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Surgical Education's 100 Most Cited Articles: A Bibliometric Analysis

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BACKGROUND: Bibliometric analysis highlights the key topics and publications, which have shaped surgical education. Here, the 100 most cited articles in the arena of surgical education were analyzed.

METHODS: Thomson Reuters Web of Science was interrogated using the keyword search terms "surgery" and ("learning" or "skills" or "competence" or "assessment" or "training" or "procedure-based assessments" or "performance" or "technical skills" or "curriculum" or "education" or "mentoring"] to identify all English language full articles, and the 100 most cited articles were analyzed by topic, journal, author, year, institution, and country of origin.

RESULTS: A total of 403,733 eligible articles were returned and the median citation number was 164 (range: 107-1018). The most cited article (by Seymour, Yale University School of Medicine, Annals of Surgery, 1018 citations) focused on the use of virtual reality surgical simulation training. Annals of Surgery published the highest number of articles and received the most citations ($n = 16$, 3715 citations). The countries with the greatest number of publications were the USA ($n = 45$), Canada ($n = 19$), and the UK ($n = 18$). The commonest topics included simulation ($n = 45$) and assessment of clinical competence ($n = 40$).

CONCLUSION: Surgical skill acquisition and assessment was the area of focus of 85% of the most cited contemporary articles, and this study provides the most cited references, serving as a guide as to what makes a citable published work in the field of surgical education. (J Surg Ed ▮:▮▮▮-▮▮▮. © 2016 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

KEY WORDS: surgery, training, education, citations, bibliometric analysis

COMPETENCIES: Medical Knowledge, Patient Care, Practice-Based Learning and Improvement, Professionalism

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INTRODUCTION

The development of surgical education and published works has a long and distinguished history, originating from Galen of Pergamon (AD 131-201), a prominent Greek physician, surgeon, and philosopher in the Roman Empire, and arguably the most accomplished of all medical researchers of antiquity. His theories dominated western medical science for more than 1500 years and his anatomical reports were a mainstay of medieval physicians' university curricula, with medical students continuing to study his writings well into the 19th century.[1]

The western world's most senior surgical college, in 1505, the surgeons and barbers of Edinburgh, now known as Royal College of Surgeons of Edinburgh, UK, was formally incorporated as a Craft of the Burgh,[2] when a seal of cause (charter of privileges) was granted by the town council of Edinburgh, conferring certain privileges and imposing certain crucial duties, the most important of these being that every master surgeon should have full knowledge of anatomy and surgical procedures; that all apprentices be literate; and that this knowledge be thoroughly tested at the apprenticeship end. All clauses remain relevant to contemporary surgical practice, and with the development of formal training programs, the development of published research works has become allied with successful training progression and more recently associated with assessment of competence progression.

The standard of published works can be rated by means of citation analysis (ranking and evaluating an article or journal related to the number of citations received), thereby establishing a citation rank list, a surrogate marker of quality, which identifies the most influential publications.[3] Several reports have used citation rank analysis to identify the most influential articles in specialist fields, including trauma and orthopedic surgery,[4] plastic surgery,[5] general surgery,[6] urology,[7] and oncology.[8,9] Yet at the time of writing, only 1 report exists regarding the most influential articles in surgical

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education by Wohlauer, describing the 20 most cited publications between 2002 and 2012.[10] The aim of this study was to amplify the above and determine the topics and specifically the studies that had been most cited in the arena of surgical education by means of a bibliometric analysis of the 100 most cited articles over the past 100 years.

METHODS

A search of the Thompson Reuters Web of Science citation indexing database and research platform was completed using the search term "surgery" and also using the following terms ("learning" or "skills" or "competence" or "assessment"

