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Criterion-Based Training With Surgical Simulators: Proficiency of Experienced Surgeons

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ABSTRACT

Objective: In our effort to establish criterion-based skills training for surgeons, we assessed the performance of 17 experienced laparoscopic surgeons on basic technical surgical skills recorded electronically in 26 modules selected in 5 commercially available, computer-based simulators.

Methods: Performance data were derived from selected surgeons randomly assigned to simulator stations, and practicing repetitively during one and one-half day sessions on 5 different simulators. We measured surgeon proficiency defined as efficient, error-free performance and developed proficiency score formulas for each module. Demographic and opinion data were also collected.

Results: Surgeons' performance demonstrated a sharp learning curve with the most performance improvement seen in early practice attempts. Median scores and performance levels at the 10th, 25th, 75th, and 90th percentiles are provided for each module. Construct validity was examined for 2 modules by comparing experienced surgeons' performance with that of a convenience sample of less-experienced surgeons.

Conclusion: A simple mathematical method for scoring performance is applicable to these simulators. Proficiency levels for training courses can now be specified objectively by residency directors and by professional organizations for different levels of training or post-training assessment of technical performance. But data users should be cautious due to the small sample size in this study and the need for further study into the reliability and validity of the use of surgical simulators as assessment tools.

Key Words: Surgical simulation, Proficiency scores, Laparoscopic surgery, Experienced surgeons.

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INTRODUCTION

The 1999 Institute of Medicine report *To Err is Human*[1] riveted the medical establishment's attention onto errors made during patient care. A significant portion of the errors occurred during the care of surgical patients, and the report made recommendations for mitigation. Also in 1999, the American Council on Graduate Medical Education (ACGME) endorsed 6 competencies required for resident medical education.[2-4] Those in *Patient Care* and in *Practice-Based Learning* concern several components of surgical management, one of which is technical competence in conducting surgical procedures. By 2002, training programs were required to implement the ACGME recommendations to achieve program certification. Simultaneously and independently, surgical simulation has become established as a valid technique for training basic surgical skills performance of novice surgeons and demonstrating that their performances suffer compared with those of experienced surgeons.[5–7]

Performance can be measured electronically on many surgical simulators, thereby affording objective assessments of technical competency not possible with prior methods of training and assessment.[6,8–11] Commercially available surgical simulators have unique outputs of performance and errors that are different between systems because standards have not been developed. The metrics found in simulators are of several types including units that describe distances that instrument tips travel (mm) in pursuit of a prescribed target, an economy measure (%) that relates the distance traveled compared with the direct distance, smoothness of the movement (a rate), the percentage of targets touched and transferred, the number (#) of minor or major errors, and other things (**Appendices 1-4**). This diverse set of outputs provides immediate feedback to users, but only a few (such as time taken) can also be utilized for determining normative performances across the various commercially available simulators. This research project has its roots in the need to document these metrics, to establish performance data for guiding the use of simulators in surgical training, and to develop a criterion-based training capability that is useful for residency program directors, vendors, and professional surgical organizations that seek to adopt surgical simulation as a learning and assessment technology.

METHODS

The Surgical Simulation Committee of the Society of Laparoendoscopic Surgeons (SLS) (Drs Satava, McDougall, Hasson, Heinrichs, Youngblood, Wetter) authorized SUMMIT to conduct this study before the 15th Annual Meeting in San Diego, California, during September 2005. Committee members and vendors met at SUMMIT on July 25th to review the modules of each simulator and select the 26 modules to be performed **(Table 1)**. Based on professional reputation of surgical excellence and volume of surgical cases, laparoscopic surgeons in General Surgery, 7; Obstetrics and Gynecology, 6; and Urology, 3, (one surgeon's specialty was unknown) were recruited by committee members not conducting the trials. The 17 surgeon-participants included members of the following professional organizations: the American Association of Laparoendoscopic Laparoscopists, American College of Surgeons, American Urological Association, Society of American Gastrointestinal Endoscopic Surgeons, and Society of Laparoendoscopic Surgeons. The participants were paid to join this one and one-half day study group to provide their performance of surgical skills in an IRB-approved study. The number and type of systems available from vendors were *Lap Mentor* (2, Symbionix, Cleveland, OH), *LapSim* (4, Surgical-Science AB, Göteborg Sweden), *LTS2000 ISM60* (4, RealSim, Albuquerque, NM), *ProMIS* (2, Haptica, Boston, MA), and *SurgicalSIM,* (3, METI, Sarasota, FL).

Data were collected anonymously, and participants completed 2 questionnaires, one providing demographic information and the other a rating scale filled out immediately after participants completed their last performance on each simulator. Participants were assigned randomly to each system that was initially demonstrated by trained personnel who then answered the subjects' questions before logging them into the system. After the demonstration, surgeons completed the first module at least once and repeated the module if time were available before participants were signaled to move to another system; performance data were collected on all trials. After completion of a trial, assistants logged participants out and saved their results. On Day 1, 35 minutes was allocated for each system; later sessions allocated 30 minutes per system. In the interest of accumulating the maximal number of performances, a flexible schedule allowed participants to complete a module before moving to their next assigned system. The mean number of trials per surgeon was 3.5, and the maximum was 10. A preliminary report of this study has been presented.[12]

These procedures are very similar to those developed and used on 2 previous occasions for collecting data from a "convenience sample" of attendees at the 2004 annual meetings of the SLS and the AAGL in New York City and San Francisco, respectively.[13] These trials, used in this report as a reference sample of less-experienced surgeons, were limited to the Peg Manipulation module of the LTS 2000 and the Lifting and Grasping module of the LapSim. These trials were not timed and were not repetitive, although some surgeons performed them more than twice.

We developed a proficiency score formula for each module of the form $b_0 + b_1X_1 + b_2X_2 + \ldots + b_kX_k$, where b_0, b_1, $b_2, \ldots$ b_k are constants (called coefficients) and X_1, $X_2, \ldots$, X_k are the measures (variables) recorded in the module. As an example, one possible proficiency score formula is proficiency score=120 – (2 x Time) – (4 x Errors). The number 120 is arbitrary and can be adjusted upward or downward to achieve a desired shift of the values. Achieving a theoretical proficiency score of 120 would require using zero time and making zero errors during a performance, obviously impossible conditions. The coefficient of each variable indicates the amount by

Table 1.
Modules/Tasks Selected for Each Simulator

Lap Mentor	**Skills for Completing the Tasks**
Camera navigation - 0°	Navigate to target, fix on target, activate hand signal of completion
Camera navigation - 30°	Same as for 0° endoscope
Eye-hand coordination	Navigate instruments to targets, touch target to signal completion
Clip applying	Navigate instrument to target, apply clip(s)
Grasping and clipping	Select instruments, navigate to target, grasp tube, retract & clip
Two-handed maneuvers	Select instruments, navigate, retract, grasp, transfer, & place
Cutting - dissecting	Select instruments, navigate, grasp, retract, expose, excise
Hook electrodes	Navigate, identify & hook (band), expose, desiccate (foot pedal)
Translocation of objects	Navigate, elevate, rotate, orient, transfer, place
LapSim	
Camera navigation	Navigate camera to target, fix on target, hold
Eye-hand coordination	Navigate instruments to target, touch target
Grasping	Navigate, grasp, extract, transfer, insert, place
Grasping & cutting	Navigate, grasp, retract, incise, place
Lifting & grasping	Navigate, expose, grasp, transfer, place
Suturing	Navigate, grasp, penetrate target, rotate, grasp, tie square knot
LTS2000 ISM60	
Peg manipulation	Navigate, grasp, transfer, place, release
Ring manipulation	Navigate, grasp, rotate, traverse, guide, stretch, place, release
Ductal cannulation	Navigate, grasp, push to cannulate, grasp, extract
Lasso loop formation & cinching	Navigate, grasp suture, loop instrument around, navigate to suture end, grasp and pull; repeat to make lasso, place onto peg, and pull
Intracorporeal suturing	Navigate, grasp, penetrate target, rotate, grasp, tie knot, test
Tissue "disc" dissection	Navigate, grasp, incise, rotate, elevate, release
ProMIS	
Object positioning: grasp & transfer	Navigate, grasp, transfer
Sharp dissection: cut out circle	Navigate, grasp, position, incise, rotate, excise repeatedly
Knot tying: surgeon's knot	Navigate, grasp suture, loop instrument around, navigate to suture end, grasp and pull; repeat twice
Surgical SIM	
Retract-dissect	Navigate, grasp, navigate, desiccate, repeat
Traverse tube	Navigate, grasp, navigate, grasp, and others things
Place arrow	Navigate, grasp, navigate, grasp, place, hold, repeat
Dissect gallbladder	Navigate, grasp, retract, navigate, desiccate, excise

which the proficiency score changes for each unit increase in the measure. In the example proficiency score formula above, each extra error results in a proficiency score decrease of 4 points.

