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# Hierarchical task analysis for identification of interrelationships between ergonomic, external disruption, and internal disruption in complex laparoscopic procedures

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## Abstract

**Background** Traditionally, hierarchical task analysis (HTA) in surgery examines observable disruption in a predefined set of tasks as performed, rather than examining the ergonomics requirements, which may predispose surgical teams to act erroneously. This research aims to address this gap in the literature. It develops a HTA protocol taking into consideration surgical team actions, observable external disruption, internal disruption, and ergonomic goals required for safer conducting procedures. Laparoscopic radical prostatectomy (LRP) is selected as a case.

**Methods** This research involved observations inside operating rooms (ORs) of three large teaching hospitals in Australia and China. Two rounds of observations are conducted: observations for developing HTA, and observations after presenting the developed HTA among surgical teams. The traditional HTA format is expanded to include two additional columns: technical considerations and ergonomics considerations. Two groups are formed from the observed LRPs. LRPs in the first group were conducted with no regard to the specified ergonomic goals and associated ergonomic features, and the second are conducted with the surgical teams attempting to follow specified ergonomic goals and features as prescribed in HTA. Careful attempt is required to select procedures such that the total operative times for both groups are approximately equal (±5%).

**Results** Between March 2016 and November 2017, a total of 29 LRPs were observed, and a HTA developed. The results reveal significant reduction (43%) in the total external disruptive events and approximately 58% reduction in the internal disruptive events in LRPs conducted with HTA requirements.

**Conclusions** The developed HTA appears to have some utility, but needs evaluation in larger studies. It can potentially be used as a training aid, and as a checklist for evaluating surgical performance.


**Keywords** Disruption · Ergonomic requirements · Hierarchical task analysis · Laparoscopic radical prostatectomy · Performance appraisal, training aid

HTA is a goal-based analysis of systems. It divides a system into tasks based on their hierarchical goals. It begins with a main task defined by its top-level goal and delineates it into subtasks. There is a hierarchical relationship between the goals and sub-goals and there are rules to guide the sequence that the sub-goals are attained [6]. HTA is used to map interactions of humans with other system elements [4, 5], and

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its techniques have been used as the analytical interface for a variety of Human Error Identifications techniques. It can be applied to observe or predict potential human errors in healthcare services, including medication administration [5], anaesthesia [7], endoscopic surgery [8], spinal surgery [9], and nephrectomy [10]. In addition, HTA has been used as a training aid and as a checklist for assessing or self-appraisal the technical performance of the surgeons [11–14].

The term ‘error’ in HTA taxonomies has a wide meaning ranging from simple work disruptions to major errors. An error is the failure of a planned action to be completed as intended (error of execution) or the use of a wrong plan to achieve an aim (error of planning) [15]. Disruption is any event that obstructs the natural flow of surgery [16, 17]. Disruption may comprise minor events, e.g. surgeon receives successive unrelated telephone calls. The accumulation of these events, however, creates stress and fatigue and may predispose the surgical team to error [17, 18]. In this study, we concentrate on disruption during laparoscopic procedures.

## HTA protocols

HTA can be represented using hierarchical diagrams and tabular formats [6]. Both hierarchical diagram and tabular format illustrate the hierarchical relationships as well as rules for sequencing the tasks. The tabular format, however, accommodates additional information resulting from the application of error taxonomies, such as observed errors or potential errors. Although HTA protocols (representation and methods) have continually evolved [19], they have several weaknesses that limit their applications in surgery.

In surgery, there are two types of disruption: external disruption that occurs outside the surgical field of the patient, and internal disruption that occurs inside the surgical field. External disruption can be directly observed, while internal disruption can only be recognised if the surgical field can be visualised, e.g. by means of video monitors for endoscopic surgery. Most literature in surgery identifies only the observable external disruption [20–22]. Our recent work (Al-Hakim et al. [16]) recognises relationships between the application of ergonomics during patient positioning and internal disruption. The current HTA protocols in surgery are not designed to accommodate explicitly internal disruption and ergonomics requirements that prevent or reduce external and internal disruption—see for example [8–10, 14]. In addition, surgeons cannot manage procedures in isolation from the work of other members of the team. Annett et al. [23] and Acton and Reinach [24] attempted to accommodate teamwork as part of task plan, but their work lacks a HTA protocol for predicting potential errors arisen from failure to follow the correct plan [10]. The work of Saker et al. [11] is a nice attempt to accommodate the work of the surgical team as part of HTA protocol. However, their model may create difficulty in coordinating the work of surgical team members as it considers actions conducted by each of them in a separate HTA tabular format.

