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Establishing the learning curve for elbow arthroscopy: surgeon and trainee perspectives on number of cases needed and optimal methods for acquiring skill

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Background: Elbow arthroscopy has increased in frequency as its indications have widened. Despite this growth, a learning curve has not yet been defined.

Hypothesis: We hypothesized that there would be significant differences in perspective between trainees and established surgeons for the number of cases needed to reach each skill level and what they felt are the most valuable training tools.

Methods: Orthopedic attending physicians and trainees were asked to complete a questionnaire assessing participant demographics, case volumes required to reach defined skill levels (novice, safe, competent, proficient, and expert), and the efficacy of various learning methodologies for elbow arthroscopy. The value of educational methods was assessed using a 5-point Likert scale (1 = not at all valuable; 5 = extremely valuable).

Results: The study population consisted of 323 total participants, of whom 224 (69.3%) were attending surgeons and 99 (30.7%) were trainees (resident or fellow physicians). According to the attending physicians, the mean numbers of cases needed to reach each skill level were 19 to be safe, 42 to be competent, 93 to be proficient, and 230 to be expert. These case numbers were not significantly different from the perspectives of trainees. Across the respondents, there were no significant differences in the number of cases needed to reach each level of skill based on the respondents' level of training, years of experience, type of fellowship, or self-reported skill level.Although both groups highly valued live surgery (4.7 of 5) and cadaveric practice (4.6 of 5) for acquiring skill, attendings placed higher value on reading (4.0 vs. 3.3, $P < .001$), videos/live demos (4.2 vs. 3.6, $P < .001$), and formal courses (4.5 vs. 4.1, $P < .001$) than trainees. Both groups place relatively low value on surgical simulators (2.8-3.6).

Conclusions: There was considerable agreement among attending surgeons and trainees in terms of the number of cases needed to attain various skill levels of elbow arthroscopy, which was consistent regardless of fellowship background, self-reported skill level, career length, and elbow arthroscopy case volume. However, there was some disagreement between attending surgeons and trainees over the most valuable methods for acquiring surgical skill with trainees placing less value on textbooks, surgical videos, and formal courses compared with attending surgeons. An understanding of the elbow arthroscopy learning curve will help trainees and their training programs establish case volume targets before safe, independent practice. Future studies should aim to clinically validate this learning curve.

Primary location where this investigation was performed: Mayo Clinic, Rochester, MN.

Institutional review board approval was not required for this survey study.

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As technology advances and surgical indications expand, the role for elbow arthroscopy is growing rapidly.[6] Initially pioneered by Burman in the early 1930s,[4,5] elbow arthroscopy was not a primary focus of research in the United States until the 1980s.[1,2,11,24] There has been expansion in the applications of and indications for elbow arthroscopy[34] in both young and older patients.[6,19,32] However, the proximity of critical neurovascular structures and complex geometry of the elbow joint make elbow arthroscopy a technically demanding tool for the novice surgeon.[7] The reported complication rate of elbow arthroscopy ranges from 5% to 14%.[10,15,19,21,26,27,29] Although those complications are mostly minor, this rate is notably higher than that of the knee, shoulder, and hip arthroscopy. In light of the growing practice of elbow arthroscopy and its relatively high complication rates, there remains a lack of consensus regarding optimal training methodologies and determining when a surgeon is ready for independent practice. In other words, the "learning curve" of elbow arthroscopy has not yet been defined.

Although the surgical learning curve has been thoroughly investigated for procedures such as hip arthroscopy,[12-14,20,23,25] there is a paucity of literature for elbow arthroscopy. A few studies have described the experiences of individual surgeons learning elbow arthroscopy,[16,22] but the nature of these single-surgeon studies makes the findings challenging to generalize. Furthermore, the surgeons involved in these studies were relatively experienced in other arthroscopic procedures, possibly skewing the learning curve given a presumed basic proficiency with arthroscopy in general as compared with a true novice.