Assumptions in the analysis are that the proficiency levels of our participants (the experts) are at least 50 on a 0–100 scale, proficiency increases with practice, and that best performances are near 100. We compared other formulas that made assumptions of longer-time-to-plateau in proficiency scores, but the data reported below represent the "best fit" to the formulas.

RESULTS

The dataset for this benchmark study comprises 204 measurements for the 26 modules selected and was performed 0 to 10 times each by 17 surgeons. As expected and illustrated in **Figure 1**, the earlier practice attempts demonstrate a sharp learning curve followed by less proficiency score improvement. **Table 2** provides data that guided our decision for using attempt #4 for presenting benchmark data: out of 204 measures across all of the modules, 183 (90%) exhibited their largest changes between attempts by attempt #4.

Median scores and performance levels at the 10th, 25th, 50th, 75th, and 90th percentiles are provided in **Table 3** to characterize the behavioral (performance) domain for experienced surgeons performing each module. See **Appendices 1–5** for the remaining data. To provide the most uniform dataset and proficiency scores, data points further than 2 SD away from the mean were purged, to reduce the influence of outliers.

Each proficiency score has behind it a formula that combines the measures taken by the simulator into a single score. For LapSim Lifting & Grasping, that formula is:

Proficiency = 132.0551
- 0 Left instrument misses
- 9.7609 Left instrument path length
- 0.002 Left instrument angle path
- 0.098 Right instrument misses
- 1.6881 Right instrument path length
- 0 Right instrument angle path
- 0.4771 Total time
- 0 Tissue damage
- 0.0971 Max damage

For example, a surgeon with a median-level performance on each of the variables (the 50th percentile column in **Table 3**) would have a proficiency score of

Proficiency = 132.0551
- 0x0.0
- 9.7609x1.442
- 0.002x333.868
- 0.098x0.0
- 1.6881x1.497
- 0x320.654
- 0.4771x52.455
- 0x2
- 0.0971x17.529

= 88.06

Mean values and SDs were also computed for completeness. However, for technical reasons, we prefer the use of percentiles rather than means and standard

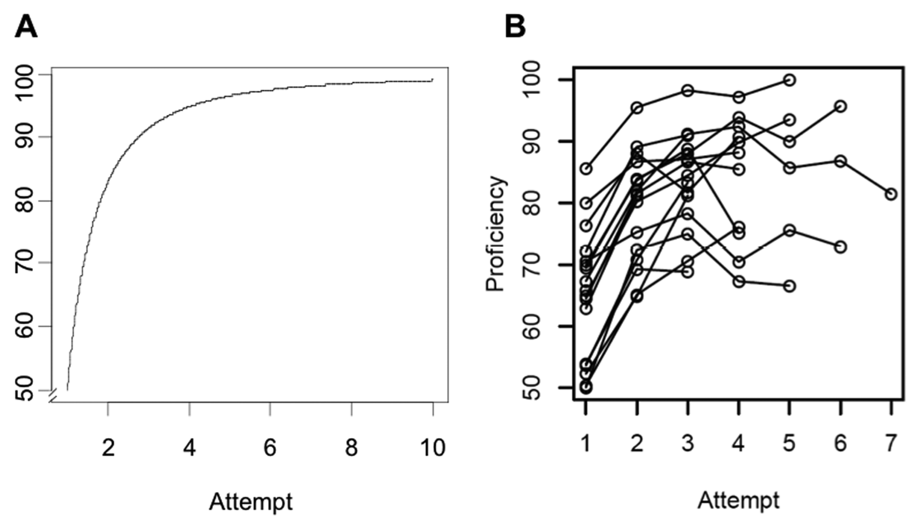

Figure 1. Graph of proficiency scores: (A) ideal practice curve; (B) lifting and grasping module of LapSim.

Table 2.
Rationale for Selecting Attempt #4*† for Calculation of Proficiency Scores: Attempts and Variables

The Change Between Attempts	Was Largest for This Many Variables (out of 204)
#1–#2	100
#2–#3	73
#3–#4	10
#4–#5	03

*We present Attempt #2 data from the LapMentor tasks because less data were available for these tasks.
†Because the number of surgeons present for Attempt #3 was on average about 2.1 higher than the number present for Attempt #4, the accompanying website presents data for both Attempts #3 and #4.

deviations, so such information can be found in **Appendix 1.**

Some participants were unable to complete the 3 half-days due to competing activities and unexpected responsibilities. Also, one vendor's systems were delayed in US Customs, and 2 provided fewer than the ideal number of 4 systems needed for this number of participants. The consequence was fewer data for those systems, particularly the Lap Mentor.

Opinions for Surgeon Users

On the third half-day of the study, the surgeons evaluated the overall effectiveness of the 5 simulators as training tools (in comparison with training not given on a computer) on a 4-point scale. Their average ratings ranged from 3.1 to 3.8, signifying the range of *very good* to *excellent* **(Figure 2)**. Nevertheless, the mean effectiveness ratings for each

Reliability

One simple way to get a measure of reliability is to compute the correlation between proficiency scores on successive attempts after the learning curve has flattened out. We computed the correlations between proficiency scores on attempts 3 and 4 on all the systems except LapMentor tasks for which we had only 2 attempts. The average correlation was 0.65, with quite a large range (0.14 to 0.96).

Validity

One simple measure of the validity of our proficiency score formula is to see whether it distinguishes between the experts in our sample and the "convenience sample" taken at the 2004 SLS and AAGL meetings. Unfortunately, we only had 2 tasks of overlap between the 2 samples, and the sample sizes were fairly small. However, the results do suggest some validity for the proficiency score formulas tested. For the Peg Manipulation task of the LTS 2000 simulator, our expert sample had a mean score of 85.49, while the convenience sample had a mean score of 81.43. However, this difference was not significant ($P=0.25$). For the Lifting and Grasping task of the LapSim simulator, our expert sample had a mean score of 79.36, while the convenience sample had a mean score of 68.04. This difference was statistically significant ($P<0.01$). It should be noted that these results are merely suggestive

Table 3.
LapSim: Variables Measured and Criterion Percentile, Lifting and Grasping

Variable	10	25	50	75	90
Left instrument misses	0.0	0.0	0.0	0.0	0.0
Left instrument path length	1.593	1.562	1.442	1.332	1.183
Left instrument angle path	432.997	358.058	333.868	315.473	306.557
Right instrument misses	0.0	0.0	0.0	0.0	0.0
Right instrument path length	1.81	1.626	1.497	1.443	1.17
Right instrument angle path	483.922	381.742	320.654	303.44	293.167
Total time	74.787	71.879	52.455	46.602	43.455
Tissue damage	5	3.5	2	1	0
Maximum damage	45.042	33.066	17.529	5.035	3.323
Proficiency score	70.509	75.581	88.227	91.579	93.929

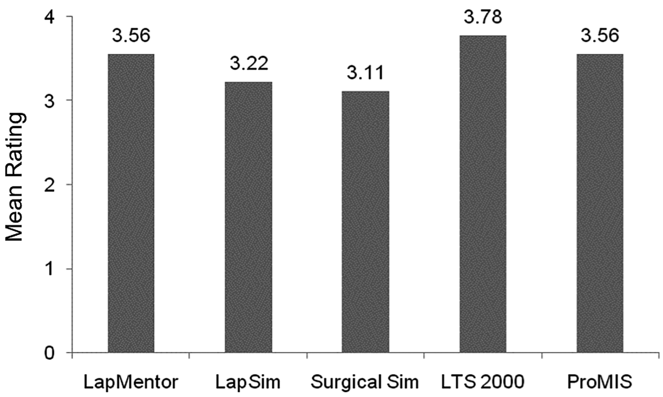

Figure 2. Mean ratings of the effectiveness of the 5 simulators (1 is poor and 4 is excellent).

for a number of reasons (eg, only 2 tasks were available for comparison, and the expert sample was used to create the proficiency score in the first place). Further work is needed to ensure that our proficiency score formulas are valid. For example, a validity study might compare our proficiency score formulas with independent ratings of surgeon performance by experts in the field.