TABLE 1. The Top 100 Cited Articles in Surgical Education

Rank	Citations	Study	Rank	Citations	Study
1	1018	Seymour et al.[11]	51	163	Hyltander et al.[61]
2	811	Martin et al.[12]	52	161	Herrell and Smith[62]
3	517	Grantcharov[13]	53	160	Aggarwal et al.[63]
4	475	Reznick and Macrae[14]	54	160	Derossis et al.[64]
5	473	Reznick et al.[15]	55	154	Norcini and Burch[65]
6	429	Martling et al.[16]	56	151	Aggarwal et al.[66]
7	422	Edmondson et al.[17]	57	151	Grantcharov et al.[67]
8	387	Issenberg et al.[18]	58	150	Wishner et al.[68]
9	369	Scott et al.[19]	59	149	Sroka et al.[69]
10	353	Bridges and Diamond[20]	60	149	Debas et al.[70]
11	351	Fried[21]	61	149	Winckel et al.[71]
12	336	Ahlering et al.[22]	62	148	Gallagher and Satava[72]
13	322	Derossis[23]	63	146	Matsumoto et al.[73]
14	312	Regehr et al.[24]	64	146	Rosser et al.[74]
15	310	Gallagher[25]	65	144	Gurusamy et al.[75]
16	263	Anastakis et al.[26]	66	143	Yule et al.[76]
17	259	Reznick[27]	67	141	Larsen et al.[77]
18	247	Moorthy et al.[28]	68	141	Fraser et al.[78]
19	244	Schlachta et al.[29]	69	140	Scott and Dunnington[79]
20	238	Peters et al.[30]	70	139	Hamilton et al.[80]
21	223	Schauer et al.[31]	71	138	Okuda et al.[81]
22	223	Rosser et al.[32]	72	138	Gallagher et al.[82]
23	220	Bennett et al.[33]	73	137	Link et al.[83]
24	219	Greenberg et al.[34]	74	136	Gallagher et al.[84]
25	219	Meyers and Bennett[35]	75	135	Torkington et al.[85]
26	214	Satava[36]	76	135	Fried et al.[86]
27	213	Cook et al.[37]	77	134	Andreatta et al.[87]
28	212	Cotin et al.[38]	78	134	Datta et al.[88]
29	208	Aggarwal et al.[39]	79	134	Dahl et al.[89]
30	206	Vickers et al.[40]	80	133	Older[90]
31	203	Ahlberg et al.[41]	81	133	Eastridge et al.[91]
32	202	Vassiliou et al.[42]	82	133	Gallagher et al.[92]
33	195	Yule et al.[43]	83	128	Schueneman et al.[93]
34	193	Rosser et al.[44]	84	122	Haluck and Krummel[94]
35	190	Sturm et al.[45]	85	122	Liem[95]
36	188	Korndorffer et al.[46]	86	122	Simons et al.[96]
37	188	Kneebone[47]	87	121	Sloan et al.[97]
38	188	Datta et al.[48]	88	120	Marescaux et al.[98]
39	188	Darzi et al.[49]	89	118	Kneebone et al.[99]
40	186	Patel et al.[50]	90	117	Basdogan et al.[100]
41	185	Watson et al.[51]	91	116	Yule et al.[101]
42	182	Moulton et al.[52]	92	115	Liu et al.[102]
43	180	Taffinder et al.[53]	93	114	Bell et al.[103]
44	178	Hutter et al.[54]	94	111	Marshall et al.[104]
45	176	Sutherland et al.[55]	95	109	Dincler et al.[105]
46	176	Grober et al.[56]	96	109	O'Toole et al.[106]
47	173	Pisano et al.[57]	97	108	Carter et al.[107]
48	171	Barden et al.[58]	98	108	Senagore et al.[108]
49	169	Faulkner et al.[59]	99	107	Gallagher and Cates[109]
50	165	Munz et al.[60]	100	107	Ahlberg et al.[110]

or "training" or "workplace-based assessments)" or "procedure-based assessments" or "performance" or "technical skills" or "curriculum" or "education" or "mentoring"). The returned dataset was filtered to include only English language and full articles and sorted by number of citations, a method initially developed by Paladugu et al.[6] The 100 most cited articles were identified, and the dataset was further evaluated examining title, first and senior author, institution and department of the first author, topic, year of publication, and the country of origin. The individual and 5-year impact factors (both for the year 2013) of each journal publishing the articles were recorded.

Surgical education was defined as a discipline covering the education of medical knowledge and the acquisition of cognitive and technical skills in the domain of surgery. Exclusion criteria were articles in languages other than English, articles focused on education issues for undergraduates, and articles focused on issues not of interest to the surgical education community.

Articles accruing identical numbers of citations were ranked by dividing the number of citations by the number of years since publication to give a citation rate.

RESULTS

The Thompson Reuters Web of Science returned 403,733 full length, English language articles. Table 1 lists the 100 most cited of these articles.[11-110] All of the articles were published during a 27-year period (1984-2011). The most frequently cited article by Seymour et al.,[11] investigating the use of virtual reality in operating room performance, was published in the Annals of Surgery in 2002 and cited 1018 times.

The oldest article published in 1984 by Schueneman et al.[93] featured at number 83, cited 128 times. The most recent article was published by the Office of Education Research at Mayo Medical School in the United States of America in 2011.[37] It was cited 213 times, ranked at

TABLE 2. Journals With the Top 100 Cited Surgical Education Articles

Journal Title	Impact Factor 2015	5-Year Impact Factor	No. of Articles in the Top 100	Number of Citations
Annals of Surgery	8.33	8.84	16	3715
American Journal of Surgery	2.29	2.74	14	3132
Surgical Endoscopy and Other Interventional Techniques	3.26	3.33	14	2121
Journal of the American College of Surgeons	5.12	5.26	6	1244
Archives of Surgery	4.93	4.89	5	904
British Journal of Surgery	5.54	5.52	4	1680
Journal of the American Medical Association	35.29	31.03	3	707
Journal of Urology	4.47	4.1	3	619
British Medical Journal	16.3	13.511	3	576
Surgery	3.38	3.77	3	561
Diseases of the Colon & Rectum	3.75	3.69	3	475
Medical Education	3.2	3.69	3	449
Academic Medicine	2.93	3.42	2	481
Urology	2.18	2.2	2	347
World Journal of Surgery	2.64	2.84	2	254
New England Journal of Medicine	55.87	54.39	1	475
Lancet	45.22	42.72	1	429
Administrative Science Quarterly	4.21	6.55	1	422
Visual Computer	0.91	0.89	1	212
Journal of the National Cancer Institute	12.58	13.58	1	206
Studies in health technologies and informatics	Book series	Book series	1	180
Management Science	2.48	3.4	1	173
Medical Teacher	1.68	1.91	1	154
Journal of Gastrointestinal Surgery	2.8	2.81	1	140
Mount Sinai Journal of Medicine	1.62	2.14	1	138
Endoscopy	5.05	4.86	1	136
Cinical Orthopaedics and Related Research	2.77	3.37	1	134
Surgeon-Journal of the Royal Colleges of Surgeons of Edinburgh and Ireland	2.18	2.11	1	133
Ieee Computer Graphics and Applications	0.91	1.25	1	117
Presence-Teleoperators and Virtual Environments	0.73	1.05	1	115
Journal of Trauma-Injury Infection and Critical Care	2.96	2.94	1	111
American Surgeon	0.82	1.11	1	108

