

Observational Learning During Simulation-Based Training in Arthroscopy: Is It Useful to Novices?

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1 **Structured Abstract**

2

3 *Objective:* Observing experts constitutes an important and common learning experience for
4 surgical residents before operating under direct guidance. However, studies suggest that
5 exclusively observing experts may induce suboptimal motor learning, and watching errors
6 from non-experts performing simple motor tasks may generate better performance. We
7 investigated whether observational learning is transferrable to arthroscopy learning using
8 virtual reality (VR) simulation.

9 *Setting/Design:* In our surgical simulation laboratory, we compared students learning basic
10 skills on a VR arthroscopy simulator after watching an Expert video demonstration of VR
11 arthroscopy tasks or a Non-Expert video demonstration of the same tasks to a Control group
12 without video demonstration. Ninety students in three observing groups (Expert, Non-
13 Expert, Control) subsequently completed the same procedure on a VR arthroscopy
14 simulator. We hypothesized the Non-Expert-watching group would outperform the Expert-
15 watching group, and both groups to outperform the Control group. We examined
16 performance pre-test, post-test and one week later.

17 *Participants:* Participants were recruited from the final year of medical school and the very
18 early first year of surgical residency training programs (orthopaedic surgery, urology,
19 plastic surgery, general surgery) at Western University (Ontario, Canada).

20 *Results:* All participants improved their overall performance from pre-test to retention
21 ($p < .001$). At initial retention testing, Non-Expert-watching group outperformed the other
22 groups in Camera Path Length $p < .05$ and Time to completion, $p < .05$, and both the
23 Expert/Non-Expert groups surpassed the Control group in Camera Path Length ($p < .05$).

24 *Conclusion:* We suggest that error-observation may contribute to skills improvement in
25 the Non-Expert-watching group. Allowing novices to observe techniques/errors of other
26 novices may assist internalization of specific movements/skills required for effective
27 motor performances. This study highlights the potential impact of observational learning
28 on surgical skills acquisition and offers preliminary evidence for peer-based practice
29 (combined non-experts and experts) as a complementary surgical motor skills training
30 strategy.

31

32

33 *Key words:*

34 Observational learning, motor learning, surgical simulation, arthroscopy, orthopaedic
35 surgery, error observation.

36

37 *ACGME competencies:*

38 Patient Care, Practice Based Learning and Improvement

39

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44

45 **Introduction**

46 Surgical skills training has a direct and significant impact on patients' well-being and
47 quality of care [1, 2], as surgical outcomes directly relate to a surgeon's skills [3, 4].
48 Adequate training results in improved efficiency [4, 5], improved quality of surgery [6],
49 superior outcomes [1, 4, 7], efficient use of healthcare resources [7], decreased
50 complications [1, 4, 7-9] and reduced costs [1, 10].

51 Arthroscopy is a complex skill that can be challenging for trainees to learn efficiently in a
52 busy teaching centre. Successful arthroscopists require excellent hand-eye coordination
53 [11-13], three-dimensional visualization [12-14], knowledge of anatomy and
54 pathophysiology, knowledge of different procedures, good surgical judgment and
55 experience [13]. In contrast to laparoscopy, successful acquisition of arthroscopy skills
56 presents challenges due to the constrained and variable surgical fields relative to the
57 different joints, each with slightly differing morphologies and limited space available for
58 maneuvering. In addition, the various patient positions that are used during arthroscopy
59 can alter the learner's frames of reference [15, 16]. Because of this complexity, effective
60 arthroscopic training is critical, as the learning curve is steep, the visuospatial demands
61 for arthroscopy are high and trainees require many hours of practice and mentors'
62 feedback to gain basic competence [17, 18].

63 Traditional surgical education practices, which continue to rely on the traditional
64 apprenticeship model of instruction and the modus operandi: "See one, Do one, Teach
65 one", are being scrutinized [19-21]. Changes in work hours, increased subspecialization
66 and increased concerns about patient safety have motivated surgical educators to explore
67 alternative educational strategies [22].