DISCUSSION AND CONCLUSION

This study provides the surgical community with the first set of performance data for criterion-based training on a group of 5 surgical simulators based on the performance of 17 experienced laparoscopic surgeons. Three objectives were met[1]: acquiring standardized data simultaneously from a practically large group of experienced surgeons,[2] providing vendors with data for guiding their development of courses for general use, and[3] providing surgical program directors and professional organizations with data for setting standards for criterion-based training and assessment. Using these criteria, training program administrators will tentatively be able to calibrate their training programs and requirements with any of these systems. We say tentatively because experience with the proficiency scores will provide feedback only as to reasonable levels of performance in practice, because *none of the simulators were developed as an assessment instrument per se, and because future studies should map the link between performance on the simulator tasks and performance in surgery.* Although we believe that these data are too few for attempting to certify the technical skills of surgeons with the present systems, they provide a strong resource for guiding self-learning goals by surgical residents and residency achievement benchmarks. They also may inform medical students making career decisions about the level of technical skills required in laparoscopic surgery.

The data provide a criterion against which trainee performance can be evaluated. Two different representations of the criterion data were provided: percentiles and means ±SD. We recommend use of percentiles for criterion setting as this representation is directly interpretable—for example, a trainee's performance is equivalent to the 25th percentile performance of experienced surgeons, is less influenced than means by extreme performance scores, and does not depend on the assumption of normality to interpret, as does the interpretation of means with SD.

A *Proficiency Score* at or near the median is consistent with performances by the middle individual among a group of experienced surgeons who performed this exercise/module; a score at or near the 25th percentile indicates a performance better than those given by 25% of the experienced group, and a score at or near the 75th percentile indicates a performance better than those given by 75% of the experienced group."

With further experience with criterion-referenced data, our objective will become competence-based training, fulfilling the ACGME objectives. Academic surgeons, professional societies, and certifying boards must soon adopt training objectives and curricula that move away from the calendar as a training-endpoint.[14] The United Kingdom has already taken a step in that direction.[15,16]

The language of metrics used within the surgical community deserves comment. All of the several skills required for performing these tasks are based on and reflect the inherent *abilities* of each user, including eye-hand coordination, visual-spatial perception, focus, neuro-muscular stability, and other such things.[17,18] The *skills* required for performing the *tasks* listed in **Table 1** require practice to improve performance and are shared by most of the simulators. Beyond *tasks,* procedures are the product of choreographing multiple *tasks* that, when combined, comprise a surgical manipulation or procedure.[19,20] Some systems describe tasks by using the names of skills, providing confusion for users. For example, grasping and transfer or grasping and lifting are individual skills, not tasks, but the combination of 2 skills has been labeled as a task in the LapSim. As development of simulators evolves, additional graphics and functions are being introduced, moving toward "part-procedure" trainers. Thus, nomenclature too has not been standardized across systems.[21] Delineation of the skills that comprise each task is presented in **Table 1** to clarify the nomenclature.

Similarly, error(s) recorded vary among modules. In the Peg Manipulation module of the LTS2000, dropping a peg is recorded as one error. Errors could also reflect touching the target with the shaft of a grasper, or striking the edge of a bounding box with the target-in-transfer, or the instrument tip, or the instrument shaft, etc. The LapSim module on Lifting and Grasping records errors of several types, such as touching the cover lying over a target object (surgical needle) with the shaft of a handle or touching the background (producing a *red-out*), and it records the depth of pressure-distortion of the background. It does not record the number of attempts the user makes in lifting the lid, nor the number of times that it is dropped inadvertently. These are additional features by which stability of performance can be assessed on that module. The Simulation Committee will respectfully address each vendor with suggestions for improvement of the measures recorded, with a request that such changes be introduced as an incentive for obtaining endorsement from professional surgical societies.

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Appendix 1. LapSim Modules (Medium Difficulty) Attempt #4

Module 1: Camera Navigation, 0°

Proficiency = 112.4693 Intercept - 3.9135 Path length - 0.3464 Total time - 0.0982 Drift

Variables Measured and Criterion Percentile Values

Variable	10	25	50	75	90
Path length	2.155	1.768	1.502	1.373	1.268
Angular path	915.586	596.561	472.468	370.479	279.943
Total time	70.359	58.448	38.893	31.447	28.312
Drift	7.417	6.516	5.372	3.829	3.302
Tissue damage	0	0	0	0	0
Maximum damage	0	0	0	0	0
Proficiency score	78.546	84.654	93.052	95.782	96.787

Means ± Standard Deviations for Each Variable

Variable	−1.5	−1	0	+1	+1.5
Path length	1.061	1.246	1.618	1.989	2.175
Angular path	137.723	270.31	535.483	800.656	933.242
Total time	20.839	29.405	46.537	63.668	72.234
Drift	2.467	3.386	5.224	7.062	7.981
Tissue damage	0	0	0	0	0
Maximum damage	0	0	0	0	0
Proficiency score	78.082	81.792	89.213	96.634	100.344

Module 2: Instrument Navigation

Proficiency = 136.4479 - 36.7202 Left instrument path length −21.4565 Right instrument path length -0.012 Right instrument angular path - 0.6106 Right instrument time - 0.2756 Tissue damage - 0.1563 Maximum damage

Variables Measured and Criterion Percentile Values

Variable	10	25	50	75	90
Left instrument path length	0.06	0.65	0.72	0.77	0.81
Left instrument angle path	168.37	180.38	204.47	228.95	245.88
Left instrument time	9.20	10.13	11.11	12.76	14.86
Right instrument path length	0.58	0.62	0.70	0.74	0.81
Right instrument angle path	131.35	142.44	155.53	180.19	194.22
Right instrument time	9.74	11.39	14.11	15.53	17.32
Tissue damage	0.00	0.00	1.00	1.00	4.00
Maximum damage	0.00	0.00	0.75	1.37	5.33
Proficiency score	77.49	78.89	84.37	88.50	93.37

Means ± Standard Deviations for Each Variable

Variable	−1.5	−1	0	+1	+1.5
Left instrument path length	0.545	0.6	0.709	0.819	0.874
Left instrument angle path	132.508	151.354	189.045	226.736	245.582
Left instrument time	7.639	8.783	11.071	13.36	14.504
Right instrument path length	0.491	0.551	0.669	0.787	0.846
Right instrument angle path	102.534	120.756	157.202	193.648	211.87
Right instrument time	8.284	9.736	12.64	15.545	16.997
Tissue damage	−0.716	0.038	1.545	3.053	3.807
Maximum damage	−1.015	−0.182	1.484	3.15	3.983
Proficiency score	75.113	78.898	86.466	94.035	97.819

Module 3: Grasping

Proficiency = 111.5076 − 2.9354 Left instrument path length − 0.0013 Left instrument angular path -0.0632 Left instrument misses - 1.2948 Right instrument path length - 0.2603 Right instrument time -0.1122 Right instrument misses − 0.1343 Maximum damage