Therefore, given the inherent risks of elbow arthroscopy and its increasing use, the purpose of this study was to take the first steps in establishing a learning curve for elbow arthroscopy. Specifically, we sought to (1) compare and contrast the perspectives of trainees (residents and fellows) and attending physicians on the number of cases required to become safe, competent, proficient, or expert level elbow arthroscopists; (2) compare these recommended case volume requirements based on physician demographics, training, career experience, and skill level; and (3) determine which training methodologies attendings and trainees felt were most valuable when attempting to acquire skill in elbow arthroscopy. We hypothesized that there would be significant differences in perspective between trainees and established surgeons for the number of cases needed to reach each skill level and what they felt were the most valuable training tools given their varying experience levels.

Methods

This is a cross-sectional prospective survey study designed to examine current perspectives held by all types of orthopedic surgeons at various stages of their career.

Questionnaire

The electronic questionnaire was divided into 3 sections (Supplementary Fig. S1). The initial section inquired about participants' demographic information, including age, sex, current level of training, career type, and annual number of elbow arthroscopies performed. The second portion of the questionnaire provided specific definitions for the following 5 levels of arthroscopic skill:

Novice: Very limited exposure or skill. Would have difficulty with establishing portals and may be at risk for causing damage to articular or neurovascular structures.
Safe: Does not cause significant damage to cartilage, soft tissue, or neurovascular structures during arthroscopic procedures of the elbow. Would likely have trouble completing basic arthroscopic procedures.
Competent: Able to reliably complete basic arthroscopic procedures of the elbow, but may have some inefficiencies of movement and execution.
Proficient: Able to consistently complete basic and most complex arthroscopic procedures of the elbow in a predictable, reliable, fashion.
Expert: Distinguished leader in the field who is recognized by his or her peers as having made significant contributions to advancing the surgical technique.

Participants were asked to select the skill level that best described their own ability in elbow arthroscopy. They were then asked to estimate the number of elbow arthroscopy cases required for the average orthopedic surgeon to reach each of these levels. They were also asked to estimate the number of cases they *personally* required (or will require) to become a safe, competent, proficient, and expert level elbow arthroscopist. Lastly, they were asked to rank the relative value of various training methods and resources for attaining skills in elbow arthroscopy using a 5-point Likert scale (1 = not at all valuable; 3 = neutral; 5 = extremely valuable). These resources included literature, on line videos/live demonstrations, formal courses, high-fidelity simulators (computer-based virtual reality surgical simulators), low-fidelity simulators (table top or "box top" trainers), cadaveric practice, and live patient practice (Supplementary Fig. S1).

Study population and design

Following a preliminary review, this study was deemed exempt by our institutional review board. Members of the American Shoulder and Elbow Surgeons, members of the Mayo Elbow Club, and orthopedic surgical residents and fellows were asked to participate and complete the study questionnaire. The questionnaire assessed participant demographics, case volume required to achieve specific elbow arthroscopy skill levels, and the efficacy of various learning tools. All participants volunteered to partake in the survey and were not provided with any compensation for their contributions. All data were collected and analyzed in a completely anonymous and deidentified fashion.

Statistical analysis

Questionnaire responses were stored in Microsoft Excel (2010; Microsoft Corp., Redmond, WA, USA) and analyzed both in Microsoft Excel and with JMP Pro (v14.1.0; SAS Institute, Cary, NC, USA). Participant demographics were reported using descriptive statistics including means with standard deviation, percentages, and variance where appropriate. Participants were subdivided into a number of different groups for comparative analyses based on the following factors: level of training (fellows and resident physicians vs. attending physicians), self-assigned skill level (novice, safe, competent, proficient, or expert), or fellowship (none, sports, shoulder and elbow, hand, or multiple fellowships). After assessing the data for any parametric or nonparametric assumptions, all continuous variables were compared between the aforementioned groups using Student *t*-tests or analysis of variance tests. When comparing means between 2 groups, mean difference and 95% confidence interval (CI) were determined. P values <.05 were taken to be significant.

Results

The survey was completed by 323 participants (96.4% response rate); their demographics and surgical backgrounds are further described in Table I and Fig. 1. There was notable variability in total career cases of attending physicians within each self-assigned skill subgroup, particularly in those considering themselves to be experts (range, 70-5000; standard deviation, 489.8).