68 Recently, Wulf and colleagues [23] identified that observational practice, external focus
69 of attention, feedback and self-controlled practice were, together, effective methods for
70 enhancing motor skill learning in medical education. Learning through observation has
71 been a growing area of interest in neuroscience and motor control literature [24]. Several
72 studies have demonstrated that individuals may learn a variety of simple visuomotor
73 skills by watching the skills being executed by another individual [25, 26]. Moreover, the
74 processes that underlie this learning appear to be automatic, persistent and unaffected by
75 distraction [25]. Recent unexpected evidence has shown that learning basic motor skills is
76 enhanced by the observation of errors, rather than the observation of a flawless
77 performance [27]. Brown and colleagues [28] demonstrated that observing trials which
78 contained high degrees of error facilitated more rapid learning of a pointing task than
79 observing trials which contained minimal error. Similarly, Buckingham et al.
80 [27] demonstrated that individuals learn to apply the correct gripping and lifting forces to
81 objects which have an unexpected weight after observing lifting errors, whereas they did
82 not benefit from observing error-free lifts. The goal of the current study was to test these
83 lab-based findings of error-based observational learning by introducing peer observation
84 in the sensorimotor tasks of basic arthroscopic training.

85 Surgical learning needs innovative techniques to meet the modern challenges of skill
86 acquisition. Learning by observation of error-laden performances done by other novices
87 is a novel idea that contradicts the commonly held belief that motor skills are best learned
88 by observing and imitating experts [28, 29]. The purpose of this study was to examine the
89 learning of surgical skills by measuring and comparing basic arthroscopic skills
90 performance on a VR surgical simulator by students who observed either an expert or

91 non-expert demonstrating the task (Expert-watching or Non-Expert-watching), versus a
92 control group who received no such intervention. We hypothesized enhanced learning
93 and superior performance metrics of simulated knee arthroscopy following the
94 observation of Non-Expert (high error) performance in comparison to the control group
95 (no observation) or the observation of Expert (low error) performance.

96

97 **Materials and Methods**

98 *Participants*

99 Eligible participants were recruited from the final year of medical school and the very
100 early first year of surgical residency training programs (orthopaedic surgery, urology,
101 plastic surgery, general surgery) at Western University (Ontario, Canada). All subjects
102 were between the ages of 18-40, spoke English fluently and were screened to ensure that
103 they had no prior experience with arthroscopic surgery, endoscopic surgery or any form
104 of surgical VR simulation. Most participants had baseline understanding of arthroscopic
105 surgery, but had not seen or used the arthroscopic instruments or an arthroscopy
106 simulator. The sample size was estimated from previously published study, which
107 examined the effect of active observation on the learning of a simple motor task [27].
108 After informed consent, research assistants randomly assigned subjects to either the
109 Expert-watching, or Non-Expert-watching groups by coin toss. A Control group was
110 added later to account for the effect of practice alone without observational learning.
111 The study included two testing sessions (see description in sections below). Session 1
112 included a pre-test (Test 1), intervention/rest and post-test (Test 2). Session 2 occurred
113 one week later and included a retention test (Tests 3-4-5). The retention test was

114 performed three times to evaluate the maintenance and recovery of skills after a resting
115 period.

116 *Simulator and Videos*

117 The *insight*ARTHRO-VR (GMV, Spain, now called ArthroMENTOR, Symbionix, Ohio,
118 USA) is a validated virtual-reality arthroscopy simulator that was used in the creation of
119 the Non-Expert and Expert instructional videos (see “**Novice**” and “**Expert**” videos) and
120 for data collection during this study [30-32]. This simulator uses phantoms of a leg and a
121 shoulder as well as a set of instruments (camera, probe, shaver and grasper) that are very
122 similar to real surgical instruments. The simulator’s library includes 40 knee and shoulder
123 arthroscopy modules. The modules are designed to develop bimanual coordination and
124 navigation skills by providing visual and haptic feedback and increasing task complexity.
125 Variables and performance measures recorded by the simulator included: 1) Camera Path
126 Length (distance covered by the camera, in millimeters [33]), 2) Camera Roughness
127 (intensity of contact of camera with simulated tissues in newtons [33]), 3) Probe Path
128 Length (distance covered by the probe, in millimeters [33]), 4) Probe Roughness
129 (intensity of contact of probe with simulated tissues in newtons [33]) and 5) Time to
130 Completion (seconds) [30, 34].