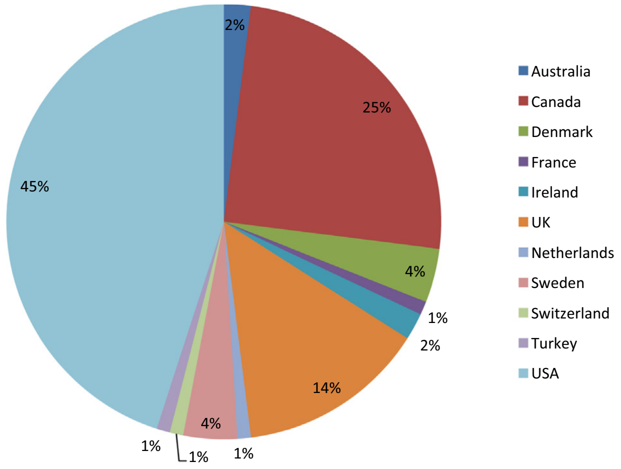

FIGURE. Proportion of citations by country.

number 27, and examined the effectiveness of technology-enhanced simulation training.

The 100 most cited articles were across 31 journals and 1 book series with the number of articles per journal ranging from 1 to 16 (Table 2). Annals of Surgery published the most articles and citations ($n = 16$ and 3715 citations). The Annals of Surgery had an impact factor of 8.33. The New England Journal of Medicine had the highest impact factor (55.87), yet only 1 publication from this journal featured in the top 100 accruing 475 citations.

Most articles originated from academic institutions, and the country with the greatest number of publications was the United States of America with 45, followed by Canada with 19 publications, and the UK with 18 (Fig). The University of Toronto received the highest number of citations with 3659 and was the joint highest institution related to the number of publications in the top 100 with 12 articles (Table 3).

Some authors contributed to more than 1 article in this list. Dr. Anthony Gallagher (Emory University School of Medicine, Atlanta, GA) had the greatest number of first author publications in the top 100 ($n = 6$), and Dr. Richard Reznik (University of Toronto, Canada) had the largest volume of first author citations (1207). The senior author with the most citations was Professor Richard Satava (University of Washington, USA) with 1823.

Simulation training was the topic most widely reported ($n = 45$, Table 4), closely followed by assessment and clinical competence ($n = 40$). Reliability and validity of assessment tools and transferability of training regimens made up the focus of 15 articles, and 8 articles reported developments in clinical skills training. Most articles were research papers ($n = 76$) and reviews ($n = 16$). Of the 76 research papers, 8 were randomized controlled trials, 5 were systematic reviews, and 3 were consensus guideline statements.

A possible limitation of this type of study is that the historical article may accrue a larger number of citations despite lacking the effect of newer publications. To control for this, the number of citations were divided by the number of years since publication to give a citation rate (Table 5).[11,37,14,13,12,21,25,17,69,16] The citation rate for the top 10 articles ranged from 78.3 for Seymour et al.[11] (virtual reality training improves operating room performance—

TABLE 3. Top 20 Institutions With the Highest Number of Articles in the Top 100

Institution	Number of Publication in Top 100	Total Number of Citations
Imperial College London	12	2062
University of Toronto	12	3659
McGill University	6	1325
Harvard University	4	923
University of Texas Southwestern medical centre	4	781
Copenhagen University	3	688
Emory university	3	550
Karolinska University Hospital	3	739
Queens University of Belfast	3	422
University of Aberdeen	3	454
Yale University	3	1387
Royal Australasian College of Surgeons	2	366
The Milton S. Hershey Medical Center	2	233
University of Miami School of Medicine, Miami	1	387
University of Tennessee Medical Center-Knoxville,	1	353
University of California (Irvine) Medical Center	1	336
The Society of American Gastrointestinal Endoscopic Surgeons	1	238
University of Pittsburgh	1	223
Chicago Healthcare System-Lakeside Division	1	220
Duke University Medical Center	1	219

TABLE 4. Most Frequently Referenced Topics

Subject	Number of Articles
Simulation	45
Assessment and clinical competence	40
Clinical skills	8
Communication skills	2
Professionalism	2
Cost of education	1
Patient safety	1
Teaching clinical sciences	1

TABLE 5. Top 10 Articles With the Highest Citation Rate

Rank	Citation Rate	Study	Title	Institution	Country
1	78.3	Seymour et al.[11]	Virtual Reality Training Improves Operating Room Performance: Results of a Randomized, Double-Blinded Study	Yale University School of Medicine	USA
2	53.2	Cook et al.[37]	Technology-Enhanced Simulation for Health Professions Education A Systematic Review and Meta-analysis	Mayo Medical School	USA
3	52.7	Reznick and Macrae[14]	Medical education—Teaching surgical skills—Changes in the wind	University of Toronto	Canada
4	47	Grantcharov[13]	Randomized clinical trial of virtual reality simulation for laparoscopic skills training	University of Copenhagen & Hvidovre Hospital	Belgium
5	45	Martin et al.[12]	Objective structured assessment of technical skill (OSATS) for surgical residents	University of Toronto	Canada
6	31.9	Fried[21]	Proving the value of simulation in laparoscopic surgery	Steinberg-Bernstein Centre for Minimally Invasive Surgery, McGill University	Canada
7	31	Gallagher[25]	Virtual reality simulation for the operating room—Proficiency-based training as a paradigm shift in surgical skills training	Emory University School of Medicine	USA
8	30.1	Edmondson et al.[17]	Disrupted routines: Team learning and new technology implementation in hospitals	Harvard	USA
9	29.8	Sroka et al.[69]	Fundamentals of Laparoscopic Surgery simulator training to proficiency improves laparoscopic performance in the operating room—a randomized controlled trial.	McGill University	Canada
10	28.6	Martling et al.[16]	Effect of a surgical training program on outcome of rectal cancer in the County of Stockholm	Stockholm Colorectal Cancer Study Group, Karolinska Hospital	Sweden