Further, HTA protocols fail to recognise root factors that predispose operators to make erroneous actions, including ergonomic requirements. The ergonomic requirements can also be expressed in terms of goals and sub-goals or features required to achieve the goals. Literature emphasises that HTA is a description of sub-goal hierarchy but considers only one hierarchical direction relating to the technical goals of tasks, that is, the ‘technical’ goals of lower-level tasks should help achieve the ‘technical’ goals of the upper-level tasks [6]. This may not be the case with the hierarchical direction of ergonomic goals.

## Research aim

We aimed to develop a HTA tool which addresses the interrelationships between ergonomic features of the operative environment, and external and internal disruptive events during laparoscopic procedures. The premise of our research is that we cannot change the tasks or surgical team skillset during surgery, but we can change the ergonomics of the environment in which surgical teams work.

We also undertook a preliminary assessment of the developed HTA in terms of effectiveness as an aid for training surgical teams, especially resident surgeons and scrub nurses, on ergonomics. To achieve our aim, we need to also develop observation instrument that take into consideration ergonomics and both types of disruptions.

To show the applicability of our developed HTA, the laparoscopic radical prostatectomy (LRP) was selected as an illustrative case. LRP is a complex procedure and is routinely performed at the participating hospitals.

## Materials and methods

This research comprises prospective observations inside operating rooms (ORs) of three hospitals: two large Australian teaching hospitals (20 ORs in size) located in Melbourne, Australia and a large Chinese hospital (with two campuses and approximately 15 and 25 ORs, respectively), located in Hangzhou, China. The research methodology included three phases: preparation, observation, and statistical analysis.

## Preparation

Initially, ethics approval was obtained from participating hospitals. The study team comprises four senior urologists (SS, MW, JX, and DG) with experience of more than 5 years in LRPs and a human factor expert (LAH) with experience of more than 8 years in undertaking observations in ORs—see for example Al-Hakim [20].

During this phase, the authors discussed the LRP tasks, HTA structures, and analysed more than 10 video recordings of LRPs conducted at the participating hospitals, including the two LRPs used for earlier publication [16]. The outcome of this phase was the development of an initial draft of the HTA in tabular format.

### HTA tabular format

The current HTA tabular formats include columns for task code, task description, roles for task sequencing, instrument and tools used, and observed/potential errors [6, 7]. Some HTA tabular formats comprise additional columns such as recovery column, and checklist column, that is, a column indicating whether the task was implemented [11, 12]. We redesigned the HTA format to include two new additional columns, technical considerations and ergonomics considerations, and modify the use of potential errors and checklist columns. The technical considerations column includes a brief medical description of the goal and technical requirements for implementing the task. The ergonomics considerations column specifies the ergonomic goals and features required to conduct safely the technical goals for the task. Both technical and ergonomic considerations columns allow us to specify what each member of the surgical team should do to implement the task safely and correctly. The potential errors column specifies the potential disruptive events that could occur if a member of surgical team fails to follow ergonomic considerations. This column is applied in HTA tabular format for surgery subtasks. A checklist column is used to confirm or not the completion of specified technical and ergonomics considerations for each task as stated in the developed HTA tabular format.

**Ergonomic goals** The patient safety forms the ultimate (top-level) LRP goal which, in turn, requires no or minimal disruption/errors. To achieve this goal, the surgeon and other surgical members should conduct the surgery with adequate physiological posture, that is, a posture creates no musculoskeletal problems associated with bended trunk, shoulder movement, and axial rotation of neck and spine [10, 25–28]. Accordingly, having physiological posture forms a main goal for achieving the LRP ultimate goal. Two additional main goals are required for achieving physiological posture. The first is to arrange the location of surgical team to prevent hand crossing (mainly between surgeon and assistant) [16]. The second goal is to limit the hand movement to lowest classification to prevent shoulder movement [10, 29]. The three main ergonomic goals should be applied before the start of actual surgery, that is, during patient positioning and checked at the placement of trocars. The relationships between LRP ultimate and main goals are depicted in Fig. 1.

## Observations

Prospective observations were then conducted in two stages: observations for further developing the HTA, and observations after presenting the developed HTA among surgical teams. Observations at the first stage identified ergonomic goals and features of LRP tasks and associated external or internal disruption. At the end of each observation, the video tape of the case was obtained and reviewed. The results were discussed with the surgeon and the HTA forms modified as appropriate. The outcomes of this stage were the development of our final HTA for LRP, and the observation instrument comprising four observation sheets (Tables S1a–d). The HTA tool and instrument development and refinement based on observation of surgical procedures was undertaken by the HFE expert (LAH) and revised with input from the urologist authors.