There were no statistically significant differences in the estimated case volume requirements for the average surgeon to achieve each of the 4 skill levels between trainees and attending physicians (Fig. 2; $P > .060$ for all comparisons). When asked to estimate the case volume required to personally achieve each skill level, the only difference noted between attendings and trainees was for reaching the expert level (mean of 204 vs. 294 cases, respectively; mean difference, 90.2; 95% CI, 5.9-186.3; $P = .031$). When comparing the number of cases needed to progress to higher skill levels, there were no significant differences in the number of cases surgeons felt that they personally needed compared with other surgeons (Table II).

The number of cases estimated for "other surgeons" to achieve each skill level was not significantly different based on the surgeons' self-reported skill level ($P > .330$ for all) (Fig. 3, *A*). The same was true for the number of cases for surgeons to personally reach each skill level ($P > .466$ for all) (Fig. 3, *B*). Similarly, no statistically significant difference was noted between responses from attending physicians when subdivided by fellowship training ($P > .171$ for all) (Fig. 4).

Of the learning resource options available to participants, performing on live patients, cadaveric practice, and formal courses were considered to be the most valuable among attending physicians and trainees (Table III). Generally, attending physicians placed greater value on the following training methods compared with trainees: attending formal courses (4.5 vs. 4.1; 95% CI, 0.14-0.62; $P < .001$), reading literature (4.0 vs. 3.2; 95% CI, 0.41-0.94; $P < .001$), and watching video or live surgical demonstrations (4.2 vs. 3.6; 95% CI, 0.31-0.77; $P < .001$). Overall, both groups place a relatively low value on high- and low-fidelity simulators (Table III).

Discussion

Elbow arthroscopy is an evolving surgical field that is increasing in both its capabilities and popularity, but unlike other orthopedic procedures, the learning curve has not yet been characterized. This work was intended as a first step in that important process, and we found strong consensus regarding the case volume necessary to achieve defined skill levels in elbow arthroscopy across established elbow surgeons and trainees. Overall, the mean number of cases attendings felt that a surgeon needs to achieve each skill level was as follows: 19 to progress from novice to safe, 42 to be competent, 93 to be proficient, and 230 to achieve expert level performance. The perspectives were similar for trainees and attending surgeons, and these perspectives were similar regardless of career length, prior case volume, surgical skill level, and fellowship background.

Although there was notable agreement on the elbow arthroscopy learning curve, trainees and attending surgeons did disagree on the relative values of certain supplementary learning tools for improving elbow arthroscopy skill. Overall, trainees placed less value on reading, watching technique videos, and attending formal courses than did attending physicians. This may reflect generation differences in learning styles and the evolving nature of surgical education. Trainees estimated they would need on average 90 cases more than the attending physicians to become an expert elbow arthroscopist (204 vs. 294). This discrepancy may be a reflection of lower levels of confidence among surgeons during the earlier stages in career. Despite this, the general agreement among trainees and attending physicians of all backgrounds was in direct contrast to the initial hypothesis of the study, which theorized participants' surgical

Table I Participant demographics

Group	Attending physicians	Trainees	Total
Number of participants (%)	224 (69.3)	99 (30.7)	323
Males (%)	218 (97.3)	80 (80.1)	298 (92.3)
Females (%)	6 (2.7)	19 (19.2)	25 (7.7)
Mean age (SD)	45.4 (8.8)	30.1 (2.6)	40.9 (10.4)
Mean total career cases (SD)	207.6 (489.8)	4.8 (9.2)	140.4 (408.4)

SD, standard deviation.