Variables Measured and Criterion Percentile Values

Variable	10	25	50	75	90
Left instrument path length	2.965	2.764	2.424	1.778	1.608
Left instrument angular path	701.949	626.146	499.675	399.267	379.985
Left instrument time	61.518	59.456	50.205	34.913	31.722
Left instrument misses	0	0	0	0	0
Right instrument path length	2.765	2.429	2.173	1.891	1.613
Right instrument angular path	496.771	424.834	331.345	305.61	295.78
Right instrument time	57.939	54.327	39.816	35.297	31.411
Right instrument misses	0	0	0	0	0
Tissue damage	5	5	4	2	1
Maximum damage	8.207	5.748	4.453	3.055	1.43
Proficiency score	80.914	84.84	88.821	92.713	95.749

Means ± Standard Deviations for Each Variable

Variable	−1.5	−1	0	+1	+1.5
Left instrument path length	1.37	1.689	2.327	2.965	3.284
Left instrument angular path	315.689	382.294	515.504	648.713	715.318
Left instrument time	28.369	34.912	47.997	61.083	67.626
Left instrument misses	0	0	0	0	0
Right instrument path length	1.509	1.727	2.165	2.603	2.821
Right instrument angular path	238.458	281.731	368.278	454.825	498.099
Right instrument time	24.833	31.098	43.63	56.161	62.426
Right instrument misses	0	0	0	0	0
Tissue damage	−1.05	0.633	4	7.367	9.05
Maximum damage	0.244	1.771	4.824	7.877	9.404
Proficiency score	79.908	82.833	88.683	94.533	97.458

Module 4: Cutting

Proficiency = 120.2763 - 0.0461 Cutter angular path - 0.4382 Total time - 0.0685 Maximum stretch damage - 0.1884 Rip failure

Variable Measured and Criterion Percentile Values

Variable	10	25	50	75	90
Cutter path length	0.685	0.594	0.487	0.417	0.324
Cutter angular path	162.363	146.659	122.407	96.565	78.135
Total time	95.647	71.46	48.401	44.088	43.322
Maximum stretch damage	97.481	64.448	37.526	24.817	2.407
Tissue damage	2	1	1	0	0
Maximum damage	4.688	3.73	1.534	0	0
Rip failure	0	0	0	0	0
Drop failure	0	0	0	0	0
Proficiency score	68.967	83.389	89.569	93.428	94.8

Means ± Standard Deviations for Each Variable

Variable	−1.5	−1	0	+1	+1.5
Cutter path length	0.268	0.35	0.515	0.679	0.761
Cutter angle path	59.773	81.837	125.965	170.092	192.156
Total time	25.18	36.957	60.511	84.065	95.842
Maximum stretch damage	−4.899	11.828	45.282	78.735	95.462
Tissue damage	−0.922	−0.312	0.909	2.13	2.741
Maximum damage	−4.058	−1.746	2.876	7.499	9.81
Rip failure	0.00	0.00	0.00	0.00	0.00
Drop failure	0.00	0.00	0.00	0.00	0.00
Proficiency score	70.489	75.78	86.36	96.94	102.23

Module 5: Lifting and Grasping

Proficiency = 132.0551 - 9.7609 Left instrument path length - 0.002 Left instrument angle path - 0.098 Right instrument misses - 1.6881 Right instrument path length - 0.4771 Total time - 0.0971 Max damage

Variables Measured and Criterion Percentile Values

Variable	10	25	50	75	90
Left instrument misses	0.0	0.0	0.0	0.0	0.0
Left instrument path length	1.593	1.562	1.442	1.332	1.183
Left instrument angle path	432.997	358.058	333.868	315.473	306.557
Right instrument misses	0.0	0.0	0.0	0.0	0.0
Right instrument path length	1.81	1.626	1.497	1.443	1.17
Right instrument angle path	483.922	381.742	320.654	303.44	293.167
Total time	74.787	71.879	52.455	46.602	43.455
Tissue damage	5	3.5	2	1	0
Maximum damage	45.042	33.066	17.529	5.035	3.323
Proficiency score	70.509	75.581	88.227	91.579	93.929

Means ± Standard Deviations for Each Variable

Variable	−1.5	−1	0	+1	+1.5
Left instrument misses	0.0	0.0	0.0	0.0	0.0
Left instrument path length	1.128	1.231	1.435	1.639	1.741
Left instrument angle path	274.425	299.511	349.682	399.854	424.939
Right instrument misses	0.0	0.0	0.0	0.0	0.0
Right instrument path length	1.152	1.275	1.523	1.77	1.894
Right instrument angle path	241.43	279.339	355.157	430.975	468.884
Total time	36.137	43.184	57.277	71.37	78.416
Tissue damage	−0.734	0.268	2.273	4.277	5.28
Maximum damage	−5.776	3.008	20.576	38.143	46.927
Proficiency score	68.917	74.033	84.263	94.494	99.61

Appendix 2: LTS2000 ISM60* Attempt #4

Module 1: Peg Manipulation
Proficiency = 104.319 - 0.1309 Time - 2.5093 Errors

Variables Measured and Criterion Percentile Values

Variable	10	25	50	75	90
Time	143.0	135.5	83.0	54.0	47.0
Errors	1.2	1	0	0	0
Proficiency score	77.552	85.734	93.456	95.462	96.728

Means ± Standard Deviations for Each Variable

Variable	−1.5	−1	0	+1	+1.5
Time	29.198	50.617	93.455	136.292	157.711
Errors	−0.849	−0.366	0.6	1.566	2.049
Proficiency score	77.901	81.793	89.579	97.364	101.257

Module 2: Ring Manipulation (Dominant Hand)
Proficiency = 103.0973 - 0.4425 Time

Variables Measured and Criterion Percentile Values

Variable	10	25	50	75	90
Time	143.0	135.5	83.0	54.0	47.0
Errors	1.2	1	0	0	0
Proficiency score	77.552	85.734	93.456	95.462	96.728

Means ± Standard Deviations for Each Variable

Variable	−1.5	−1	0	+1	+1.5
Time	5.883	9.407	16.455	23.502	27.026
Errors	−0.131	0.413	1.5	2.587	3.131
Proficiency score	91.139	92.698	95.817	98.935	100.494

Module 3: Ring Manipulation (Non-dominant Hand)
Proficiency = 100.4142 - 0.1381 Time - 11.282 Errors

Variables Measured and Criterion Percentile Values

Variable	10	25	50	75	90
Time	26	23	12	10.5	8
Errors	3	3	1	1	1
Proficiency score	62.978	63.6	86.233	87.648	88

Means ± Standard Deviations for Each Variable

Variable	−1.5	−1	0	+1	+1.5
Time	3.989	8.023	16.091	24.159	28.193
Errors	0.057	0.594	1.667	2.74	3.276
Proficiency score	57.515	64.408	78.194	91.98	98.873

Module 4: Knot Integrity
R-Proficiency = 106.8519 - 0.1852 Time

Variables Measured and Criterion Percentile Values

Variable	10	25	50	75	90
Time	133	132.25	107	74.75	58.7
Proficiency score	82.222	82.361	87.037	93.009	95.981

Means ± Standard Deviations for Each Variable

Variable	−1.5	−1	0	+1	+1.5
Time	52.229	68.708	101.667	134.625	151.104
Proficiency score	78.87	81.921	88.025	94.128	97.18

Module 5: Circle Cutting *Proficiency = 116.7375 - 0.172 Time - 1.1435 Errors*					
Variables Measured and Criterion Percentile Values					
Variable	**10**	**25**	**50**	**75**	**90**
Time	220.3	189.25	166.5	148.5	98.1
Errors	7.9	5.5	2	1	0.1
Proficiency score	78.375	81.567	87.614	90.316	91.591
Means ± Standard Deviations for Each Variable					
Variable	**−1.5**	**−1**	**0**	**+1**	**+1.5**
Time	94.317	118.85	167.917	216.983	241.517
Errors	−1.323	0.201	3.25	6.299	7.823
Proficiency score	77.167	80.046	85.803	91.561	94.44

*As of 1/1/07, this second generation model, superseded by the LTS 3e model has been licensed by METI (personal communication, Dr. Hasson).

