate between different expert groups (construct validity); and (d) be capable of performance feedback. Our hypothesis was that a validated wrist arthroscopy simulator would be perceived by the future users as a useful tool to teach wrist arthroscopy skills.

![Figure 1: Radiocarpal joint space with a curvature in the radial to ulnar direction (a) and an inclination in the dorsal to volar direction (b)](image-url)
METHODS

Defining the requirements for a wrist arthroscopy simulator

The requirements for an adequate resemblance to reality of the wrist arthroscopy simulator were determined by questioning a panel of expert surgeons. For this purpose, an electronic questionnaire (compiled using Google Docs) was sent to the members of the EWAS (European Wrist Arthroscopy Society). This questionnaire was composed of questions about the position of wrist arthroscopy in their daily practice and the way wrist arthroscopy is currently taught (21). The expert panel was also asked to answer one yes/no question and two open questions concerning a wrist arthroscopy simulator. The questions were:

- Do you think a wrist arthroscopy simulator would be an asset in teaching wrist arthroscopy?
- Which things do you think can be taught on a wrist arthroscopy simulator?
- Which things do you think cannot be taught on a wrist arthroscopy simulator?

The response rate to the questionnaire was 35% (64 / 185). The summary of the answers to these questions is that 60 out of 64 participants (94%) confirmed a need for a wrist arthroscopy simulator. The aspects that were considered most important to train were: normal anatomy, diagnostic arthroscopy, basic interventions, portal placement and triangulation skills (Table 1).

These responses from the survey were reviewed with a small group of experts and weighted for their importance. The defined skills were similar to the top five specific skills identified by Safir et al. among orthopedic surgeons, and by Hui et al. among orthopedic residents (16,17).

For this simulator, we decided to focus on three specific tasks for wrist arthroscopy:

- Placement of portals and introduction of the scope and the hook into the radiocarpal space (portal placement).
- Visualizing the hook centrally in the arthroscopic image (triangulation skill).
- Diagnostic sweep through the wrist from the radial to the ulnar side following the radio-ulnar curvature (diagnostic arthroscopy).

Training of therapeutic interventions can be incorporated into future versions of this proposed wrist simulator.

In addition, the experts were asked which anatomical structures (skin components, bones, ligaments and other structures) should be present in a simulator. The most
frequently mentioned anatomical structures were the superficial nerves, the styloid processes of the radius and ulna, Lister’s tubercle, the triangular fibrocartilage complex (TFCC) and the volar capsular and intercarpal ligaments (Table 2).

Table 1: Summary of the results of the survey among EWAS members. (The number between brackets is the number of times this aspect was mentioned. N=65)

<table>
<thead>
<tr>
<th>Can be taught</th>
<th>Cannot be taught</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal anatomy (15)</td>
<td>Feedback / Tissue handling (7)</td>
</tr>
<tr>
<td>Basic interventions like shaving (14)</td>
<td>Pathology (6)</td>
</tr>
<tr>
<td>Diagnostic arthroscopy (14)</td>
<td>Difficulties in visualization (6)</td>
</tr>
<tr>
<td>Orientation (3D) (12)</td>
<td>Haptic feedback / Feeling of the skin (5)</td>
</tr>
<tr>
<td>Portal placement (11)</td>
<td>Interventions like synovectomies (4)</td>
</tr>
<tr>
<td>Triangulation skills (10)</td>
<td>Real-life factors like time and stress (4)</td>
</tr>
<tr>
<td>How to use the scope (8)</td>
<td>TFCC reattachment (3)</td>
</tr>
<tr>
<td>How to use the instruments (8)</td>
<td>Clinical judgment / Indications (3)</td>
</tr>
<tr>
<td>Moving in a small joint space (6)</td>
<td>Fragility of the cartilage (3)</td>
</tr>
<tr>
<td>Everything can be taught (5)</td>
<td>Pearls and pitfalls (2)</td>
</tr>
<tr>
<td>Introduction of instruments (4)</td>
<td>Instability assessment (2)</td>
</tr>
<tr>
<td>Hand-eye coordination (3)</td>
<td>Fracture manipulation (2)</td>
</tr>
<tr>
<td>Technical skills (3)</td>
<td>Fluid extravasation (2)</td>
</tr>
<tr>
<td>Recognizing pathology (3)</td>
<td>Dexterity (2)</td>
</tr>
<tr>
<td>TFCC examination (3)</td>
<td>Patient set-up (2)</td>
</tr>
<tr>
<td>Gentleness (2)</td>
<td>Anomalies / Anatomical variations (1)</td>
</tr>
<tr>
<td>Ligament assessment (2)</td>
<td>Evaluation of findings (1)</td>
</tr>
<tr>
<td>Theory (2)</td>
<td>There is nothing that cannot be taught (1)</td>
</tr>
</tbody>
</table>