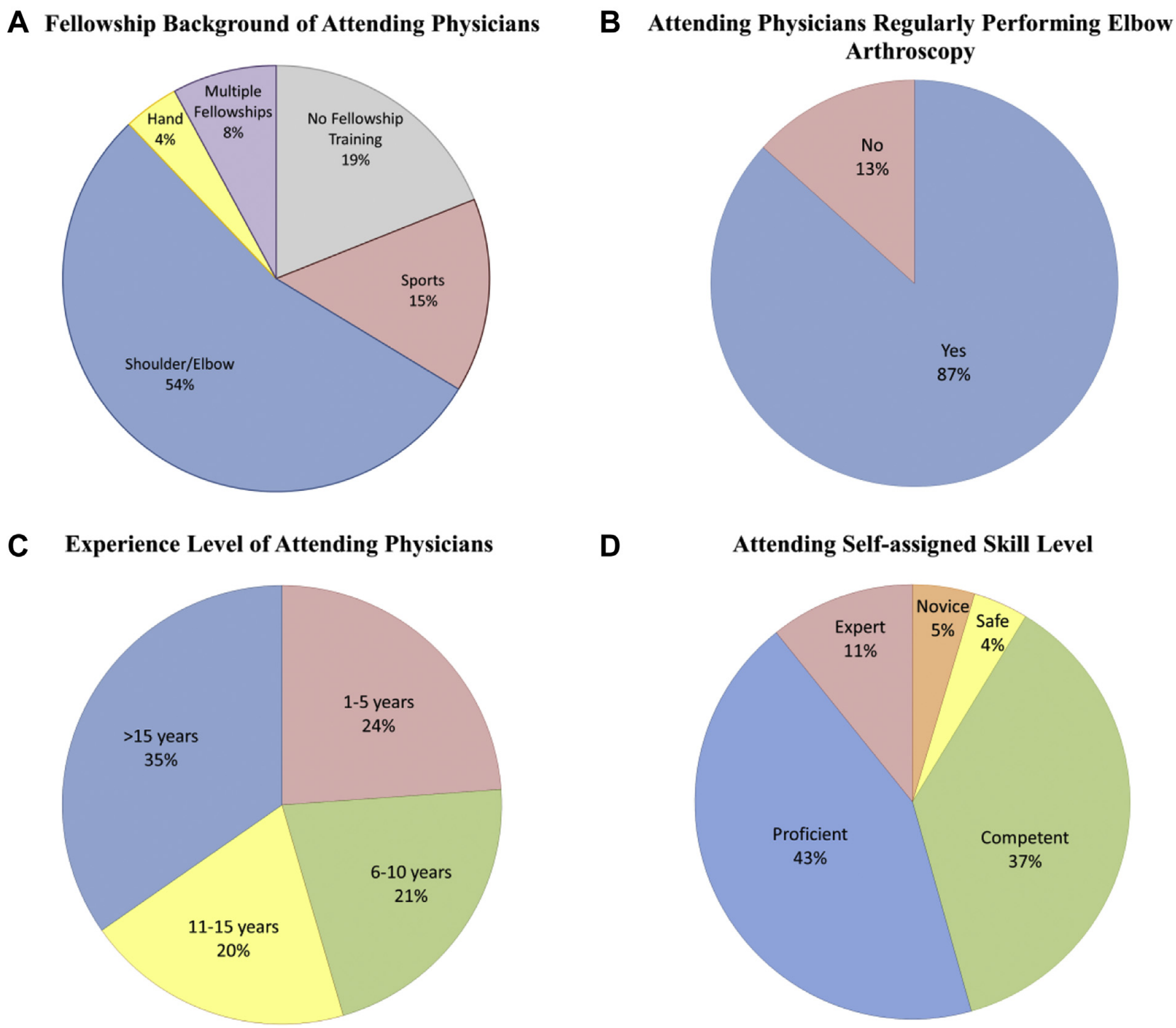


Figure 1 (**A**) Fellowship training of all attending physicians. (**B**) Percentage of all attending physicians who stated that they regularly perform elbow arthroscopy in their practice. (**C**) Duration of practice of all attending physicians. (**D**) Self-assigned elbow arthroscopy skill level of all attending physicians.

experience and degree of training would influence perspectives on necessary case volumes. There is a clear need for further research on this topic, and this broad agreement in case volumes may serve as a starting point for future efforts in characterization of the learning curve.