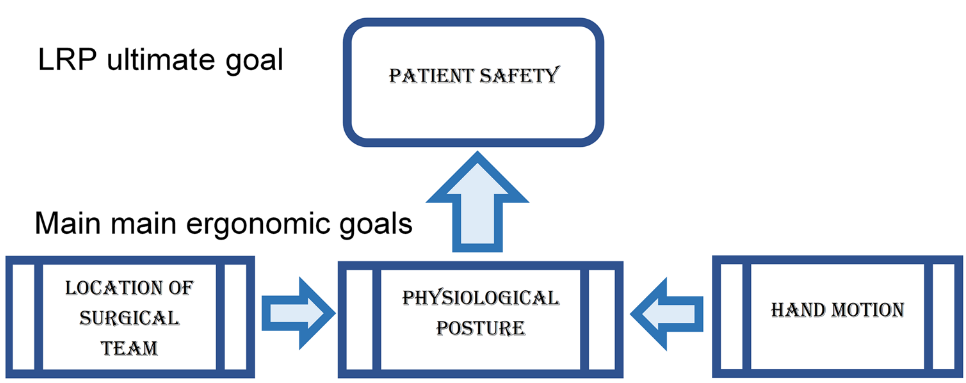


**Fig. 1** Relationships between LRP goals

We proceeded to discuss the outcome of the developed HTA with surgeons and assistants. Our hypothesis was that optimisation of ergonomics will reduce disruptive events during surgery. After presentation the developed HTA, another round of observations was conducted to enable a preliminary assessment of the HTA. Two groups were formed from the total observed LRPs. Group A was selected from the pool of observed LRPs conducted without specific attention to ergonomic goals and features stated in the developed HTA, and the second (Group B) was conducted with the surgical team attempting to follow specified ergonomic goals as prescribed in the developed HTA. We carefully select procedures such that the operative times, patient age, and Body Mass Index (BMI) are matched between the two groups.

Observations were conducted mainly by human factor expert (LAH) and MW, a senior urologist. In some cases, the observer was accompanied by another member of the urology team who is familiar with LRPs. On the day of observation, the surgeon introduces the observers to the patient and the surgical team. After each observation, the video record of the LRP surgical field was subsequently reviewed and the data collected during the observation was cross-checked against that recorded in the video. If required, discussion with the treating surgeon was undertaken to clarify observed events and classify errors.

### Statistical analysis

Data were entered into Microsoft Excel and analysed using SPSS 24. Measurement data are described by mean ± standard deviation (SD) with Min and Max values. Categorical data are presented as $n$ (%). Differences between groups are assessed using Wilcoxon signed rank test, given small sample size and likely non-parametric data distribution [30]. Where two observers observe the procedures simultaneously, inter-rater reliability is used to test the dependability and consistency of the developed HTA and the observation. A $\rho < 0.05$ is considered statistically significant and Kappa coefficient $\beta \geq 0.61$ indicates acceptable inter-rater reliability [31, 32].

## Results

Between March 2016 and November 2017, a number of urological procedures were observed, including 29 LRPs. During 9 LRPs, there were two observers. The resulting Kappa coefficient was 0.82 ($\rho < 0.05$) indicating good inter-rater agreement and supporting the reliability test. The supplementary tables (Table S1a–d) illustrate the data collection instrument comprising four observation sheets. Figure 2 presents the HTA hierarchical diagram for LRP level 1 and level 2 tasks. Table 1 illustrates the tabular format for task 3.0 'position patient' and task 4.0 'access the abdomen and check'. We selected these two tasks to analyse the three main ergonomic goals stated below, (also refer to Fig. 1), which are required to be applied during their implementation:

1. Physiological posture: to avoid non-physiologic posture, e.g. bended trunk and axial rotation of neck or spine.
2. Hand motion: to conduct surgery with low classification of hand—limited to lower and upper arm movements with no shoulder movement.
3. Team location: the location of the assistants and scrub nurse should not restrict surgeon with manoeuvring instruments or create hand crossing.

To achieve the above goals, several sub-goals (feature) should be applied. The second level subtask 4.5 'check and adjust' illustrates these specific ergonomic features (Table 2). They are mainly related to operating table height, locations, and heights of monitors displaying the surgical fields, hand motions, locations of assistant and camera man relative to surgeon, and the arrangement of instrument table (to be used by scrub nurse).

To illustrate how the main ergonomic goals affect the implementation of lower-level surgical tasks, we select the LRP task 'Dissection of NVB'. Table 3 illustrates the HTA tabular format of the first three subtasks for the LRP task. The table shows the potential errors that could occur if the subtask's considerations were not considered. Actions with each subtask would be implemented much easier and safer where surgeon and assistants are in adequate posture as specified in Table 1.