131

132 **Video 1: Novice video**

133 **Video 2: Expert video**

134

135 For this study, an introductory module, the “Knee -Diagnostic Arthroscopy - Locate and
136 palpate” module, was selected for the creation of the instructional videos (Expert and

137 Non-Expert). The instructional videos provided a viewpoint that was akin to standing as a
138 surgical assistant and displayed the hands of the surgeon on the arthroscope (camera) and
139 probe, along with the patients' knee and the arthroscopy monitor (Figure 1). The
140 arthroscope was held in the left hand (lateral portal), and a probe held in the right hand
141 (medial portal) was used to palpate targets located in various locations throughout a right
142 knee joint.

143 Subjects randomized to the Non-Expert-watching group observed a video of one of the
144 authors (GB), an academic psychology researcher with no arthroscopic (simulated or
145 real) training, completing the selected module on the simulator. Subjects randomized to
146 the Expert-watching group were assigned to watch a video showing one of the authors
147 (ML), an experienced fellowship-trained expert arthroscopist and expert on the simulator,
148 completing the same task. The outcomes of both videos were the same and the module
149 was completed but the performances were different: compared to the video of the Expert,
150 the video of the Non-Expert was about three times longer (3 minutes-12 seconds vs 58
151 seconds). At times, the Non-Expert video demonstrated more erratic camera and probe
152 motion, slower progression and inadequate visualization of both the probe and target.
153 These translated in an increased camera and probe path length, increased camera and
154 probe roughness, increased time to completion as well as the probe and target seen off
155 center on the arthroscopy monitor.

156

157 **Figure 1: Screenshot of a video watched by participants.**

158

159 *Testing sessions*

160 Baseline knowledge disparities among subjects were addressed by providing all subjects
161 with a standardized introduction on knee anatomy, an orientation to the simulator and
162 tasks to perform and, most importantly, safe and efficient use of the arthroscope (rotating
163 optics, triangulation, avoidance of collisions). The subjects were encouraged before each
164 of the testing sessions to do the tasks efficiently, as accurately and as quickly as possible
165 with no imposed time limit. To learn basic camera maneuvering techniques, a “warm-up”
166 module entitled “Operating Room” followed the standardized introduction. This module
167 provides standardized and scripted instructions (visible at the bottom of the simulator
168 monitor) on the concepts of withdrawing the arthroscope to widen the field of view and
169 on maintaining a leveled perspective for ease of safe and efficient navigation. After
170 completion of the “Operating Room” module, all subjects received instruction on the use
171 of an arthroscopic probe.

172 The knee arthroscopy module “Knee -Diagnostic Arthroscopy - Locate and palpate” was
173 used for the pre-test (or Test 1) and all the subsequent tests (Tests 2-5). No assistance or
174 feedback was provided during or after any trial and subjects were instructed to complete
175 the tasks independently. The tasks were explicit and the trials were identical each time.
176 Each test began with the leg in extension to allow the subject to place the arthroscope into
177 the patello-femoral joint; then the knee was flexed for the remainder of the task. To
178 successfully complete the task, subjects were prompted in a standardized manner by the
179 simulator software to visualize and palpate targets (using the tip of the probe) in the
180 patello-femoral groove, medial tibial plateau, trochlear notch, lateral tibial plateau,
181 insertion of ACL and femoral attachment of the PCL. Targets responded to palpation by
182 changing color, then disappearing and prompting instructions to locate the next target.

183 Following the pre-test, participants assigned to the Non-Expert-watching or Expert-
184 watching video groups watched their respective demonstration video three times. To
185 standardize the protocol, the same “Knee -Diagnostic Arthroscopy - Locate and palpate”
186 module was watched. The Control group was given a period of rest instead of a video
187 observation. After the playback of the three video demonstrations ended, participants
188 completed the knee arthroscopy module once again (post-test, or Test 2). During each
189 test, the spheres were located and presented in the same position, with a fixed path model,
190 so that the sequence was not modified. Again, no feedback was provided to participants
191 following the conclusion of the second testing session. Five to seven days following the
192 first testing session, participants completed the retention test, consisting of three
193 repetitions (Tests 3 to 5) of the same task, without video stimuli or feedback.

194 *Outcomes*

195 The primary outcome evaluated in this project was whether enhanced learning (i.e.
196 improved performance and retention of skills) would occur following the observation of
197 novice performance in comparison to the observation of expert performance. Trainee
198 performance was assessed using validated performance measures generated by the VR
199 simulator [30, 34].