Table 2: Required structures for a wrist arthroscopy simulator according to the participants of the survey (N=65)

<table>
<thead>
<tr>
<th>Superficial</th>
<th>%</th>
<th>Bones</th>
<th>%</th>
<th>Ligaments</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Branches of radial nerve</td>
<td>86</td>
<td>Carpal bones</td>
<td>9</td>
<td>Volar capsular ligaments</td>
<td>83</td>
</tr>
<tr>
<td>Branches of ulnar nerve</td>
<td>86</td>
<td>Radius / Ulna</td>
<td>92</td>
<td>Intercarpal ligaments</td>
<td>91</td>
</tr>
<tr>
<td>Extensor tendons</td>
<td>18</td>
<td>Appropriate RC angle</td>
<td>80</td>
<td>TFCC</td>
<td>94</td>
</tr>
<tr>
<td>Superficial veins</td>
<td>41</td>
<td>Lister’s tubercle</td>
<td>80</td>
<td>Synovial tissue</td>
<td>49</td>
</tr>
<tr>
<td>FCR</td>
<td>1</td>
<td>Cartilage</td>
<td>63</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

% = Percentage of the respondents that mentioned this structure as being important.
Other structures mentioned were: NIP (24%), DRU, dorsal capsule, midcarpal joint and TC joint (all only mentioned once)
Based on the theoretical criteria mentioned in the introduction, and these responses from the wrist arthroscopy experts on both the teaching goals and the anatomical structures to be incorporated, the following design criteria were defined:

- Realistic feel of the skin.
- Possibility to teach portal placement.
- Realistic representation of the carpal bones.
- Sufficient space between the bones to navigate.
- Semi-flexibility of the volar plate.
- Representation of the volar ligaments.

Although five experts indicated in the survey that the feeling of the skin cannot be simulated (Table 1), we took up the challenge to design a skin that would feel natural, as this is crucial to train portal placement. For the design of realistic skin tissue, more detailed requirements were set. Namely, the skin substitute should not tear once portals are created and the skin should feel realistic. This realistic feel is characterized by the skin softness, the ability to palpate the bony structures through the skin for orientation, and the adequate resistance of the skin when it is penetrated with the mosquito or trocar. Furthermore, we decided to make a skin substitute that would be replaceable to allow for multiple trainings of portal placement on one simulator.
Regarding performance tracking, similar to other anatomical bench models, the task time can be measured with a separate stopwatch. For this design of the wrist simulator, we also wanted to be able to mount the prototype simulator in front of a force platform that would allow performance tracking by measuring the time and forces, and would provide visual feedback on the amount of force that is applied during the exercise (Fig. 2) (22). Previous studies have shown that these forces are indicative of the level of experience when training navigation and probing in the wrist joint (23). As the use of this force platform has already been studied, this part is not further analyzed in this paper.

**Building of a prototype wrist arthroscopy simulator that met the defined criteria**

Once the criteria (both physical and functional) had been set, the choices for the design of the simulator could be made. Using a previously presented philosophy on the design of simulators that closely resemble reality (2), we made the fundamental choice to design a physical anatomical wrist model. The advantage of this approach is that actual instruments can be used during training and, if properly designed, this anatomical bench model offers realistic visual and haptic feedback that is crucial for the training of wrist arthroscopy. On the basis of these requirements, the design of the prototype wrist arthroscopy simulator was executed with a focus on two parts: offering a realistic intra-articular joint space and offering a realistic skin substitute.

*Intra-articular joint space*

The realistic representation of the carpal bones in their distracted position was achieved by making a CT scan of a living human wrist in distraction using a 5 kg weight. The images were segmented and printed with a 3D printer (STT1200es 3-D printer, Dimension Inc. Material: Acrylonitrile butadiene styrene).