Like elbow arthroscopy, hip arthroscopy is relatively new to the field of orthopedics and there has been much progress in the characterization of the hip arthroscopy learning curve. Several studies reported initial experiences of surgeons learning hip arthroscopy and concluded that

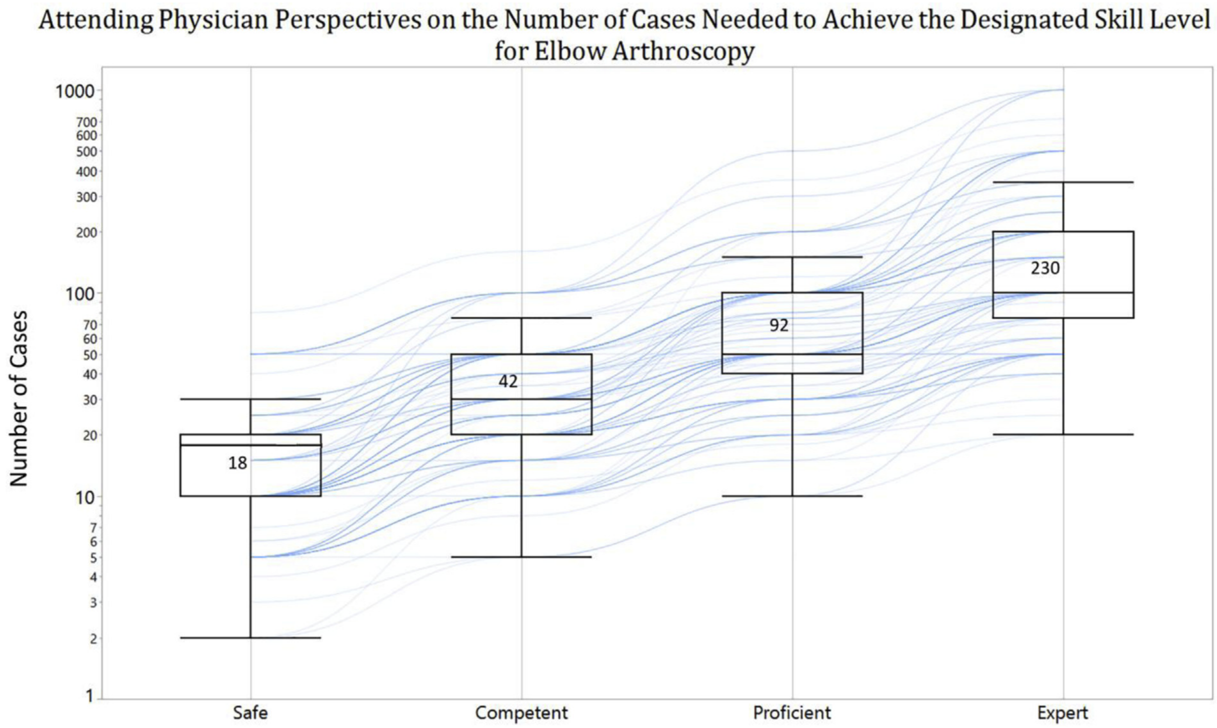


Figure 2 All attending physician estimations for number of cases necessary for the average surgeon to become safe, competent, proficient, and expert at elbow arthroscopy. Each line represents the estimations of an individual attending physician. Box plots indicate nonoutlier maximums, upper quartiles, median values, lower quartiles, and nonoutlier minimums. Mean values are provided in the center of each box.

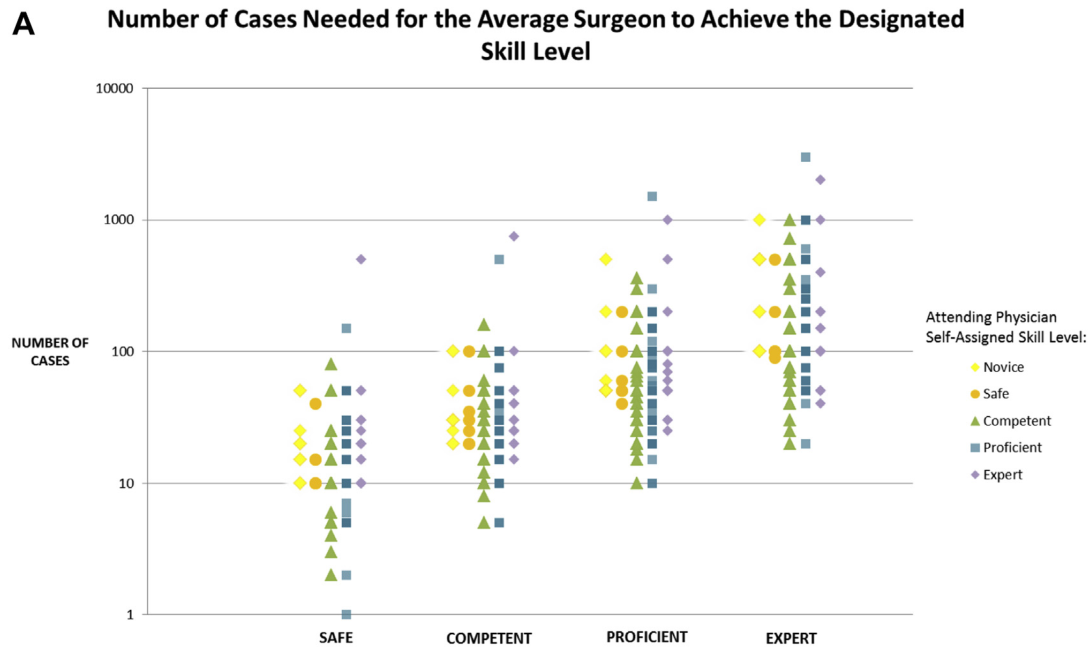
Table II Attending physician responses for number of cases required to achieve stated skill level