results of a randomized, double-blinded study) to 28.6 for Martling et al.[16] (effect of a surgical training program on outcome of rectal cancer in the County of Stockholm). Canada and the USA had the most articles in the top 10 citation rate, followed by Belgium and Sweden.

DISCUSSION

Education per se, derived from the Latin word educo (comprising e; out of, and duco; I lead) has long been cherished as the key to improved opportunity, well-being, and quality of life. Almost 2 millennia ago, the Roman Emperor Marcus Aurelius[111] in the book "Meditations" (Book 1, AD 115-180) wrote,

"Not to have frequented public schools and to have had good teachers at home, and to realize that on such things man should spend lavishly." Physician to the famously philosophical emperor, Claudius Galen, first sought to demonstrate the workings of the human body through dissection. His work emphasized the importance of physical practice and experimentation in the medical discipline for more than 1500 years. The principal findings of this study underpin the mantra that the surgical training and competency assessment of the here and now, equate to the patient safety and quality of care of tomorrow. Mounting pressures in the clinical environment, allied to initiatives introduced to reduce working hours and emphasis on operating room efficiency, have diminished the global surgical training time available.[112] Little wonder then that no fewer than 45% of the highest cited works concerned simulation skills training with the aim of better preparing trainees so that clinical operative time is optimized.[14] A total of 17 of the top 100 journals were surgical, 7 were medical, 5 were technology based, and 3 were educational. Surgical journal publications attracted more citations than medical journal publications, and only 8 were randomized controlled trials, highlighting the challenges of designing such studies within educational programs.

The impact factor of a journal quantifies the average citations of the articles published within the journal during a specific period of time. Journals with a higher impact factor are recognized as being of a higher quality and therefore more likely to contain articles of importance to the scientific community. The Annals of Surgery with a relatively high impact factor published the most articles ranked within the top 100. Journals with very high impact factors such as the NEJM, the Lancet, and the JAMA, only contained 5% of the top 100 publications, and the majority were found in journals with an impact factor of 3.38 or less. The citation rate index for the surgical education articles ranked as the upper decile ranged from 78.3 to 28.6; relatively weak when compared with the citation rate index of the most influential articles published in other clinical arenas. For example, Powell et al.[9] reported that the most influential articles related to gastric cancer had citation rates ranging from 255 to 81.

Review of the topics covered by the articles in this study revealed that the assessment of clinical competence was among the most frequently studied with 40 publications. Evaluating technical performance in surgery is challenging, and most studies have focused on techniques that standardize the assessment process. The report by Martin et al.[10] had the fifth highest citation rate and compared the reliability and validity of the Objective Structured Assessment of Technical Skills, in which trainees carry out a series of standardized surgical procedures under the direct observation of an expert, to that of the more traditional Objective Structured Clinical Examination. This form of operative competence assessment has now become integral to the assessment of progression of UK surgical trainees, in the form of Procedural Based Assessments.[113] Advances in technology have led to innovative developments in simulation training. Consequently, there has been a greater effort in developing virtual reality training methods, and the emergence of these studies in the top 100 confirms their relative importance to the surgical community. Moreover, virtual reality provides the opportunity for very detailed feedback and may allow for more careful assessment of performance than is possible in the clinical setting.[11]

The main limitation of this study is the potential for several types of bias, which may confound the results. Disproportionate citation may result from institutional bias, language bias, self-citation, or powerful person bias. In addition, older journals may receive more citations, and although an attempt to control this has been made by using the citation rate index, it may take a number of years for influential articles to accrue citations because of publication lead-time.

CONCLUSION

The most cited articles highlighted in the current study describe the use of simulation training as a means of acquiring technical skills and competence, as well as reporting methods of clinical competence assessment. In addition to providing a benchmark as to what may be considered the most cited articles in surgical education, this work serves as a reference for researchers and clinicians alike as to the characteristics of a citable article in the arena of surgical education and training. The findings also suggest that newer articles have a higher citation rate that may have a significant effect on the top 100 in the next decade.

REFERENCES

1. Vivian Nutton. The chronology of Galen's early career. *Classical Q*. 1973;1973(23):158-171.

2. Dobson J, Walker RM. Barbers and Barber-Surgeons of London: A History of the Barbers' and Barber-Surgeons Companies. Oxford: Blackwell scientific publications for the worshipful company of barbers; 1979. 171.

3. Murray MR, Wang T, Schroeder GD, Hsu WK. The 100 most cited spine articles. *Eur Spine J*. 2012;21(10):2059-2069.

4. Kelly JC, Glynn RW, O'Briain DE, Felle P, McCabe JP. The 100 classic papers of orthopaedic surgery: a bibliometric analysis. *J Bone Joint Surg Br*. 2010;92(10):1338-1343.