To ensure that the carpal bones remained in their relative position while still allowing some movement, they were embedded in a volar plate made of silicone and anchored using bolts (Fig. 3). The choice of a plate located at the volar side was made because routinely used portals are on the dorsal side of the wrist. The volar and dorsal ligaments have a complicated anatomy that makes it difficult to reproduce them realistically with the correct amount of tension. The volar plate offers the same functionality as it holds the carpal bones in an anatomically aligned position while also offering some flexibility. With regard to construction, it is a good alternative and allows for representative training.
Figure 3: Attachment of the carpal bones to the volar plate
(a) Volar view: Printing reinforcement is partially removed. Wax has been added on the dorsal side to keep the carpal bones in the distracted position while small bolts are attached to the palmar side of the bones.
(b) Dorsal view: The carpal bones with the bolts have now been fixed to the silicone palmar plate en the dorsal wax has been removed.

Figure 4: Representation of the intercarpal ligaments
The yellow arrows indicate the silicon injected around the cords, between the carpal bones to mimic the intercarpal ligaments.
Cords were threaded through the radius, the ulna and the scaphoid, lunate and triquetrum. Air-dying silicone was then injected around the cords to mimic the inter-carpal ligaments (Fig. 4).

Construction of the skin coverage
To mimic the natural behavior of the skin when performing arthroscopy and especially when creating portals, the substitute skin was built up out of two layers – a durable reinforced base layer covered by a thin flexible layer. This allows skin shifting upon palpation and prevents tearing once a portal is created. For adequate portal placement, the palpation of the anatomical landmarks is important. Therefore the compressibility or hardness of the substitute skin was matched with that of actual skin. The hardness of a material can be expressed on a Shore hardness scale. Kissin et al. (24) determined the Shore hardness of the skin of the hand to be 16 ± 5 (durometer scale 0). The substitute skin was made of silicone with a Shore A hardness of 10 (Smooth-On 940, Dragon Skin, Form x, Amsterdam, The Netherlands). The 2.5 mm-thick base layer was reinforced with gauze to prevent tearing once the portals are made. The top layer was 1 mm thick and had no reinforcement. In between the silicone layers a film of lubricating oil was applied to allow gliding of the top layer over the base layer.

To fix the skin to the bony structure and to cope with the triangular shape of the anatomical carpal bones model, the skin was laced at the back in order to fit tightly over the bony structures (Fig. 5).

Technical validation of the wrist arthroscopy simulator
As the skin is such an important feature of this new wrist arthroscopy simulator, considerable effort was put into the evaluation of its behavior from a technical point of view before it was actually tested with subjects. Especially the tear strength and force generation in the portals were tested to assess the skin quality. The evaluation was performed using data on human skin behavior as presented in the literature.

The skin substitute should be able to withstand the forces exerted during manipulation of the instruments without tearing. Saulis et al. determined the tear strength of human skin by measuring the force required to pull a 3.0 Vicryl suture through cadaver skin samples. The average force required to tear the skin was 36 N (SD 9 N) (25). A literature search revealed no reports of the forces exerted on the skin during wrist arthroscopy. We therefore used the average force measured by Saulis et al. plus three times its standard deviation as an indication for the upper limit of the tear strength of human skin tissue (minimum tear strength = 62 N). To assess the resistance against tear propagation in the mimicked reinforced deep-layer skin, a rod (diameter = 3 mm) was fixed to a tensile
Figure 5: Fixation of the skin substitute to the model.
Lacing hooks are fixed to the gauze at the edges of the skin substitute. By treading a cord along the hooks, the skin substitute can be fixed tightly around the carpal bones in the silicon base plate.

Figure 6: Forces on the cadaver wrist and on the wrist arthroscopy simulator
Box plot of the absolute forces exerted in the last five repetitions by one surgeon. Box plots 1 (W1) and 2 (W2) are the forces exerted on two cadaver wrists and box plot 3 (Simulator) represents the forces exerted on the simulator.
testing machine positioned in a prefabricated hole in the mimicked skin. In 30 seconds the skin material was displaced 15 cm with respect to the fixed rod at a constant speed. The average break force of the reinforced deep-layer skin was 69 N (SD 5 N). We thus considered this mimicked skin to be fulfilling the requirement regarding the tear strength.