Appendix 3: Surgical Sim Attempt #4

Module 1: Gallbladder Dissection *Proficiency = 109.0262 - 0.0398 Total time - 0.0238 Tip trajectory*					
Variables Measured and Criterion Percentile Values					
Variable	**10**	**25**	**50**	**75**	**90**
Total time	335.3	296	213	188.5	176.5
Tip-trajectory	475.579	370.53	319.762	237.19	204.669
Burning-in-air time	13.242	7.733	3.5	1.804	1.276
Tissue overstretched	5	4.25	2.5	1	1
Dissection-outside-target	24.8	14	8	3	3
Proficiency score	85.024	88.044	92.922	96.066	97.782
Means ± Standard Deviations for Each Variable					
Variable	**−1.5**	**−1**	**0**	**+1**	**+1.5**
Total time	122.734	163.962	246.417	328.872	370.099
Tip-trajectory	104.294	184.53	345.003	505.476	585.712
Burning-in-air time	−2.143	0.372	5.402	10.432	12.947
Tissue overstretched	−4.531	−1.715	3.917	9.549	12.365
Dissection-outside-target	−2.752	1.652	10.462	19.271	23.675
Proficiency score	80.47	83.977	90.99	98.003	101.51

Module 2: Place Arrow

Proficiency = 113.4184 - 1.3418 Total time − 1.1734 Dropped arrow - 1.7601 Closed entry right tool

Variables Measured and Criterion Percentile Values

Variable	**10**	**25**	**50**	**75**	**90**
Total time	22.2	19	16	13	12
Tip-trajectory	55.789	39.438	37.375	34.313	31.128
Dropped arrow	0.4	0.35	0.2	0	0
Lost arrow	0.2	0.05	0	0	0
Closed-entry-left-tool	0.2	0	0	0	0
Closed-entry-right-tool	0.2	0.05	0	0	0
Proficiency score	83.442	87.689	91.597	95.974	96.982

Means ± Standard Deviations for Each Variable

Variable	**−1.5**	**−1**	**0**	**+1**	**+1.5**
Total time	9.906	12.091	16.462	20.832	23.018
Tip-trajectory	26.013	30.687	40.035	49.383	54.057
Dropped arrow	−0.088	−0.001	0.171	0.344	0.431
Lost arrow	−0.086	−0.04	0.05	0.14	0.186
Closed-entry-left-tool	−0.128	−0.065	0.062	0.188	0.251
Closed-entry-right-tool	−0.129	−0.064	0.067	0.197	0.262
Proficiency score	81.965	84.929	90.851	96.775	99.737

Module 3: Retract and Dissect

Proficiency = 105.6126 - 0.244 Total time - 6.8972 Dissected outside target left - 5.3848 Dissected outside target right - 1.3444 Lost aligned pod left - 10.7167 Lost aligned pod right

Variables Measured and Criterion Percentile Values

Variable	10	25	50	75	90
Total time	40.8	37.5	32	28	23.5
Tip-trajectory	126.543	79.923	75.77	70.803	61.879
Burning-in-air time-left	0.624	0.437	0.242	0	0
Burning-in-air time-right	0.483	0.354	0.143	0.021	0
Tissue overstretched-left	0.25	0.25	0	0	0
Tissue overstretched-right	0.975	0.562	0.25	0	0
Dissected outside target-left	0.5	0.312	0.125	0	
Dissected outside target-right	0.7	0.5	0.25	0	0
Dissected pod-not aligned-left	0.45	0.25	0	0	0
Dissected pod-not-aligned-right	0.5	0.25	0.25	0	0
Lost-aligned pod-left	0.25	0.25	0	0	0
Lost-aligned pod-right	0.225	0	0	0	0
Proficiency score	84.162	89.144	93.725	96.079	97.41

Means ± Standard Deviations for Each Variable

Variable	−1.5	−1	0	+1	+1.5
Total time	22.077	25.44	32.167	38.893	42.256
Tip-trajectory	47.198	59.383	83.754	108.125	120.311
Burning-in-air time-left	−0.159	−0.012	0.282	0.575	0.72
Burning-in-air time-right	−0.09	0.008	0.206	0.404	0.503
Tissue overstretched-left	−0.089	−0.025	0.104	0.233	0.297
Tissue overstretched-right	−0.286	−0.052	0.417	0.885	1.12
Dissected outside target-left	−0.304	−0.119	0.25	0.619	0.804
Dissected outside target-right	−0.183	−0.039	0.25	0.539	0.683
Dissected pod-not aligned-left	−0.134	−0.038	0.154	0.346	0.442
Dissected pod-not-aligned-right	−0.12	−0.016	0.192	0.4	0.504
Lost-aligned pod-left	−0.101	−0.04	0.083	0.206	0.268
Lost-aligned pod-right	−0.104	−0.056	0.042	0.139	0.188
Proficiency score	83.783	86.527	92.014	97.501	100.245

Module 4: Transverse Tube

Proficiency = 116.6667 - 1.2821 Total time

Variables Measured and Criterion Percentile Values

Variable	10	25	50	75	90
Total time	29.6	28	22	18	17
Tip-trajectory	93.841	78.917	75.802	62.419	60.805
Dropped tube	1	0.4	0.2	0	0
Wrong segment	0.56	0.4	0.2	0.2	0.0
Proficiency score	78.718	80.769	88.462	93.59	94.872

Means ± Standard Deviations for Each Variable

Variable	−1.5	−1	0	+1	+1.5
Total time	14.22	17.198	23.154	29.11	32.088
Tip-trajectory	54.989	61.679	75.059	88.438	95.128
Dropped tube	−0.245	−0.035	0.385	0.805	1.015
Wrong segment	−0.011	0.085	0.277	0.469	0.565
Proficiency score	75.528	79.346	86.982	94.618	98.436

Appendix 4. ProMIS Attempt #4

Module 1: Dissection

Proficiency = 111.4094 - 0.0649 Left instrument path - 0.0097 Right instrument path - 0.0286 Left instrument smoothness - 0.0106 Right instrument smoothness

Variables Measured and Criterion Percentile Values

Variable	10	25	50	75	90
Total time	118.101	99.993	69.165	59.37	52.875
Left instrument path	107.904	96.62	85.22	72.22	68.876
Right instrument path	318.034	281.74	223.38	195.33	128.32
Left instrument smoothness	497.9	406	259.5	236.25	207.5
Right instrument smoothness	381.6	316	282	225	170.2
Proficiency score	84.751	90.112	93.47	94.981	98.031

Means ± Standard Deviations for Each Variable

Variable	−1.5	−1	0	+1	+1.5
Total time	33.043	48.79	80.284	111.778	127.525
Left instrument path	55.91	66.055	86.347	106.638	116.784
Right instrument path	117.488	156.129	233.41	310.691	349.332
Left instrument smoothness	133.918	194.745	316.4	438.055	498.882
Right instrument smoothness	134.885	184.22	282.889	381.558	430.893
Proficiency score	83.519	86.389	92.13	97.871	100.741

Module 2: Instrument Handling

Proficiency = 127.6061 - 0.7341 Total time - 0.09 Left instrument path - 0.0171 Left instrument smoothness - 0.0149 Right instrument smoothness

Variables Measured and Criterion Percentile Values

Variable	10	25	50	75	90
Total time	39.457	36.848	32.855	29.105	25.323
Left instrument path	121.697	117.532	113.115	102.043	93.457
Right instrument path	120.204	114.25	109.845	99.373	95.195
Left instrument smoothness	110.7	105.75	94.5	82.5	71.8
Right instrument smoothness	120.2	117	112	97	81.4
Proficiency score	84.392	86.033	90.194	93.06	98.247

Means ± Standard Deviations for Each Variable

Variable	−1.5	−1	0	+1	+1.5
Total time	24.296	27.04	32.526	38.012	40.756
Left instrument path	88.268	95.651	110.417	125.183	132.566
Right instrument path	92.082	97.361	107.921	118.481	123.76
Left instrument smoothness	66.525	75.383	93.1	110.817	119.675
Right instrument smoothness	79.733	88.155	105	121.845	130.267
Proficiency score	82.336	85.075	90.554	96.032	98.771