Skill level	For themselves		For other surgeons		*P* value
	Mean ± SD	Range	Mean ± SD	Range	
Safe	15.3 ± 17.5	0-150	18.9 ± 39.6	0-500	.258
Competent	37.5 ± 46.8	2-500	42.3 ± 68.0	5-750	.431
Proficient	79.5 ± 128.1	10-1500	92.7 ± 143.7	10-1500	.364
Expert	203.7 ± 302.3	15-3000	230.1 ± 329.5	20-3000	.444

SD, standard deviation.

the first significant reduction in both operative time and complications can be detected after 30 cases.[8,18,28,30] Furthermore, patient outcomes and reduced complication rates have been reported to continuously improve through approximately 100 cases.[3,9,14] Supervision by experienced hip arthroscopists may also expedite a novice's progression along the learning curve and reduce complications throughout.[9] These advancements made in the development of hip arthroscopy may serve as a model for similar work regarding the elbow, including quantitative measurements such as patient outcomes, complication rates, reoperation rates, and surgical time to assess rates of improvement in elbow arthroscopy.

When assessing the participants' views of the most valuable education tools, attending physicians and trainees both ranked learning from live patients as the best technique for acquiring skill, followed closely by cadaveric practice. Similar findings have also been reported in a number of studies involving orthopedic trainees and other arthroscopic procedures.[17,31,33] Interestingly, simulators were ranked among some of the lowest valued resources for elbow arthroscopy by both attending physicians and trainees. Although arthroscopy simulators have already been shown to improve general arthroscopic performance in orthopedic residents in other joints, there are limited options available for surgical simulation of the elbow. This is certainly an area in need of additional exploration and study.