The performance of a diagnostic arthroscopy was mentioned as one of the things a simulator should be able to train. In order to assess whether the movements executed in the wrist arthroscopy simulator are comparable to the movements made during a cadaver wrist arthroscopy, an expert performed a diagnostic sweep through a cadaver wrist mounted in front of the aforementioned force measurement platform. The same expert performed the same diagnostic sweep in the wrist arthroscopy simulator mounted in front of the same force platform. This preliminary evaluation showed that the forces exerted are within comparable ranges as depicted in the box plots (Fig. 6). These results indicated that a diagnostic sweep through the simulator has a comparable feeling to a diagnostic sweep through a cadaver wrist.

**Does the simulator prototype fulfill the requirements of the future users?**

To answer our main research question and to assess the face validity of the prototype, it was tested at the international hand surgery conference (FESSH Antwerp 2012). Experts (defined as performing >5 wrist arthroscopies per month) were asked to test the prototype. Each participant filled in a questionnaire specifically designed to analyze arthroscopy simulators. This questionnaire is an adapted version of the general arthroscopy questionnaire presented by Tuijthof et al. and is scored predominantly on yes/no answers and a 10-point visual analog scale (26). Besides the questions with a visual analog scale, four open questions were asked. The experts were asked about (1) the usefulness of the simulator for training wrist arthroscopy, (2) how good it would be in preparing residents for a real wrist arthroscopy, (3) their opinion on the outer appearance of the simulator, and (4) crucial anatomical structures that were missing from the prototype.

**RESULTS**

Fourteen participants were included in the evaluation. Of these participants, five performed between five and ten arthroscopies per month and the other nine performed more than ten wrist arthroscopies per month. The items with the highest scores were the realism of the skin feel, the size of the joint structures, the joint spaces and the arthroscopic image (Table 3). A high score was given for the suitability of the simulator as a training modality. Relatively low scores were given to the flexibility of the physical
Table 3: Results of the survey among wrist arthroscopy experts during the FESSH in Antwerp (2012)

<table>
<thead>
<tr>
<th>Item</th>
<th>Experts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>Realism of outer appearance</td>
<td>7.0</td>
</tr>
<tr>
<td>Realism of flexibility</td>
<td>6.0</td>
</tr>
<tr>
<td>Realism of palpation anatomical landmarks</td>
<td>6.1</td>
</tr>
<tr>
<td>Realism of lubricated top layer</td>
<td>7.7</td>
</tr>
<tr>
<td>Realism of trocar insertion force</td>
<td>7.2</td>
</tr>
<tr>
<td>Realism of arthroscope manipulation forces</td>
<td>7.1</td>
</tr>
<tr>
<td>Realism of intra-articular anatomy</td>
<td>6.7</td>
</tr>
<tr>
<td>Realism of texture of structures</td>
<td>6.1</td>
</tr>
<tr>
<td>Realism of color of structures</td>
<td>5.4</td>
</tr>
<tr>
<td>Realism of size of structures</td>
<td>7.7</td>
</tr>
<tr>
<td>Realism of size of joint spaces</td>
<td>8.0</td>
</tr>
<tr>
<td>Realism of arthroscopic image</td>
<td>7.9</td>
</tr>
<tr>
<td>Suitability as a training modality in a skills lab</td>
<td>8.3</td>
</tr>
<tr>
<td>Value of portal placement</td>
<td>7.1</td>
</tr>
</tbody>
</table>

Face validity rating on a scale of 0 to 10

Figure 7: Radiocarpal arthroscopic view of the simulator
model (mean 6.0 / SD 2.3) and the color of the anatomical structures (mean 5.4 / SD 1.9). By contrast, the realism of the arthroscopic image was rated with a high mean of 7.9 (SD 1.2) (Fig.7). All 14 participants found the simulator to be a useful addition to the training curriculum, and considered this first prototype of the wrist simulator to be a good tool to prepare residents for a real wrist arthroscopy. All but one participant was of the opinion that the outer appearance of any simulator is important.