Eleven LRPs were observed with surgical team attempting to follow the ergonomic principles as stated in HTA forms. These procedures form group B. From the pool of remaining LRPs, we selected 11 procedures (group A), which match group B. As shown in Table 4, there were no statistical differences in operative time ($\rho = 0.398$), age ($\rho = 0.656$), and BMI ($\rho = 0.790$) between the two groups (Table 4). The total operative time for group A was 1635 min (148.64 ± 13.93, 130–170) and for group B was 1591 min (144.64 ± 12.79, 125–169), which is 1% less than the total operative time for group A. Figure 3 presents the frequencies of external disruptive events for group A and group B. The number of external disruptive events in group B (168 events) was 43% less than external disruptive events of group A (294 events). The most frequent disruptive events in group A included hand crossing (31 events), surgeon cessation of the operation (27 events), answering of unrelated calls (23 events), and delays in inserting instruments (23 events), followed by surgeon use upper arm/shoulder (19 events). The non-physiological posture and improper location of

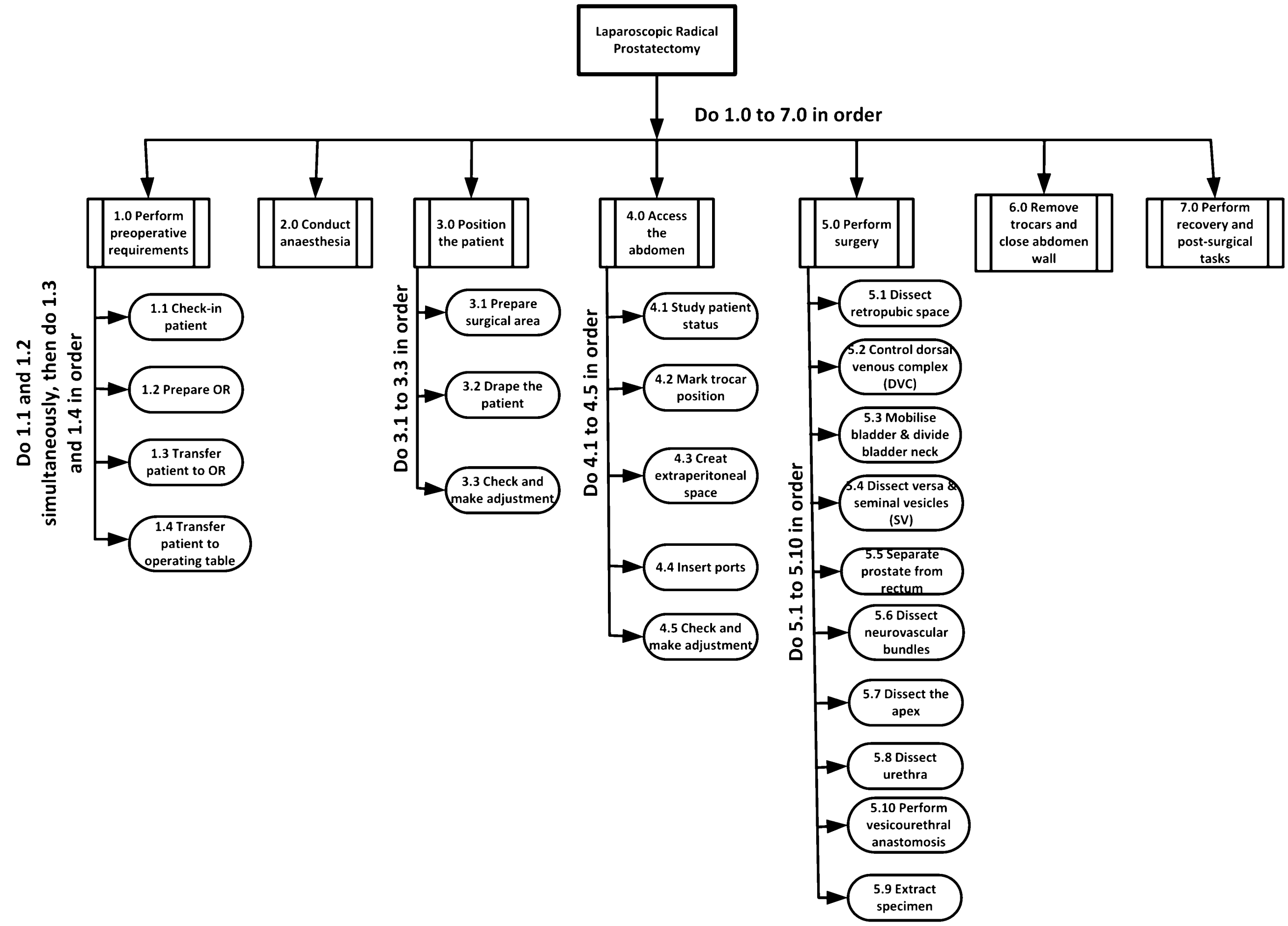


**Fig. 2** HTA diagram for LRP tasks

assistant creates hand crossing. The non-physiological posture forces surgeons to stop operations frequently, especially at the second half of the procedure. For group B, the most frequent disruptive event was interruption of staff entering ORs (17 events). This type of disruption is out of the surgeon's control and should be sorted out by OR management. The second frequent disruption is the surgeon cessation of the operation (15 events), and answering of unrelated calls (15 events), and hand crossing (13 events). It should take into account that the static posture during long LRP procedure creates musculoskeletal pain and disorder, and is, most likely, behind surgeons stopping procedures, and answering unrelated calls (instead of asking the circulator to answer the calls), especially during the second half of the procedure.