5. Joyce CW, Carroll SM. Microsurgery: the top 50 classic papers in plastic surgery: a citation analysis. *Arch Plast Surg*. 2014;41(2):153-157.

6. Paladugu R, Schein M, Gardezi S, Wise L. One hundred citation classics in general surgical journals. *World J Surg*. 2002;26(9):1099-1105.

7. Heldwein FL, Rhoden EL, Morgentaler A. Classics of urology: a half century history of the most frequently cited articles (1955-2009). *Urology*. 2010;75(6):1261-1268.

8. Tas F. An analysis of the most-cited research papers on oncology: which journals have they been published in? *Tumour Biol*. 2014;35(5):4645-4649.

9. Powell AG, Hughes DL, Wheat JR, Lewis WG. The 100 most influential manuscripts in gastric cancer: A bibliometric analysis. *Int J Surg*. 2016;28:83-90.

10. Wohlauer MV, George B, Lawrence PF, Pugh CA, Van Eaton EG, DaRosa D. Review of influential articles in surgical education: 2002-2012. *J Grad Med Educ*. 2013;5(2):219-226.

11. Seymour NE, Gallagher AG, Roman SA, O'brien MK, Bansal VK, Andersen DK, Satava RM. Virtual reality training improves operating room performance—results of a randomized, double-blinded study. *Ann Surg*. 2002;236(4):458-464.

12. Martin JA, Regehr G, Reznick R, et al. Objective structured assessment of technical skill (OSATS) for surgical residents. *Br J Surg*. 1997;84(2):273-278.

13. Grantcharov TP. Randomized clinical trial of virtual reality simulation for laparoscopic skills training. *Br J Surg*. 2004;91(2):146-150.

14. Reznick RK, Macrae H. Medical education—teaching surgical skills—changes in the wind. *N Engl J Med*. 2006;355(25):2664-2669.

15. Reznick R, Regehr G, MacRae H, Martin J, McCulloch W. Testing technical skill via an innovative 'bench station' examination. *Am J Surg*. 1997;173(3):226-230.

16. Martling AL, Holm T, Rutqvist LE, Moran BJ, Heald RJ, Cedemark B. Effect of a surgical training programme on outcome of rectal cancer in the County of Stockholm. *Lancet*. 2000;356(9224):93-96.

17. Edmondson AC, Bohmer RM, Pisano GP. Disrupted routines: team learning and new technology implementation in hospitals. *Adm Sci Q*. 2001;46(4):685-716.

18. Issenberg SB, McGaghie WC, Hart IR, et al. Simulation technology for health care professional skills training and assessment. *J Am Med Assoc*. 1999;282(9):861-866.

19. Scott DJ, Bergen PC, Rege RV, et al. Laparoscopic training on bench models: better and more cost effective than operating room experience? *J Am Coll Surg*. 2000;191(3):272-283.

20. Bridges M, Diamond DL. The financial impact of teaching surgical residents in the operating room. *Am J Surg*. 1999;177(1):28-32.

21. Fried GM. Proving the value of simulation in laparoscopic surgery. *Ann Surg*. 2004;240(3):518-525.

22. Ahlering TE, Skarecky D, Lee D, Clayman RV. Successful transfer of open surgical skills to a laparoscopic environment using a robotic interface: initial experience with laparoscopic radical prostatectomy. *J Urol*. 2003;170(5):1738-1741.

23. Derossis AM. Development of a model for training and evaluation of laparoscopic skills. *Am J Surg*. 1998;175(6):482-487.

24. Regehr G, MacRae H, Reznick RK, Szalay D. Comparing the psychometric properties of checklists and global rating scales for assessing performance on an OSCE-format examination. *Acad Med*. 1998;72(9):993-997.

25. Gallagher AG. Virtual reality simulation for the operating room—proficiency-based training as a paradigm shift in surgical skills training. *Ann Surg*. 2005;241(2):364-372.

26. Anastakis DJ, Regehr G, Reznick RK, et al. Assessment of technical skills transfer from the bench training model to the human model. *Am J Surg*. 1999;177(2):167-170.

27. Reznick RK. Teaching and testing technical skills. *Am J Surg*. 1993;165(3):358-361.

28. Moorthy K, Munz Y, Sarker SK, Darzi A. Objective assessment of technical skills in surgery. *Br Med J*. 2003;327(7422):1032-1037.

29. Schlachta CM, Mamazza J, Seshadri PA, Cadeddu M, Gregoire R, Poulin EC. Defining a learning curve for laparoscopic colorectal resections. *Dis Colon Rectum*. 2001;44(2):217-222.

30. Peters JH, Fried GM, Swanstrom LL, et al. Development and validation of a comprehensive program of education and assessment of the basic fundamentals of laparoscopic surgery. *Surgery*. 2004;135(1):21-27.

31. Schauer P, Ikramuddin S, Hamad G, Gourash W. The learning curve for laparoscopic Roux-en-Y gastric bypass is 100 cases. *Surg Endosc*. 2003;17(2):212-215.

32. Rosser JC, Rosser LE, Savalgi RS. Skill acquisition and assessment for laparoscopic surgery. *Arch Surg*. 1997;132(2):200-204.