The structure that the experts missed most was the TFCC. In the simulator, the ulna head was clearly visible because of the absence of the TFCC. This caused some orientation problems because surgeons confused it with the distal end of the radius. Apart from the TFCC, the addition of volar ligaments would be an improvement to this simulator, according to the experts. Two experts noted that the skin should be attached to the dorsal side of the bones in the next version of the simulator, because the scope could now move between the radius and the dorsal skin. As this is not the case in a patient, this is hampering the general orientation in the wrist. The realism of the trocar insertion force was rated with a mean of 7.2 (SD 1.8), and the arthroscope manipulation force was rated with a mean of 7.1 (SD 1.6) indicating that the diagnostic sweep through the wrist does come close to the actual feel in the clinical situation according to the experts.

DISCUSSION

When developing a new educational product it is important to focus on the desires and expectations of its future users. In this study, the requirements for the simulator were defined based on the opinion of a group of experts, and subsequently translated into technical design criteria to choose the proper materials for the prototype. For the skin cover, we tested the compressibility and tear strength and it mimicked the quality of human skin when compared to the values found in the literature (25,26).

The prototype developed was tested by seeking expert opinions during the 2012 FESSH conference and the results were favorable. In the face validity test, the judgment of the experts was generally good, with average scores above 7.0. Especially the realism of the intra-articular image, the trocar insertion and arthroscopic manipulation forces received above-average scores, which is promising as these were the focus points of our design.

Stepwise testing and improving a prototype ensures the development of a prototype that complies with the predefined requirements. Engaging the prospective users in the development process ensures the development of a product with a broad user support.
Testing of the prototype by experts is a logical step to verify fulfillment of the criteria that were initially set. The attachment of the skin to the dorsal side of the radius and the flexibility of the construct were mentioned as aspects that needed further work. These two points will be relatively easy to improve by adding an adhesive layer to the inside of the skin substitute in order to attach it to the dorsal side of the radius. Choosing another silicone material for the volar plate could change the flexibility of the construct.

In the original requirements that were set the experts mentioned the representation of dorsal structures such as extensor tendons and the superficial branches of the radial and ulnar nerves as being important (Table 2). However, in the evaluation of the prototype the lack of these structures was not mentioned as a downside of the model; it depends greatly on the learning goals of the simulator. It therefore seems correct that these structures were omitted. A remarkable result is that only 9% of the experts mentioned it as being important to represent the carpal bones in a model. We can only assume that this percentage is so low because most experts would find it obvious to include these structures in a model.

The development of this simulator prototype is part of an entire wrist arthroscopy curriculum development. The first step in the curriculum would be an introduction to the theory behind wrist arthroscopy (indications, instruments, patient positioning, basic anatomy and stepwise description of the diagnostic arthroscopy steps). In the second phase of the curriculum the residents could use the simulator to get acquainted with the basic skills needed for wrist arthroscopy, namely localization of the portals, introduction of the scope and other instruments, and the hand-and-eye coordination needed to make a diagnostic sweep through the wrist. For the third step we are looking at the possibilities of using virtual reality modalities to help in teaching the 3D anatomy of the wrist and to introduce pathology scenarios. For the moment the third step of the curriculum would still be cadaver courses before starting wrist arthroscopy on a patient.

Having a simulator available in the hospital would also allow residents to confirm their proficiency in arthroscopic skills between trainings or in between operations. The advantage of a simulator such as the one presented is that it could also be useful for objective assessment of skills.

**LIMITATIONS**

First of all the response rate to the electronic survey was low (35%). This is not unusual for such a survey but it does introduce a bias. It is conceivable that the EWAS members
who are in favor of a simulator would be more inclined to respond to the questionnaire. In the development of a new product choices have to be made, and not all listed requirements could be incorporated in this model. As this was a first prototype, we decided to focus on a few requirements that would give the presented simulator its unique characteristics and potentially increase its value as a training tool in the already existing range of arthroscopic training simulators.

CONCLUSION

In conclusion, the current wrist arthroscopy prototype was designed based on the assessment of a need and according to predefined design criteria. Not all of the criteria have been incorporated in the current model, but the face validity test shows that the prototype was well received among wrist arthroscopy experts. It allowed us to identify the aspects of the prototype that need further work. The results of the face validity test also show that there is room for physical models such as this one in training arthroscopic skills. Finally, this design was kept simple on purpose in order to develop a prototype that would remain affordable in production in order to make it within the reach of every training hospital.
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