Figure 4 graphically demonstrates the differences in disruptive events between two groups. We observed 31 types of internal disruptive events classified into 11 categories. The number of internal disruptive events decreased by 58% from 618 events in group A to 258 events in group B. The most common disruptive events in group A were difficulty in retraction with a grasper (43 events), difficulties in manoeuvring needle holder (39 events), improper clipping/clamping (38 events), and difficulty in dissecting/cutting with ultrasonic instrument (35 events). The most frequent disruptive event in group B was difficulty in manoeuvring needle holder (24 events), difficulty in retracting with grasper (17 events), followed by difficulty in dissecting/cutting using ultrasonic instrument (15 events), and difficulty in manoeuvring instrument (14 events). The results indicate that the difficulty in manoeuvring needle holder during vesicoureteral anastomosis task forms the highest frequency of disruptive events in both groups.

Finally, the number of surgeons recruited for this study was limited to seven. This allowed repeated observation performance of the same surgeons throughout the study. The consistency of the results obtained during testing and re-testing surgeon performance provides further evidence of the test–retest reliability of our measurement tool. While group A matches group B in operative time, statistically significant differences between group A and group B were found for external disruptive events ($\rho < 0.01$) and

**Table 1** HTA table for the tasks 'patient position' and 'access abdomen and check'

| Code | Main task | Rule | Input | Technical considerations | Ergonomics considerations | Y/N[a] |
|---|---|---|---|---|---|---|
| 0 | Laparoscopic radical prostatectomy (LRP) | Do tasks 1, 2, 3, and 4 in order | | To cure patient from prostate cancer, using laparoscopic instruments to perform surgery with better surgical exposure and less associated morbidity | To ensure patient safety and conduct LRP with minimal disruption and musculoskeletal problems to surgical team | |
| – | – | – | – | – | – | |
| – | – | – | – | – | – | |
| 3.0 | Position the patient | | | S, T: To expose adequately the operative field for surgery<br>T: Patient is placed in appropriate position—lithotomy with Trendelenburg position | T: Physiological posture: To avoid non-physiological posture, e.g. bended trunk and hand crossing, during surgery<br>T: Hand motion: To conduct surgery with low classification of hand and body motions—limited to lower and upper arm movements with no shoulder movement or axial rotation of neck or spine | |
| 4.0 | Access abdomen and final check | | | S: To select the suitable approach for accessing the abdomen, e.g. Extraperitoneal or Transperitoneal approach<br>A: To insert trocars and create extraperitoneal space<br>S, A, AN, AA: To check technical aspects, e.g. equipment connection | S, T: Team location: To allow appropriate relative location of surgical team members<br>A, SN: The location of the assistants and scrub nurse should not restrict surgeon with manoeuvring instruments, or passing of instrument to surgeon, and do not block the vision of the surgeon to the display and monitoring devices<br>T: To check main ergonomic aspects, and make the required adjustments prior to start of surgery, e.g. monitor location and operating table height | |

*S* surgeon, *A* assistant, *SN* scrub nurse, *AN* anaesthetist, *AA* anaesthetist's assistant, *T* surgical team

[a]Checklist column to confirm performing the technical and ergonomic considerations for the task

**Table 2** HTA table for the subtask 4.5 'check and adjust'

| Code | Main task | Rule | Input | Technical considerations | Ergonomics considerations | Y/N[a] |
|---|---|---|---|---|---|---|
| 4.5. | Check and adjust | Do 4.5.1, 4.5.2, 4.5.3 in any order | | To check technical goals and features | To check ergonomic goals and features | |
| 4.5.1 | Check and adjust main ergonomic aspects | Do 4.5.1.1, 4.5.1.2, 4.5.1.3 in any order | | | | |
| 4.5.1.1 | Check and adjust operating table | | | | S: the height of operating table was adjusted such that the height of the instrument handles (after patient positioning and inserting the instruments) should be close to the level of Surgeon's elbow. Steps can be used if required<br>A: the height of the instrument handles (after adjusting the operating table) should be close to the level of Assistant's elbow. Steps can be used if required | |
| 4.5.1.2 | Check monitors location and height | | | | CN: The first monitor displaying the LAPAROSCOPIC field had been in the line with the surgeon's forearm—to avoid axial rotation of spine<br>CN: the first monitor displaying the laparoscopic field had been with, or lower than, eye level of Surgeon—to avoid neck extension<br>CN: The second monitor displaying the laparoscopic field had been in the line with the Assistant's forearm—to avoid axial rotation of spine<br>CN: The second monitor displaying the laparoscopic field had been with, or lower than, eye level of Assistant—to avoid neck extension | |
| 4.5.1.3 | Check the location of surgical team | | | | T: the locations of the assistant and cameraman relative to surgeon were studied and discussed carefully, such that the hand crossing and non-physiological posture can be avoided or minimised. This principle also requires attention to be given to the location of the trocars | |
| 4.5.2 | Check and adjust other ergonomic aspects | Do 4.5.2.1, 4.5.2.2, 4.5.2.3, 4.5.2.4 in any order | | | | |