33. Bennett CL, Stryker SJ, Ferreira MR, Adams J, Beart RW. The learning curve for laparoscopic colorectal surgery—preliminary results from a prospective analysis of 1194 laparoscopic-assisted colectomies. *Arch Surg*. 1997;132(1):41-44.

34. Greenberg CC, Regenbogen SE, Studdert DM, et al. Patterns of communication breakdowns resulting in injury to surgical patients. *J Am Coll Surg*. 2007;204(4):533-540.

35. Meyers WC, Bennett CL. The learning-curve for laparoscopic cholecystectomy. *Am J Surg*. 1995;170(1):55-59.

36. Satava RM. Virtual reality surgical simulator—the 1st steps. *Surg Endosc*. 1993;7(3):203-205.

37. Cook DA, Hatala R, Brydges R, et al. Technology-enhanced simulation for health professions education a systematic review and meta-analysis. *J Am Assoc*. 2011;306(9):978-988.

38. Cotin S, Delingette H, Ayache N. A hybrid elastic model for real-time cutting, deformations, and force feedback for surgery training and simulation. *Visual Comput*. 2000;16(8):437-452.

39. Aggarwal R, Moorthy K, Darzi A. Laparoscopic skills training and assessment. *Br J Surg*. 2004;91(12):1549-1558.

40. Vickers AJ, Bianco FJ, Serio AM, et al. The surgical learning curve for prostate cancer control after radical prostatectomy. *J Natl Cancer Inst*. 2007;99(15):1171-1177.

41. Ahlberg G, Enochsson L, Gallagher AG, et al. Proficiency-based virtual reality training significantly reduces the error rate for residents during their first 10 laparoscopic cholecystectomies. *Am J Surg*. 2007;193(6):797-804.

42. Vassiliou MC, Feldman LS, Andrew CG, et al. A global assessment tool for evaluation of intraoperative laparoscopic skills. *Am J Surg*. 2005;190(1):107-113.

43. Yule S, Flin R, Paterson-Brown S, Maran N. Non-technical skills for surgeons in the operating room: a review of the literature. *Surgery*. 2006;139(2):140-149.

44. Rosser JC, Lynch PJ, Cuddihy L, Gentile DA, Klonsky J, Merrell R. The impact of video games on training surgeons in the 21st century. *Arch Surg*. 2007;142(2):181-186.

45. Sturm LP, Windsor JA, Cosman PH, Cregan P, Hewett PJ, Maddern GJ. A systematic review of skills transfer after surgical simulation training. *Ann Surg*. 2008;248(2):166-179.

46. Korndorffer JR, Dunne JB, Sierra R, Stefanidis D, Touchard CL, Scott DJ. Simulator training for laparoscopic suturing using performance goals translates to the operating room. *J Am Coll Surg*. 2005;201(1):23-29.

47. Kneebone R. Simulation in surgical training: educational issues and practical implications. *Med Educ*. 2003;37(3):267-277.

48. Datta V, Mackay S, Mandalia M, Darzi A. The use of electromagnetic motion tracking analysis to objectively measure open surgical skill in the laboratory-based model. *J Am Coll Surg*. 2001;193(5):479-485.

49. Darzi A, Smith S, Taffinder N. Assessing operative skill—needs to become more objective. *Br Med J*. 1999;318(7188):887-888.

50. Patel VR, Tully AS, Holmes R, Lindsay J. Robotic radical prostatectomy in the community setting—the learning curve and beyond: initial 200 cases. *J Urol*. 2005;174(1):269-272.

51. Watson DI, Baigrie RJ, Jamieson GG. A learning curve for laparoscopic fundoplication—definable, avoidable, or a waste of time? *Ann Surg*. 1996;224(2):198-203.

52. Moulton CA, Dubrowski A, Macrae H, Graham B, Grober E, Reznick R. Teaching surgical skills: what kind of practice makes perfect? A randomized, controlled trial *Ann Surg*. 2006;244(3):400-409.

53. Taffinder N, Sutton C, Fishwick RJ, McManus IC, Darzi A. Validation of virtual reality to teach and assess psychomotor skills in laparoscopic surgery: results from randomised controlled studies using the MIST VR laparoscopic simulator. *Stud Health Technol Inform*. 1998;50:124-130.

54. Hutter MM, Kellogg KC, Ferguson CM, Abbott WM, Warshaw AL. The impact of the 80-hour resident workweek on surgical residents and attending surgeons. *Ann Surg*. 2006;243(6):864-875.

55. Sutherland LM, Middleton PF, Anthony A, et al. Surgical simulation—a systematic review. *Ann Surg*. 2006;243(3):291-300.

56. Grober ED, Hamstra SJ, Wanzel KR, et al. The educational impact of bench model fidelity on the acquisition of technical skill—the use of clinically relevant outcome measures. *Ann Surg*. 2004;240(2):374-381.

57. Pisano GP, Bohmer RMJ, Edmondson AC. Organizational differences in rates of learning: evidence from the adoption of minimally invasive cardiac surgery. *Manage Sci*. 2001;47(6):752-768.

58. Barden CB, Specht MC, McCarter MD, Daly JM, Fahey TJ. Effects of limited work hours on surgical training. *J Am Coll Surg*. 2002;195(4):531-538.

59. Faulkner H, Regehr G, Martin J, Reznick R. Validation of an objective structured assessment of technical skill for surgical residents. *Acad Med*. 1996;71(12):1363-1365.