200 *Statistical Analysis*

201 Subjects whose initial attempt at the task was outside 2.5 standard deviations from the
202 mean of any performance measure for all subjects were removed as outliers from the final
203 analysis. The data were initially examined with separate 3 (group membership) by 5
204 (testing session) mixed design ANOVAs for each dependent variable. Greenhouse-
205 Geisser corrections were applied to account for inhomogeneity of the variance across

206 sessions where necessary. To directly compare performance across the groups, the
207 omnibus analyses were followed up with post-hoc one-way ANOVAs and independent
208 samples 2-tailed t-tests at each level of the Testing Session variable.

209 Institutional ethics review was obtained prior to initiation of the study and informed
210 consent was acquired from each participant.

211

212 **Results**

213 Ninety participants were recruited to take part in this study and were assigned to one of
214 the three groups (Control, Expert-watching, and Non-Expert-watching). The
215 demographics of all three groups were comparable. After removing the outliers (± 2.5
216 SD) from the data analysis, 28 subjects were left in both the Non-Expert-watching and
217 Expert-watching video observation groups, and 26 subjects in the Control group (Table
218 I).

219

220 **Table I: Participants' demographic data.**

	Non-Expert- watching group n = 28	Expert-watching group n = 28	Control group n = 26
Age (SD)	25.1 (3.86)	25.7 (2.4)	26.3 (4.6)
Sex	9 females 19 males	10 females 18 males	4 females 22 males
Hand Dominance	2 left 26 right	2 left 26 right	4 left 22 right
Days between sessions 1 & 2	5.5 (2.5)	6.1 (1.9)	5.5 (2.2)

221

222 We initially examined the change in participants' performance over the course of the five
223 tests. All participants improved from Tests 1 to 5 in all measures, with significant main
224 effects of testing session number for Camera Path Length ($F(2.66,209.97)= 22.43$;
225 $p<.001$; Figure 2A), Camera Roughness ($F(4, 316)= 11.07$; $p<.001$; Figure 2B), Probe
226 Path Length ($F(2.75,217.41$; Figure 2C)= 13.81; $p<.001$), and Time to Completion
227 ($F(2.66,210.49$; Figure 2E)= 40.75; $p<.001$). Additionally, there was a modest significant
228 main effect of Probe Roughness ($F(3.55,280.65)= 2.46$; $p=0.05$; Figure 2D). These
229 findings, demonstrate that all participants significantly improved their performance on
230 every measure provided by the simulator over the course of the multiple testing sessions.
231 No significant Group x Testing session interactions were observed for any of the study
232 variables (see Table II). However, as visual inspection of the plots showed that most of
233 the significant improvements were observed between Tests 3 and 4, we undertook a
234 series of planned comparisons to examine main effects at each level of the Testing
235 session variable.

236

237 **Figure 2. Participants' mean performance across all tests as a function of**
238 **observation group. Error bars indicate standard error of the means. 2A) Camera**
239 **Path Length; 2B) Camera Roughness; 2C) Probe Path Length; 2D) Probe**
240 **Roughness; 2E) Time to Completion. Error bars indicate standard error of the**
241 **means.**

242

243 **Table II: ANOVA summary table for the 3 (group membership) by 5 (testing**
 244 **session) mixed design ANOVAs for each dependent variable.**

Variable	Testing session	Group x Testing session
Camera path length	F(2.7,209.9)=22.4, p<.001	F(5.3, 209.9)=1.2, p=.29
Camera roughness	F(4, 316)=11.1, p<.001	F(8, 316)=0.5, p=.85
Probe path length	F(2.8,217.4)=13.8, p<.001	F(5.5,217.4)=0.8, p=.84
Probe roughness	F(2.7,210.5)=2.5, p=.05	F(7.1,210.5)=0.4, p=.94
Time to completion	F(3.6,280.7)=40.7, p<.001	F(5.3,280.7)=1.0, p=.43

245

246 We then confirmed that all three groups were similar (demographics and pre-test VR
 247 performance metrics) at pre-test, before the video intervention. No main effect of group
 248 was found in Test 1 for any of the dependent variables (all p values > .25), with the
 249 exception of the Probe Path Length (F(2,79) = 5.36, p<.005; Figure 2C).