**Table 2** (continued)

| Code | Main task | Rule | Input | Technical considerations | Ergonomics considerations | Y/N[a] |
|---|---|---|---|---|---|---|
| 4.5.2.1 | Check and adjust instrument table | | | SN: to facilitate handling of instrument to surgeon<br>SN: to allow scrub nurse working with physiological posture and minimise musculoskeletal pain | SN: the height of instrument table should allow scrub nurse to handle tools and instruments with no shoulder movement<br>SN: sharp and delicate tools and instruments should be aligned and located to permit easy and safe handling. For safety purpose the following should be followed<br>The sharp end of instruments should be pointed in the same direction<br>The curvature and angle of ring-handled instruments should be pointed in the same direction<br>The ring-handles of instruments should be placed on a rolled towel or hung over the container/tray edge<br>Blade handles should be aligned and placed over a rolled towel or special sponge | |
| 4.5.2.3 | Check instruments and materials | | | | T: to check the availability and suitability of all instrument and material needed for LRP | |
| 4.5.2.4 | Check tubes and wires | | | | CN: to check that tubes and wires laid on the OR ground are adequately covered and did not prevent movement | |
| 4.5.3 | Check technical aspects of patient positioning | Do 4.5.3.1 and 4.5.3.2 simultaneously | | | | |
| 4.5.3.1 | Check patient's connections | | | AN: to check and adjust airway passage<br>AN: to check and adjust IV infusion and oxygen cannulas | | |
| 4.5.3.2 | Check patient positioning | | | S, A: to check and ensure the following<br>All body pressure points are padded adequately<br>Patient's body and extremity were taped secured safely with no harm to the patient's body<br>Patient's surgical area is sterilised adequately<br>Patient is draped adequately | | |

*S* surgeon, *A* assistant, *CN* circulator nurse, *SN* scrub nurse, *AN* anaesthetist, *AA* anaesthetist's assistant, *T* surgical team

[a]Checklist column to confirm performing the technical and ergonomic considerations for the task

**Table 3** Detail of the first three subtasks for dissection of the neurovascular bundles (NVB)

| Code | Task | Rule | Input | Technical considerations | Ergonomics considerations | Potential errors[a] | Y/N[b] |
|---|---|---|---|---|---|---|---|
| 3.7.0 | Dissection of the NVB (with NVB preservation) | Do tasks 3.7.1 to 3.7.3 in order | | S: To developing plane between Denonvilliers' fascia and prostate<br>S: Surgeon uses the cold scissors to dissect the plane between Denonvilliers' fascia and prostate to avoid heat damage to the NVB | | S: There are three options and surgeon may select wrong option: Dissection (A) with NVB preservation, (B) without NVB preservation. (C) High interior release | |
| 3.7.1 | Grasp and retract the seminal vesicles (SV) | | Laparoscopic atraumatic grasper, suction instrument, endoscope | A: To stretch the Denovilliers' fascia and facilitate its incision<br>The Denonvilliers' fascia is a flimsy tissue containing fat, nerves, and vessels and is attached laterally to the NVB | A: Grasp and retract SV antero-superiority and towards the other side<br>A, S: Required appropriate coordination<br>A: Requires appropriate tension enough to facilitate the surgical dissection but not too much to break the vas and SV<br>CM: To redirect the endoscope and provide adequate visualisation | A: Delay in performing the task<br>A: Difficulty in grasping the SV<br>A: Moving the SV in a wrong direction<br>C: Inadequate visualisation of the field<br>S.A, & C: Lack of communication and coordination | |
| 3.7.2 | Laterally incise the Prostatic/Denonvillier's fascia | | | S: To expose NVB and the capsular arteries—which run vertically into the prostate | S: Surgeon chooses site of incision to allow varying degrees of nerve preservation<br>S: To avoid incising too deeply which may lead to capsular incision into prostate or bleeding from peri-prostatic veins<br>A: To provide adequate retraction<br>CM: To provide adequate visualisation | S. Incises deeply and causes bleeding<br>S, A: Lack of hand synchronising<br>S, A: Hand crossing<br>A: Failure to make suction correctly<br>CM: Failure to orient endoscope correctly. Poor visualisation | |
| 3.7.3 | Retract and provide tension on NVB | | Forceps or aspirator | A: To tighten the vesicoprostatic pedicles<br>Excessive traction can cause injury to NVB or tear vessel causing bleeding | A: To provide retraction to allow dissection of NVB | A: Insertion of the forceps in the wrong plane<br>S & A: Communication problem<br>A: Failure to provide adequate retraction/tension<br>CM: Inadequate visualisation | |