60. Munz Y, Kumar BD, Moorthy K, Bann S, Darzi A. Laparoscopic virtual reality and box trainers—is one superior to the other? *Surg Endosc*. 2004;18(3):485-494.

61. Hyltander A, Liljegren E, Rhodin PH, Lönroth H. The transfer of basic skills learned in a laparoscopic simulator to the operating room. *Surg Endosc*. 2002;16(9):1324-1328.

62. Herrell SD, Smith JA. Robotic-assisted laparoscopic prostatectomy: what is the learning curve? *Urology*. 2005;66(5):105-107.

63. Aggarwal R, Ward J, Balasundaram I, Sains P, Athanasiou T, Darzi A. Proving the effectiveness of virtual reality simulation for training in laparoscopic surgery. *Ann Surg*. 2007;246(5):771-779.

64. Derossis AM, Bothwell J, Sigman HH, Fried GM. The effect of practice on performance in a laparoscopic simulator. *Surg Endosc*. 1998;12(9):1117-1120.

65. Norcini J, Burch V. Workplace-based assessment as an educational tool: AMEE Guide No. 31. *Med Teach*. 2007;29(9):855-871.

66. Aggarwal R, Grantcharov TP, Eriksen JR, et al. An evidence-based virtual reality training program for novice laparoscopic surgeons. *Ann Surg*. 2006;244(2):310-314.

67. Grantcharov TP, Bardram L, Funch-Jensen P, Rosenberg J. Learning curves and impact of previous operative experience on performance on a virtual reality simulator to test laparoscopic surgical skills. *Am J Surg*. 2003;185(2):146-149.

68. Wishner JD, Baker JW, Hoffman GC, et al. Laparoscopic-assisted colectomy—the learning-curve. *Surg endosc*. 1995;9(11):1179-1183.

69. Sroka G1, Feldman LS, Vassiliou MC, Kaneva PA, Fayez R, Fried GM. Fundamentals of laparoscopic surgery simulator training to proficiency improves laparoscopic performance in the operating room-a randomized controlled trial. *Am J Surg*. 2010;199(1):115-120.

70. Debas HT, Bass BL, Brennan MF, et al. American Surgical Association Blue Ribbon Committee report on surgical education: 2004. *Ann Surg*. 2005;241(1):1-8.

71. Winckel CP, Reznick RK, Cohen R, Taylor B. Reliability and construct-validity of a structured technical skills assessment form. *Am J Surg*. 1994;167(4):423-427.

72. Gallagher AG, Satava RM. Virtual reality as a metric for the assessment of laparoscopic psychomotor skills—learning curves and reliability measures. *Surg Endosc*. 2002;16(12):1746-1752.

73. Matsumoto ED, Hamstra SJ, Radomski SB, Cusimano MD. The effect of bench model fidelity on endourological skills: a randomized controlled study. *J Urol*. 2002;167(3):1243-1247.

74. Rosser JC, Rosser LE, Savalgi RS. Objective evaluation of a laparoscopic surgical skill program for residents and senior surgeons. *Arch Surg*. 1998;133(6):657-661.

75. Gurusamy K, Aggarwal R, Palanivelu L, Davidson BR. Systematic review of randomized controlled trials on the effectiveness of virtual reality training for laparoscopic surgery. *Br J Surg*. 2008;95(9):1088-1097.

76. Yule S, Flin R, Paterson-Brown S, Maran N, Rowley D. Development of a rating system for surgeons' non-technical skills. *Med Educ*. 2006;40(11):1098-1104.

77. Larsen CR, Soerensen JL, Grantcharov TP, et al. Effect of virtual reality training on laparoscopic surgery: randomised controlled trial. *Br Med J*. 2009;338:1802-1807.

78. Fraser SA, Klassen DR, Feldman LS, Ghitulescu GA, Stanbridge D, Fried GM. Evaluating laparoscopic skills—setting the pass/fail score for the MISTELS system. *Surg Endosc*. 2003;17(6):964-967.

79. Scott DJ, Dunnington GI. The new ACS/APDS skills curriculum: moving the learning curve out of the operating room. *J Gastrointest Surg*. 2008;12(2):213-221.

80. Hamilton EC, Scott DJ, Fleming JB, et al. Comparison of video trainer and virtual reality training systems on acquisition of laparoscopic skills. *Surg Endosc*. 2002;16(3):406-411.

81. Okuda Y, Bryson EO, DeMaria S, et al. The utility of simulation in medical education: what is the evidence? *Mt Sinai J Med*. 2009;76(4):330-343.

82. Gallagher AG, Richie K, McClure N, McGuigan J. Objective psychomotor skills assessment of experienced, junior, and novice laparoscopists with virtual reality. *World J Surg*. 2001;25(11):1478-1483.

83. Link RE, Bhayani SB, Allaf ME, et al. Exploring the learning curve, pathological outcomes and perioperative morbidity of laparoscopic partial nephrectomy performed for renal mass. *J Urol*. 2005;173(5):1690-1694.

84. Gallagher AG, McClure N, McGuigan J, Crothers I, Browning J. Virtual reality training in laparoscopic surgery: a preliminary assessment of minimally invasive surgical trainer virtual reality (MIST VR). *Endoscopy*. 1999;31(4):310-313.

85. Torkington J, Smith SG, Rees BI, Darzi A. Skill transfer from virtual reality to a real laparoscopic task. *Surg Endosc*. 2001;15(10):1076-1079.