250 We subsequently studied group differences in the sessions following the video
 251 intervention (Tests 2, 3, 4, & 5). For this final analysis, we did not take into consideration
 252 the Probe Path Length variable as any further found differences may not have been due to
 253 the intervention and thus would have been difficult to interpret. In Test 2, we observed no
 254 significant effects for any dependent variables (all p values > .07). In Test 3, one week
 255 after the video intervention, we observed a significant effect for Camera Path Length
 256 based on group assignment (F(2,79)=3.1, p=.05; Figure 2A). Post-hoc analysis indicated
 257 that the Non-Expert-watching group outperformed both the Expert-watching
 258 (t(42.28)=2.05; p<.047) and Control (t(36.22)=2.45; p<.019) groups. No difference was

259 observed between the Control group and the Expert-watching group ($p=.55$). Significant
260 effects for Camera Path Length (Figure 2A) were also observed at both Test 4
261 ($F(2,79)=7.1, p<.005$), and Test 5 ($F(2,79)=5.0, p<.01$). These main effects (at Tests 4
262 and 5) were a consequence of the Control group being outperformed by the Non-Expert-
263 watching ($t(52)=2.16; p<.034$; $t(28.92)=2.44; p<.021$) and Expert-watching groups
264 ($t(34.67)=3.67; p<.001$; $t(40.69)=2.36; p<.023$). Finally, a significant group effect was
265 observed for the Time to Completion variable in Test 4 ($F(2,79) = 4.6, p<.037$). As with
266 the Camera Path Length variable, this effect was a consequence of the Control group
267 being outperformed by the Expert-watching ($t(52)=2.64; p<.011$) and Non-Expert-
268 watching ($t(52)=1.99; p=.05$) groups. No significant group effects were observed for
269 Camera Roughness or Probe Roughness in any of the five tests and no other effects on
270 Test 5 were significant.

271

272 **Discussion**

273 Surgery is a complex multi-step procedure that incorporates different cognitive processes.
274 At early stages, those processes focus on the acquisition of motor skills. As Blandin et al.
275 stated [35]: “it is generally agreed that the first determinant of motor learning is physical
276 practice. However, physical practice is not always a suitable first step, nor is it always
277 possible.” In line with previous literature on the effectiveness of video-based
278 observational learning [36, 37], our study results emphasize the importance of combining
279 the observation of others’ performance with dedicated practice of motor skills (in this
280 study, repetition of skills without explicit feedback) to enhance the acquisition of surgical
281 technical skills. Specifically, our study suggests that observing errors may provide

282 learners with more useful visual information beyond that obtained by observing expert
283 performance alone due to minimal variability from one expert performance to the next.
284 Similar to findings in psychology [27-29, 38, 39], our study indicates that observation of
285 both experts and non-experts results in improved performance over a control group [38,
286 39]. In particular, our study suggests potential benefits in learning motor skills by the
287 observation of novice performance at the very early stages of the training. Junior trainees
288 may benefit more from the observation of new tasks with error prone performance
289 because it transmits important information about the coordination of unfamiliar
290 movements or motor skills [40, 41]. In order to enable inexperienced trainees to
291 recognize key features of specific motor tasks [35, 36, 42], observing others' performance
292 and peer-to-peer practice may be worthwhile additions to current surgical teaching
293 methods [23], particularly when the learning curve is steep [36, 41, 42].
294 An improvement in Camera Path Length at Test 3 by the Non-expert watching group that
295 exceeded the improvements noted in both the Expert watching and control groups is the
296 most significant and positive result of our study. While it is the main positive result in a
297 stepwise comparison against both other groups, we feel that it is an indicator that the
298 observation of errors can improve learning compared to standard methods of
299 demonstration and observation. As novices learn arthroscopy, controlling the camera to
300 visualize the appropriate target is the most fundamental skill, from which probe
301 coordination and other bimanual skills are developed. For these reasons, we believe that
302 specific improvements in Camera Path Length for the Non-Expert group are meaningful
303 and important as the camera is always active and every movement is hence visible. In
304 comparison, the probe can go out of the view of the camera field and its movements may

305 or may not be visible at all times, therefore impacting the Probe Path Length and Probe
306 Roughness. Improvements noted at Test 3 are also the most significant as they represent
307 learning that has occurred and is maintained after a retention period, and are unlikely to
308 be influenced/overwhelmed by the effects of repeated physical practice.

309 Furthermore, our data shows that study participants seemed to imitate components of
310 surgical techniques or strategies displayed in either the Expert or Non-Expert videos,
311 demonstrating that the observation of errors is not the only enhancer of surgical expertise.