*S* surgeon, *A* assistant, *CM* cameraman

[a]Potential disruption/errors where the technical and ergonomic consideration of the task were not adequately performed

[b]Checklist column to confirm performing the technical and ergonomic considerations for the task

**Table 4** Demographic characteristics

| Patient/procedure | Demographic data | Group A | Group B | $\rho$ value |
|---|---|---|---|---|
| Patient | Age (years) [mean ± SD, min–max] | 67.73 ± 6.26, 54–75 | 66.73 ± 5.10, 58–72 | 0.656 |
| | Weight (kg) [mean ± SD, min–max] | 70.73 ± 8.31, 60–86 | 65.80 ± 7.71, 55 -82.4 | 0.266 |
| | BMI | 25.01 ± 1.84, 22.45–28.47 | 24.76 ± 1.98, 21.48–27.64 | 0.790 |
| | ASA [I–II–III–IV–V] | 10-1- 0-0-0 | 10-1-0-0-0 | 1.000 |
| | Previous surgery | 2 | 3 | |
| | Prostate volume (ml) [mean ± SD, min–max] | 30.75 ± 3.60, 25.8–37.2 | 30.35 ± 2.94, 26.2–36.2 | 0.689 |
| Procedure | Number of procedures | 11 | 11 | |
| | Operative time (min) [mean ± SD, min–max] | 148.64 ± 13.93, 130–170 | 144.64 ± 12.79, 125–169 | 0.398 |
| | Total operative time (min) | 1635 | 1591 | |

internal disruptive events ($\rho < 0.01$), with lower disruptive events being observed within group B.

## Discussion

This study develops a HTA that considers both technical and ergonomic considerations for each task and identifies interrelationships between ergonomic goals, external disruption and internal disruptions. Our research benefits from the work of Sarker et al. [11] in construction of the HTA tabular format but, unlike the work of Sarker et al. it specifies actions of various members of surgical team in one HTA format.

Despite sensible attempts to follow the HTA requirements, disruption cannot totally be eliminated. This seems mainly due to several factors other than those stated in HTA forms. These factors include, but not limited to, the following:

1. Restricted surgical working space: individual physical aspects of the patients (weight, body shape, etc.) may restrict the surgical area and causes hand crossing and other disruptive events. In addition, the use of specific LRP techniques, such as the extraperitoneal method, is useful for certain patients and may represent surgeon preference but it is known to restrict the surgical working space [34].
2. Task complexity: LRP comprises tasks with complex subtasks that require extra attention and effort from surgeons and higher instrument synchronisation from assistant. Proper suture placement into the short urethral stump during vesicourethral anastomosis forms a specific challenge for many surgeons [35, 36]. During such tasks, surgeons may use instruments or trocars assigned to assistant for further examining the surgical field. This may create hand crossing and instrument clashes.
3. Long-period static posture: literature points to musculoskeletal discomfort and disorder facing laparoscopic surgeons as a result of long-period static posture [21]. Musculoskeletal discomfort restricts the performance of surgeons and may predispose them to act erroneously. We had noticed that the rate of internal disruption increases during the second half of the LRPs, especially during dissection of DVC and performing vesicoureteral anastomosis task.
4. Existing stressors: workload, stress and fatigue, lack of teamwork, culture, and habit are factors affecting surgical performance. We argue that in the presence of these factors (stressors), disruptive events cannot be totally avoided. However, the violation of ergonomic goals can amplify the effect of these stressors.
5. Team management: in many cases, the assigned scrub nurses, assistants, or anaesthetist personnel to a surgery may have insufficient experience or are unfamiliar with the surgeon's work, which may create communication problems and increase disruption [37], which ultimately affect the team performance [38, 39].
6. Ergonomic considerations for subtasks: the ergonomic goals and features for surgery are not limited to those applied before conducting the surgery. There are also specific ergonomic features for each subtask. Failure to apply the required features will also create disruption. To facilitate the surgeon's work during dissection of Neurovascular bundles (NVB), for instance, the assistant should grasp and retract the seminal vesicles (SV) anterior-superiority and towards the other side of the dissection with tension but not too much to break VAS and SV (Table 3). Failure of the assistant to make correct traction may create disruption.
7. Monitors displaying surgical field: we have noticed that only few ORs are equipped with two or more ceiling-mounted monitors with flexible height and location. Many ORs are equipped with only one monitor displaying the surgical field. Usually the monitors are located on the 'Tower Table', (i.e. the table containing the surgical control equipment), with limited flexibility in changing the height. Some ORs are equipped with one ceiling-mounted monitor with flexible height and location and