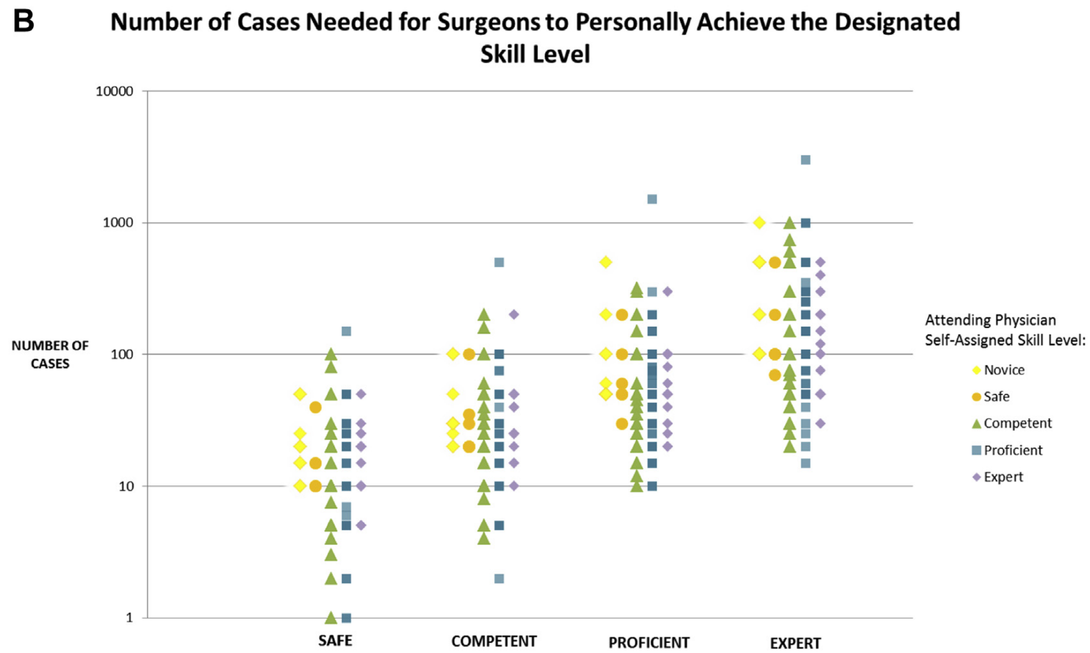


Figure 3 Attending physicians were separated into 5 groups according to their self-assigned skill level at elbow arthroscopy, as denoted by the legends above. Their estimations of number of cases necessary for the average surgeon and for themselves to personally become safe, competent, proficient, and expert elbow arthroscopists were then graphed in (**A**) and (**B**), respectively.

Limitations

There are a number of limitations to this work that merit discussion. First, as with all survey type studies, this work is subject to recall bias as the respondents were asked to provide their historical case volume, but we were unable to confirm their actual previous experience. The experience level of the respondents was quite variable, and, although it may yield responses more applicable to the general public, this could also potentially bias the overall results. In the