Module 3: Suturing & Knot Tying

R-Proficiency = 100.1275 - 0.005 Left instrument path - 0.013 Right instrument smoothness

Variables Measured and Criterion Percentile Values

Variable	10	25	50	75	90
Total time	295.784	266.577	114.63	94.248	74.59
Left instrument path	694.584	560.12	348.67	249.77	202.574
Right instrument path	854.166	672.87	409.62	246.39	241.238
Left instrument smoothness	891	817	343	301	225.8
Right instrument smoothness	1154.1	938.5	423	354.5	246.8
Proficiency score	81.612	84.144	92.947	94.031	96.019

Means ± Standard Deviations for Each Variable

Variable	−1.5	−1	0	+1	+1.5
Total time	5.068	62.387	177.024	291.661	348.98
Left instrument path	79.253	189.984	411.446	632.907	743.638
Right instrument path	72.381	210.16	485.719	761.278	899.057
Left instrument smoothness	23.086	178.835	490.333	801.832	957.581
Right instrument smoothness	−4.813	212.625	647.5	1082.375	1299.813
Proficiency score	78.65	82.206	89.318	96.43	99.985

Appendix 5: LapMentor Modules Attempt #2

Module 1: Camera Navigation (0°)

*Proficiency = 43.1963 − 0.0457 Total time *− 0.2223 The time the horizontal view is maintained while using the 0° camera + 0.7437 Maintaining the horizontal view while using the 0° camera*

Variables Measured and Criterion Percentile Values

Variable	10	25	50	75	90
Total time	85.5	83.25	78.5	61.5	58.5
Total no of camera shots	12.6	12	11	10	10
Time horizontal view maintained	78.9	69.75	63	53.75	51.2
Total path length of camera cm	269	264.5	225.7	212.4	200.0
No correct hits	10	10	10	10	10
Accuracy rate target hits	79.73	83.3	90.9	100	100
Maintain horizontal view of 0° camera	75.36	79.35	83.55	94.23	95.32
Ave speed of camera cm sec	8.88	9.225	10.3	10.5	10.59
Proficiency score	82.92	84.35	86.45	93.38	97.96

Means ± Standard Deviations for Each Variable

Variable	−1.5	−1	0	+1	+1.5
Total time	54.35	60.81	73.75	86.69	93.16
Total no of camera shots	9.167	9.861	11.25	12.64	13.33
Time horizontal view maintained	45.02	51.10	63.25	75.40	81.48
Total path length of camera cm	187.4	203.5	235.7	267.9	284.0
No correct hits	10	10	10	10	10
Accuracy rate target hits.	74.58	79.71	90.00	100.2	105.4
Maintain horizontal view of 0° camera	71.00	75.66	84.98	94.29	98.95
Ave speed of camera cm sec	8.68	9.09	9.91	10.73	11.15
Proficiency score	78.70	82.12	88.97	95.81	99.23

Module 2: Camera Navigation (30°)

Proficiency = 131.2485 − 0.1744 Total time − 11.6569 Total no of camera shots − 0.0118 Total path length of camera in cm + 9.8071 No of correct hits

Variables Measured and Criterion Percentile Values

Variable	10	25	50	75	90
Total time	84.2	77	71	66	61.2
Total no of camera shots	11	11	10	10	10
Total path length of camera cm	358.1	322.5	287.6	275.7	228.1
No correct hits	10	10	10	10	10
Accuracy rate target hits	90.9	90.9	100.0	100	100
Ave speed of camera cm sec	8.01	8.1	8.4	9.35	9.9
Proficiency score	85.13	91.11	96.1	96.75	98.28

Means ± Standard Deviations for Each Variable

Variable	−1.5	−1	0	+1	+1.5
Total time	56.47	61.89	72.71	83.54	88.96
Total no of camera shots	9.60	9.86	10.38	10.89	11.15
Total path length of camera cm	189.3	221.7	287.1	352.6	385.3
No correct hits	10	10	10	10	10
Accuracy rate target hits	89.52	91.88	96.59	101.3	103.7
Ave speed of camera cm sec	7.43	7.87	8.75	9.63	10.07
Proficiency score	83.69	86.91	93.35	99.79	103.0

Module 3: Eye-hand Coordination *R-Proficiency = 183.0005 − 2.0767 Total number of touched balls − 1.5668 Number of movements of left instrument − 0.5533 Total path length of right instrument in cm*					
Variables Measured and Criterion Percentile Values					
Variable	**10**	**25**	**50**	**75**	**90**
Total time	47.8	46.5	39	33	28.8
Total no of touched balls	10	10	10	10	10
No moves of right instrument	20.5	19.75	18	16.3	16
No moves of left instrument	19.4	18.5	18	17	15.4
Total path length right instrument cm	112.2	108.1	88.4	80.8	75.1
Total path length left instrument cm	102.7	101.6	84.8	78.2	73.9
Relevant path right Instrument cm	72.04	68.05	57.5	41.1	36.1
Relevant path left instrument cm	52.12	51.1	44.1	41.5	37.7
No correct hits	10	10	10	10	10
Accuracy rate touched targets	100	100	100	100	100
Ideal path length right instrument cm	26.44	30.1	34.1	37.8	39.62
Ideal path length left instrument cm	27.12	30.45	32.7	34.2	35.92
Economy of moves right instrument	52.26	55.5	64.8	73.3	76.06
Economy of moves left instrument	63.7	65.05	70.7	7.50	80.54
Ave speed right instrument moves cm sec	2.58	2.85	3.2	3.3	3.34
Ave speed left instrument moves cm sec	1.66	2.7	3.1	3.45	3.54
Proficiency score	70.74	72.68	85.12	91.58	96.80
Means ± Standard Deviations for Each Variable					
Variable	**−1.5**	**−1**	**0**	**+1**	**+1.5**
Total time	26.20	30.51	39.14	47.77	52.09
Total no of touched balls	10	10	10	10	10
No moves right instrument	14.96	16.03	18.17	20.30	21.37
No moves left instrument	14.09	15.20	17.43	19.65	20.77
Total path length right instrument cm	14.96	16.03	18.17	20.30	21.37
Total path length left instrument cm	14.09	15.20	17.43	19.65	20.8
Relevant path right instrument cm	28.02	36.86	54.56	72.25	81.10
Relevant path left instrument cm	34.53	38.05	45.09	52.13	55.65
No correct hits	10	10	10	10	10
Accuracy rate touched targets	100	100	100	100	100
Ideal path length right instrument cm	23.80	27.02	33.44	39.87	43.08
Ideal path length left instrument cm	25.85	27.91	32.01	36.12	38.18
Economy of moves right instrument	47.79	53.25	64.16	75.07	80.52
Economy of moves left instrument	58.73	63.07	71.74	80.42	84.76
Ave speed right instrument moves cm sec	2.489	2.674	3.043	3.412	3.596
Ave speed left instrument moves cm sec	2.453	2.664	3.086	3.508	3.719
Proficiency score	65.02	71.06	83.14	95.22	101.3

Module 4: Clip Applying

Proficiency = 143.5707 − 0.4326 Total time − 0.0838 Number of movements of right instrument − 0.2969 Number of movements of left instrument −0.1786 Relevant path length of right instrument in cm

Variables Measured and Criterion Percentile Values

Variable	10	25	50	75	90
Total time	67	64.5	60	55.5	52.5
No of lost clips	5.8	4.5	2	1	0.6
Total no of clipping attempts	14.8	13.5	11	10	9.6
No of movements of right instrument	64.8	48	38	31.5	28
No of movements of left instrument	36.4	35	28	18.5	10.4
Total path length of right instrument cm	198.1	175.5	132.3	117.5	95.34
Total path length of left instrument cm	122.0	114.3	104.1	57.7	10.62
Relevant path length right instrument cm	175.2	137.1	117.7	95.9	65.06
Relevant path length left instrument cm	98.64	93.3	81.7	71.8	51.94
Accuracy rate applied clips	61.1	66.75	81.8	90	94
Ideal path length of right instrument cm	26.92	36.55	68	98	102.7
Ideal path length of left instrument cm	16.72	30.7	37.9	39.9	47.82
Economy of movement right instrument	38.42	41.05	46.4	65.15	74.9
Economy of movement left instrument	23.5	30.1	42.8	52.8	60.12
Ave speed right instrument moves cm sec	2.7	2.75	3.1	3.45	3.8
Ave speed left instrument moves cm sec	2.65	2.7	2.95	3.2	3.25
Proficiency score	66.56	79.48	83.19	92.91	96.74