312 For example, Figure 2B shows an Expert-watching advantage for reducing Camera
313 Roughness during the session immediately following the intervention (Test 2). The
314 Expert video featured smooth, purposeful and accurate bimanual motion, which some of
315 the subjects incorporated in order to maintain focus on the targets. This contrasts with
316 the more random motion-based searching technique demonstrated in the Non-Expert
317 video, where localization of the probe and target was attempted by visualizing a broader
318 zone of interest, covering more distance with both the camera and probe, and inevitably
319 making more contact with tissues, increasing the Camera Path Length as well as Camera
320 and Probe Roughness. The simulator did not/could not capture all the nuanced actions
321 that are potentially clinically important. Many of the measures were quite crude
322 compared to, for example, the performance rating from an expert surgeon, but they have
323 obvious face validity and capture many facets of good performance.

324 While this study did not permit us to offer firm conclusions regarding the hypothesis, it
325 has provided some useful lessons to continue to build further research in the area, as
326 follows. For instance, though we were able to determine that a beneficial learning effect
327 occurs when novice trainees observe other novices, it is unknown which specific visual

328 cues promoted the improvement in subjects' performance and why some measures have
329 shown little difference. It is possible that the benefit observed is a result of the natural
330 differences in the length of observation for each group. The duration of the Non-Expert
331 demonstration was almost three times greater than the Expert demonstration, allowing
332 more time to observe the dynamics of the task, the performance and the errors, and build
333 an internal representation of the structure of the joint. Additionally, it is possible that
334 "probing" is a task that may be more challenging for certain participants and may require
335 more advanced skills because of its bimanual nature (holding the camera and
336 maneuvering it at the same time as holding and maneuvering the probe), explaining the
337 Probe Path Length differences. We also noted a practice effect, where the multiple
338 repetitions of the tasks resulted in uniformly higher scores for Tests 4 and 5, limiting our
339 ability to detect differences between the experimental groups (Expert, Non-Expert and
340 Control).

341 Limitations of this study include the small number of participants per group relative to
342 the high degree of variability in how participants could complete the tasks, as well as the
343 different durations of the video demonstrations. Further investigations with larger groups
344 are required to build upon the preliminary findings of this study, and better understand 1)
345 how trainees can most effectively learn complex surgical skills through observation with
346 or without feedback and 2) the informational content in each of the videos which had the
347 greatest influence on the motor skills learning. By focusing on studying specific visual
348 cues (e.g. field of view or camera roughness) or a variety of haptic feedback options,
349 future studies will be able to control the duration of the visual exposure to better
350 understand learning strategies during observation and promote faster skills' acquisition.

351 In the context of this experiment, what can be seen as “repeated learning activities” were
352 actually “repeated testing sessions”. Study participants probably learned because of the
353 multiple testing sessions, and we fully acknowledge that physical practice with feedback
354 would lead to far more consistent improvements than through sole observation of either
355 expert or novice video models. Additionally, giving no feedback and having a one-week
356 gap between Tests 2 and 3 may have minimized “learning through repetition” and
357 focused on “learning through observation” in Test 3. Rather than suggesting that
358 observational learning, combined with repetition of surgical skills without feedback is
359 “best practice”, this project explored one possible supplementary training method to
360 assist surgical skills training.

361

362 In conclusion, with high costs of surgical training and time pressure from restricted work
363 hours, more efficient and cost-effective ways to train residents are necessary [23, 43, 44].
364 Is observational learning a useful teaching method for novice arthroscopists? The
365 answer is: “probably”. Observational learning from models with a range of skillsets,
366 combined with physical practice/repetition without feedback, may improve the training of
367 basic surgical skills that are difficult to learn. This exploratory project is one of the few
368 surgical studies that suggest that conventional teaching of surgical skills could benefit
369 from the addition of observation of a novice committing errors. This counterintuitive
370 finding may have an impact on surgical training, redefining how surgical skills are
371 taught. Complementary to current apprenticeship training methods, improvements in
372 performance may be hastened by observing other individuals who are also at early
373 training stages to provide a basis for comparison between experts and non-experts. These

374 preliminary findings may be valuable and may lead to improvements in teaching surgical
375 skills that involve the learning of bimanual coordination of endoscopic instruments.
376 Gains in surgical skills acquisition can certainly be made outside the operating room with
377 simulation-based training, and further research is necessary to explore the value of
378 implementing cost-effective, efficient peer learning and observational learning to
379 improve surgical skills.

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