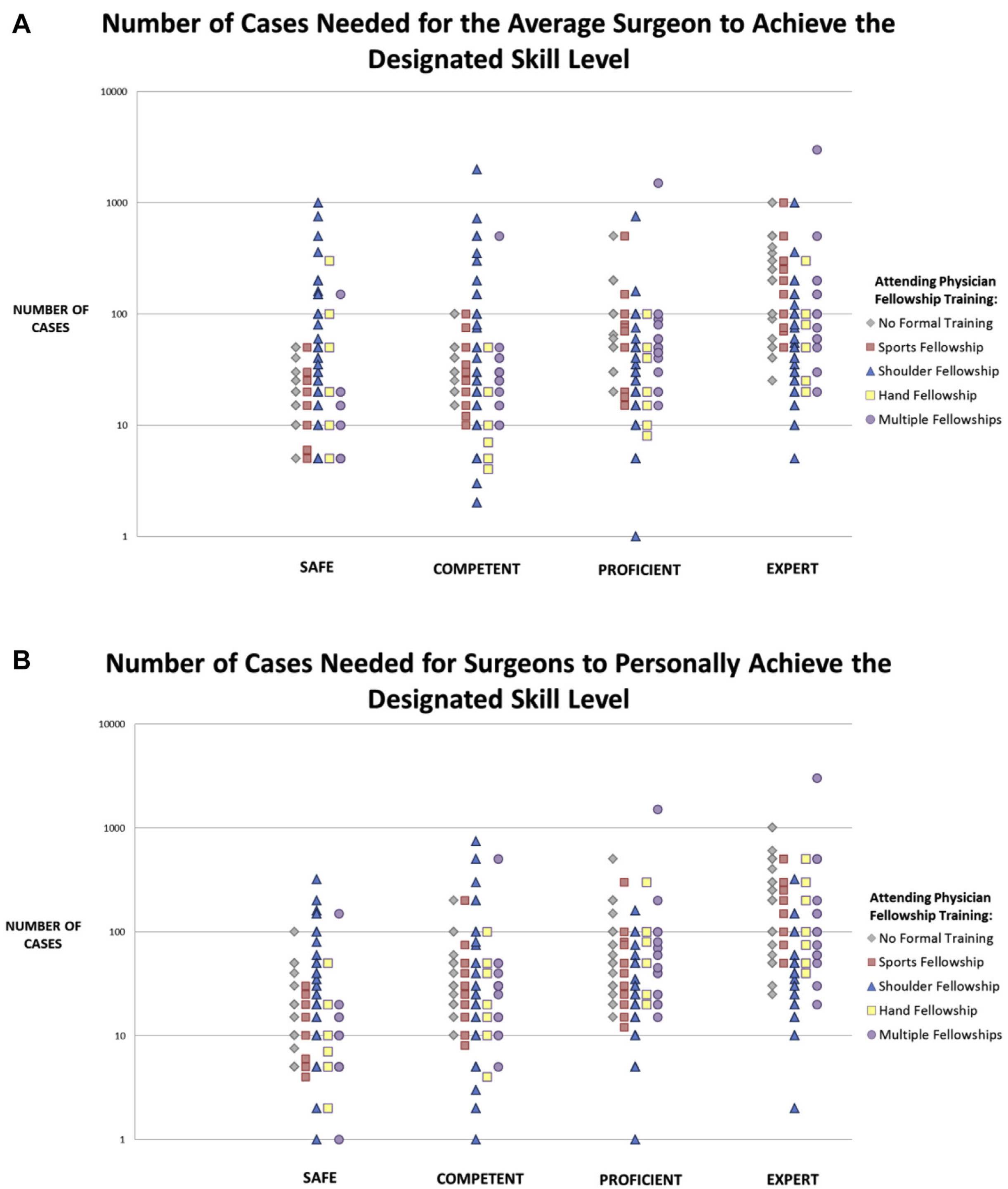


Figure 4 Attending physicians were separated into 5 groups according to their fellowship background, as denoted by the legends above. Their estimations of number of cases necessary for the average surgeon and for themselves to personally become safe, competent, proficient, and expert elbow arthroscopists were then graphed in (**A**) and (**B**), respectively.

future, a consensus may be better obtained through a multiround questionnaire or discussion, such as the Delphi technique. It is also worth noting that not all elbow arthroscopy cases are the same. There is tremendous variability in complexity, time to complete, and the educational value across the spectrum of elbow arthroscopy cases. Furthermore, there are no current objective standards or measurement tools as to what a novice, proficient, or expert arthroscopist "looks like." We were unable to control for these factors. Finally, this study was unable to use clinical

Table III Mean values of learning resources for the average surgeon

	Attending physicians	Trainees	MD	95% CI	*P* value
Reading	4.0 ± 1.0	3.3 ± 1.0	0.7	0.4-0.9	**<.001**
Videos/live demos	4.2 ± 0.9	3.6 ± 0.9	0.6	0.3-0.8	**<.001**
Formal courses	4.5 ± 0.7	4.1 ± 1.0	0.4	0.1-0.6	**<.001**
High-fidelity simulators	3.5 ± 1.1	3.6 ± 0.9	0.1	−0.2-0.3	.824
Low-fidelity simulators	3.0 ± 1.2	2.8 ± 1.0	0.2	−0.5-0.1	.614
Cadaveric practice	4.6 ± 0.7	4.5 ± 0.7	0.1	−0.3-0.1	.526
Performing on live patients	4.6 ± 0.7	4.8 ± 0.6	0.2	0.0-0.4	**.001**

MD, mean difference; *CI*, confidence interval.
Relative value of learning resources were ranked by both attending physicians and trainees on a 5-point Likert scale, with 1 being not valuable at all, 3 being somewhat valuable, and 5 being extremely valuable. Mean with standard deviation, difference between means, 95% confidence intervals, and *P* values are reported. Statistically significant differences between trainee and attending physician opinions are marked with bold *P* values.

data to measure arthroscopic proficiency, so this will be a topic of ongoing investigation.

Conclusions

Overall, there was strong agreement among attending surgeons and trainees regarding the number of cases needed to attain various skill levels in elbow arthroscopy. Ultimately, surgeons felt that others would require 19 cases to become a safe elbow arthroscopist, 42 to reach competency, 93 to obtain proficiency, and 230 to achieve expert level performance. Although respondents agreed on the value of many of the educational tools, attending physicians placed greater value on attending courses, reading literature, and watching video or live surgical demonstrations compared with trainees. Both groups placed relatively little value on high- and low-fidelity simulation. Moving forward, we hope that this work will serve as a framework for clinical validation of the elbow arthroscopy learning curve and will allow for optimization of training methodologies.

Disclaimer

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Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jse.2020.04.022.

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