Means ± Standard Deviations for Each Variable

Variable	−1.5	−1	0	+1	+1.5
Total time	49.56	53.25	59.83	66.42	69.71
No of lost clips	−0.96	0.312	2.857	5.402	6.674
Total no of clipping attempts	8.04	9.312	11.86	14.40	15.67
No of movements of right instrument	16.78	25.48	42.86	60.24	68.93
No of movements of left instrument	5.678	12.07	24.86	37.64	44.04
Total path length of right instrument cm	75.14	98.7	145.9	193.0	216.6
Total path length of left instrument cm	5.576	31.23	82.54	133.9	159.5
Relevant path length right instrument cm	40.83	67.32	120.3	173.3	199.8
Relevant path length left instrument cm	40.68	52.97	77.54	102.1	114.4
Accuracy rate applied clips	54.94	62.89	78.8	94.71	102.7
Ideal path length of right instrument cm	11.85	30.07	66.33	102.7	120.8
Ideal path length of left instrument cm	8.554	16.97	33.8	50.63	59.05
Economy of movement right instrument	28.13	36.51	53.27	70.04	78.42
Economy of movement left instrument	14.79	23.85	41.96	60.07	69.13
Ave speed right instrument moves cm sec	2.424	2.664	3.143	3.622	3.861
Ave speed left instrument moves cm sec	2.478	2.635	2.95	3.265	3.422
Proficiency score	57.99	66.18	82.57	98.95	107.1

Module 5: Grasping and Clipping

Proficiency = 148.6876 − 2e-04 Total time − 7e-04 No of lost clips−2e-04 No of movements of right instrument − 0.1511 Total path length of clipper in cm − 0.1518 Total path length of grasper in cm − 6e-04 Relevant path length clipper in cm

Variables Measured and Criterion Percentile Values

Variable	10	25	50	75	90
Total time	125.4	109.5	101	83	70.6
No of lost clips	2	2	1	1	0.6
Total no of clipping attempts	11	11	10	10	9.6
No of movements of right instrument	66	58.5	53	43	35.6
No of movements of left instrument	82.2	74	64	51	45.4
Total path length of right instrument cm	222.2	207.3	185.6	174.7	170.4
Total path length of left instrument cm	267.1	260.9	232.2	211.8	174.7
Total path length of clipper cm	244	219.1	206	169.5	157.1
Total path length of grasper cm	261.4	249.5	232.2	189.8	181.6
Relevant path length right instrument cm	215.9	202.3	177.3	165.8	161.7
Relevant path length left instrument cm	258.9	252.5	221.1	200.7	166.2
Relevant path length clipper cm	234.9	212.8	200.1	161.6	148.7
Relevant path length grasper cm	255.1	241.1	215.5	181.6	172.4
Accuracy rate applied clips	81.8	81.8	90	90	94
Ideal path length of clipper cm	92.96	99.75	108.5	124.2	132.2
Ideal path length of grasper cm	105.6	106.7	111.4	113.5	115.5
Economy of movement right instrument	50.92	56.6	60.4	62.5	69.8
Economy of movement left instrument	40.62	44.25	54.1	56.65	63.38
Economy of movement clipper	46.92	54.5	60.2	67.15	75.38
Economy of movement grasper	44.6	46.9	54.1	58.85	61.52
Ave speed of right instrument movement cm sec	2.46	2.65	2.8	3.1	3.28
Ave speed of left instrument movement cm sec	2.9	3.025	3.15	3.425	3.6
Proficiency score	74.53	77.34	85.67	90.62	95.67

Table Continues

Module 5: Continued

Means ± Standard Deviations for Each Variable

Variable	−1.5	−1	0	+1	+1.5
Total time	61.47	74.01	99.14	124.3	136.8
No of lost clips	0.152	0.53	1.286	2.042	2.42
Total no of clipping attempts	9.152	9.53	10.29	11.04	11.42
No of movements of right instrument	31.36	38.34	52.29	66.24	73.21
No of movements of left instrument	37.80	46.20	63	79.80	88.20
Total path length of right instrument cm	153.2	166.7	193.8	221.0	234.5
Total path length of left instrument cm	160.9	183.1	227.5	272.0	294.2
Total path length of clipper cm	137.6	158.1	199.2	240.3	260.8
Total path length of grasper cm	166.5	185.1	222.2	259.3	277.8
Relevant path length right instrument cm	145.1	158.8	186.1	213.5	227.2
Relevant path length left instrument cm	150.7	173.2	218.3	263.3	285.8
Relevant path length clipper cm	130.2	150.6	191.6	232.6	253.0
Relevant path length grasper cm	155.9	174.9	212.8	250.7	269.7
Accuracy rate applied clips	77.83	81.19	87.91	94.7	98.0
Ideal path length of clipper cm	81.94	91.92	111.9	131.9	141.8
Ideal path length of grasper cm	103.5	105.8	110.4	115.0	117.3
Economy of movement right instrument	45.94	50.92	60.87	70.82	75.8
Economy of movement left instrument	35.04	40.80	52.31	63.83	69.59
Economy of movement clipper	39.78	46.57	60.14	73.72	80.50
Economy of movement grasper	41.35	45.25	53.04	60.84	64.74
Ave speed of right instrument movement cm sec	2.333	2.512	2.871	3.231	3.41
Ave speed of left instrument movement cm sec	2.72	2.886	3.217	3.548	3.713
Proficiency score	69.76	74.75	84.73	94.71	99.70

Module 7: Cutting - Dissecting					
Proficiency = 112.6316 − 0.13 Number of movements of right instrument − 0.071 Total path length of left instrument in cm					
Variables Measured and Criterion Percentile Values					
Variable	**10**	**25**	**50**	**75**	**90**
Total time	175.2	136	90	74.5	65.4
Total no of cutting maneuvers	37.4	37	34	29.5	24.4
Total no of retraction operations	5.4	4.5	4	1.5	1
No of movements of right instrument	151.6	125	99	81.5	64.6
No of movements of left instrument	53	40.5	34	26.5	22
Total path length of right instrument cm	386.9	297.6	251.3	184.5	161.8
Total path length of left instrument cm	130.2	95.4	83.3	71.1	52.66
No cutting maneuvers with no injury	24.4	29.5	34	37	37.4
No of retraction operations with no overstretch	1	1	1	3	3.8
Safe retraction overstretch	40	50	75	100	100
Ave speed of right instrument movement cm sec	2.4	2.6	3	3.55	4
Ave speed of it instrument movement cm sec	1.88	2.15	2.6	2.75	2.8
Proficiency score	84.46	89.74	93.72	97.64	99.04
Means ± Standard Deviations for Each Variable					
Variable	**−1.5**	**−1**	**0**	**+1**	**+1.5**
Total time	34.13	58.66	107.7	156.8	181.3
Total no of cutting maneuvers	23.23	26.30	32.43	38.56	41.63
Total no of retraction operations	0.322	1.31	3.286	5.262	6.25
No of movements of right instrument	50.16	68.20	104.3	140.4	158.4
No of movements of left instrument	13.20	21.08	36.86	52.63	60.52
Total path length of right instrument cm	93.11	148.0	257.9	367.8	422.8
Total path length of left instrument cm	28.68	48.90	89.36	129.8	150.0
No cutting maneuver performed with no injury	23.23	26.30	32.43	38.56	41.63
No retraction operations with no overstretch.	−0.22	0.569	2.143	3.716	4.503
Safe retraction overstretch	25.87	41.05	71.43	101.8	117.0
Ave speed of right instrument movement cm sec	2.004	2.381	3.133	3.886	4.262
Ave speed of It instrument movement cm sec	1.77	1.984	2.414	2.844	3.059
Proficiency score	82.44	85.87	92.73	99.59	103.0