86. Fried GM, Derossis AM, Bothwell J, Sigman HH. Comparison of laparoscopic performance in vivo with performance measured in a laparoscopic simulator. *Surg Endosc*. 1999;13(11):1077-1081.

87. Andreatta PB, Woodrum DT, Birkmeyer JD, et al. Laparoscopic skills are improved with LapMentor (TM) training—results of a randomized, double-blinded study. *Ann Surg*. 2006;243(6):854-863.

88. Datta V, Chang A, Mackay S, Darzi A. The relationship between motion analysis and surgical technical assessments. *Am J Surg*. 2002;184(1):70-73.

89. Dahl MT, Gulli B, Berg T. Complications of limb lengthening—a learning-curve. *Clin Orthop Relat Res*. 1994;301:10-18.

90. Older J. Anatomy: a must for teaching the next generation. *Surgeon*. 2004;2(2):79-90.

91. Eastridge BJ, Hamilton EC, O'Keefe GE, et al. Effect of sleep deprivation on the performance of simulated laparoscopic surgical skill. *Am J Surg*. 2003;186(2):169-174.

92. Gallagher AG, Ritter EM, Satava RM. Fundamental principles of validation, and reliability: rigorous science for the assessment of surgical education and training. *Surg Endosc*. 2003;17(10):1525-1529.

93. Schueneman AL, Pickleman J, Hesslein R, Freeark RJ. Neuropsychologic predictors of operative skill among general-surgery residents. *Surgery*. 1984;96(2):288-295.

94. Haluck RS, Krummel TM. Computers and virtual reality for surgical education in the 21st century. *Arch Surg*. 2000;135(7):786-792.

95. Liem MS, van Steensel CJ, Boelhouwer RU, et al. The learning curve for totally extraperitoneal laparoscopic inguinal hernia repair. *Am J Surg*. 1996;171(2):281-285.

96. Simons AJ, Anthone GJ, Ortega AE, et al. Laparoscopic-assisted colectomy learning-curve. *Dis Colon Rectum*. 1995;38(6):600-603.

97. SLOAN DA, Donnelly MB, Schwartz RW, Strodel WE. The objective structured clinical examination—the new gold standard for evaluating postgraduate clinical-performance. *Ann Surg*. 1995;222(6):735-742.

98. Marescaux J, Clement JM, Tassetti V, et al. Virtual reality applied to hepatic surgery simulation: the next revolution. *Ann Surg*. 1998;228(5):627-634.

99. Kneebone RL, Scott W, Darzi A, Horrocks M. Simulation and clinical practice: strengthening the relationship. *Med Educ*. 2004;38(10):1095-1102.

100. Basdogan C, De S, Kim J, Muniyandi M, Kim H, Srinivasan MA. Haptics in minimally invasive surgical simulation and training. *IEEE Comput Graph Appl*. 2004;24(2):56-64.

101. Yule S, Flin R, Maran N, Rowley D, Youngson G, Paterson-Brown S. Surgeons' non-technical skills in the operating room: reliability testing of the NOTSS behavior rating system. *World J Surg*. 2008;32(4):548-556.

102. Liu A, Tendick F, Cleary K, Kaufmann C. A survey of surgical simulation: applications, technology, and education. *Presence*. 2003;12(6):599-614.

103. Bell RH, Biester TW, Tabuenca A, et al. Operative experience of residents in US general surgery programs a gap between expectation and experience. *Ann Surg*. 2009;249(5):719-724.

104. Marshall RL, Smith JS, Gorman PJ, Krummel TM, Haluck RS, Cooney RN. Use of a human patient simulator in the development of resident trauma management skills. *J Trauma*. 2001;51(1):17-21.

105. Dinçler S, Koller MT, Steurer J, Bachmann LM, Christen D, Buchmann P. Multidimensional analysis of learning curves in laparoscopic sigmoid resection—eight-year results. *Dis Colon Rectum*. 2003;46(10):1371-1378.

106. O'Toole RV, Playter RR, Krummel TM, et al. Measuring and developing suturing technique with a virtual reality surgical simulator. *J Am Coll Surg*. 1999;189(1):114-127.

107. Carter FJ, Schijven MP, Aggarwal R, et al. Consensus guidelines for validation of virtual reality surgical simulators. *Surg Endosc*. 2005;19(12):1523-1532.

108. Senagore aJ, Luchtefeld MA, Mackeigan JM. What is the learning-curve for laparoscopic colectomy. *Am Surg*. 1995;61(8):681-685.

109. Gallagher AG, Cates CU. Approval of virtual reality training for carotid stenting—what this means for procedural-based medicine. *J Am Med Assoc*. 2004;292(24):3024-3026.

110. Ahlberg G, Heikkinen T, Iselius L, Leijonmarck CE, Rutqvist J, Arvidsson D. Does training in a virtual reality simulator improve surgical performance? *Surg Endosc*. 2002;16(1):126-129.

111. Harold E. The Cambridge Illustrated History of Surgery. Cambridge University Press; 2009.

112. Greenaway D et al. Securing the future of excellent patient care: final report of the independent review led by professor David Greenaway. *Shape of Training Report*. Available at: ⟨http://www.shapeoftraining.co.uk/static/documents/content/Shape_of_training_FINAL_Report.pdf_53977887.pdf⟩ [Accessed 2015].

113. Intercollegiate Surgical Curriculum Programme. Procedure Based Assessment. Available at: ⟨https://www.iscp.ac.uk/surgical/assessment_pba.aspx⟩ [Accessed 2015].