Module 6: Two-handed Maneuvers

Proficiency = 103.6793 − 0.2457 No of movements of right instrument − 0.0311 Total path length of left instrument in cm − 0.0357 Relevant path length right instrument cm − 0.0377 Relevant path length left instrument cm + 1.9945 No of exposed green balls that are collected

Variables Measured and Criterion Percentile Values

Variable	10	25	50	75	90
Total time	178	112	84	73.5	50.2
No of lost balls that miss the basket	1	0.75	0	0	0
No of movements of right instrument	119.2	92	49	42	26.6
No of movements of left instrument	122	82	53	45	24.4
Total path length of right instrument cm	455.8	331.2	224.2	169.9	95.84
Total path length of left instrument cm	398.8	288.7	228.7	151.7	85.62
Relevant path length right instrument cm	253.1	207.2	148.7	80.05	61.75
Relevant path length left instrument cm	267.5	200.2	135.1	128.4	79.32
No of exposed green balls that are collected	7.5	8.25	9	9	9
Ideal path length of right instrument cm	33.2	47.2	59.75	85.43	91.85
Ideal path length of left instrument cm	24.56	29	30.9	57.8	67.16
Economy of movement right instrument	31.35	32.33	37.75	49.48	62.7
Economy of movement left instrument	14.98	22.6	36.7	42.8	44.96
Ave speed of right instrument movement cm sec	3.38	3.65	3.9	3.9	3.9
Ave speed of left instrument movement cm sec	2.82	2.95	3.2	3.55	3.86
Proficiency score	57.97	69.91	95.31	95.72	97.73

Means ± Standard Deviations for Each Variable

Variable	−1.5	−1	0	+1	+1.5
Total time	−5.11	30.64	102.1	173.6	209.4
No of lost balls that miss the basket	−0.44	−0.18	0.333	0.85	1.108
No of movements of right instrument	2.212	23.00	64.57	106.1	126.9
No of movements of left instrument	−5.54	18.36	66.14	113.9	137.8
Total path length of right instrument cm	9.343	91.30	255.2	419.1	501.1
Total path length of left instrument cm	4.044	79.75	231.2	382.6	458.3
Relevant path length right instrument cm	21.55	65.87	154.5	243.1	287.4
Relevant path length left instrument cm	16.05	65.54	164.5	264.0	313.0
No of exposed green balls that are collected	7.245	7.663	8.5	9.337	9.755
Ideal path length of right instrument cm	19.50	33.53	61.6	89.67	103.7
Ideal path length of left instrument cm	9.485	20.50	42.54	64.58	75.60
Economy of movement right instrument	19.18	27.43	43.93	60.44	68.69
Economy of movement left instrument	8.902	16.50	31.68	46.87	54.46
Ave speed of right instrument movement cm sec	3.316	3.453	3.729	4.004	4.141
Ave speed of left instrument movement cm sec	2.554	2.798	3.286	3.774	4.018
Proficiency score	49.95	60.63	82.00	103.4	114.1

Module 8: Scarification - Hook Electrodes

Proficiency = 144.9011 − 0.116 Total time − 0.2142 Total cautery time − 1.2048 No of nonhighlighted bands that were cut − 0.1173 No of movements of right instrument − 0.09 Total path length of left instrument in cm

Variables Measured and Criterion Percentile Values

Variable	10	25	50	75	90
Total time	176.5	164	154.5	149.5	145
Time cautery applied with no contact to bands	10.6	7.5	5	3	2.2
Total cautery time	52.6	48.5	45	42.5	41.6
Time cautery applied on nonhighlighted bands	6.8	6	6	4.5	2.8
No of nonhighlighted bands that were cut	0	0	0	0	0
No of movements of right instrument	106.5	102.8	87	75.75	64.5
No of movements of left instrument	75.5	72.75	70.5	66.75	58.5
Total path length of right instrument cm	346.3	275.1	202.8	197.8	175.1
Total path length of left instrument cm	201.4	194.8	186.7	152.7	123.7
Efficiency of cautery	77.7	83.15	89.9	93.05	94.1
No of highlighted bands that were cut	21	21	21	21	21
Accuracy rate highlighted bands	100	100	100	100	100
Ave speed right instrument movement cm sec	1.92	2.05	2.2	2.3	2.38
Ave speed left instrument movement cm sec	2.02	2.15	2.2	2.5	2.54
Proficiency score	84.49	89.10	93.62	93.81	94.05

Means ± Standard Deviations for Each Variable

Variable	−1.5	−1	0	+1	+1.5
Total time	135.0	142.9	158.7	174.4	182.3
Time cautery applied with no contact to bands	−0.45	1.603	5.714	9.826	11.88
Total cautery time	38.47	41.03	46.14	51.26	53.81
Time cautery applied on nonhighlighted bands	1.853	2.95	5.143	7.336	8.432
No of nonhighlighted bands that were cut	0	0	0	0	0
No of movements of right instrument	55.85	65.9	86.0	106.1	116.2
No of movements of left instrument	54.18	58.84	68.17	77.49	82.16
Total path length of right instrument cm	114.9	156.5	239.6	322.7	364.2
Total path length of left instrument cm	112.0	131.5	170.6	209.7	229.2
Efficiency of cautery	76.19	79.98	87.56	95.14	98.93
No of highlighted bands that were cut	21	21	21	21	21
Accuracy rate highlighted bands	100	100	100	100	100
Ave speed of right instrument movement cm sec	1.828	1.943	2.171	2.4	2.515
Ave speed of lt instrument movement cm sec	1.904	2.031	2.286	2.54	2.667
Proficiency score	82.88	85.49	90.72	95.95	98.56

Module 9: Translocation of Objects

Proficiency = 100.8715 − 0.1731 No of dropped objects − 0.0386 No of movements of right instrument − 0.0067 No of movements of left instrument − 0.0039 Total path length of left instrument cm + 0.8116 No of properly placed objects + 0.2401 No of translocations

Variables Measured and Criterion Percentile Values

Variable	10	25	50	75	90
Total time	460	392.8	346.5	243.3	168
Average no of translocations per object	10.6	8.9	6.6	4.45	3.4
No of dropped objects	38	31.25	17	11.75	10
No of movements of right instrument	797	633	438	328.5	245
No of movements of left instrument	708	482	375	313	240
Total path length of right instrument cm	2254	1817	1073	935.9	753.4
Total path length of left instrument cm	1625	1131	996.4	826.6	659.5
No of properly placed objects	5	5	5	5	5
No of translocations	17	22.25	33	44.5	53
Efficiency of translocations	45.9	54.55	73.85	95.7	100
Ave speed of right instrument movement cm sec	2.5	2.575	2.85	3.125	3.2
Ave speed of left instrument movement cm sec	2.3	2.4	2.5	2.6	2.75
Proficiency score	69.95	78.85	86.68	90.56	92.91

Means ± Standard Deviations for Each Variable

Variable	−1.5	−1	0	+1	+1.5
Total time	106.4	179.2	324.8	470.5	543.3
Average no of translocations per object	1.805	3.492	6.867	10.24	11.93
No of dropped objects	1.684	8.345	21.67	34.99	41.65
No of movements of right instrument	93.34	226.7	493.3	760.0	893.3
No of movements of left instrument	55.28	183.9	441	698.2	826.7
Total path length of right instrument cm	259.2	626.1	1360	2094	2461
Total path length of left instrument cm	301.1	565.2	1093	1622	1886
No of properly placed objects	5	5	5	5	5
No of translocations	9.025	17.46	34.33	51.21	59.64
Efficiency of translocations	35.66	48.18	73.25	98.32	110.9
Ave speed right instrument movement cm sec	2.378	2.535	2.85	3.165	3.322
Ave speed left instrument movement cm sec	2.156	2.277	2.517	2.757	2.877
Proficiency score	65.28	71.24	83.18	95.12	101.1