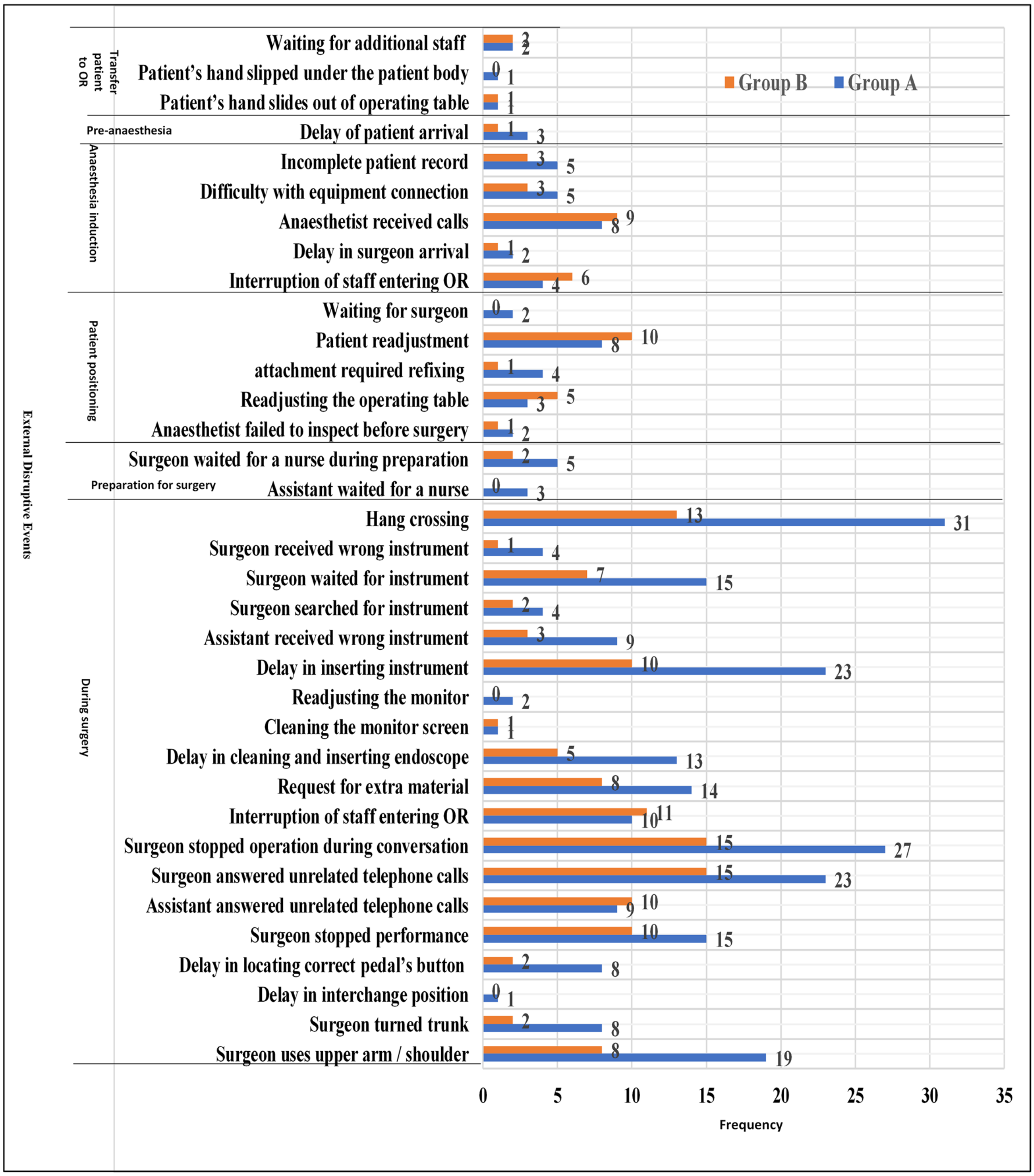


**Fig. 3** Frequency of observed external disruptive events for groups A and B

another on the Tower Table. Very few ORs are equipped with two ceiling-mounted monitors. Having inadequate location, height, and number of monitors creates neck extension and then disruption. In two cases, we noticed that the resolution of one monitor was poor which may create eyestrain.

Having physiological posture is a main ergonomic goal for save implementation of procedures [16, 25, 40]. This is the case with other two main ergonomic goals: relative location of surgical team and low classification of hand motions (Fig. 1). These three ergonomic goals should be applied before the start of surgery in order to implement its lower-level tasks with minimal disruption. This means that the three main ergonomic goals of upper-level tasks should facilitate both technical and ergonomic sub-goals or features of the lower-level surgery task. Accordingly, the hierarchical flow of ergonomic goals is in opposite to that for technical goals as shown in Fig. 5.

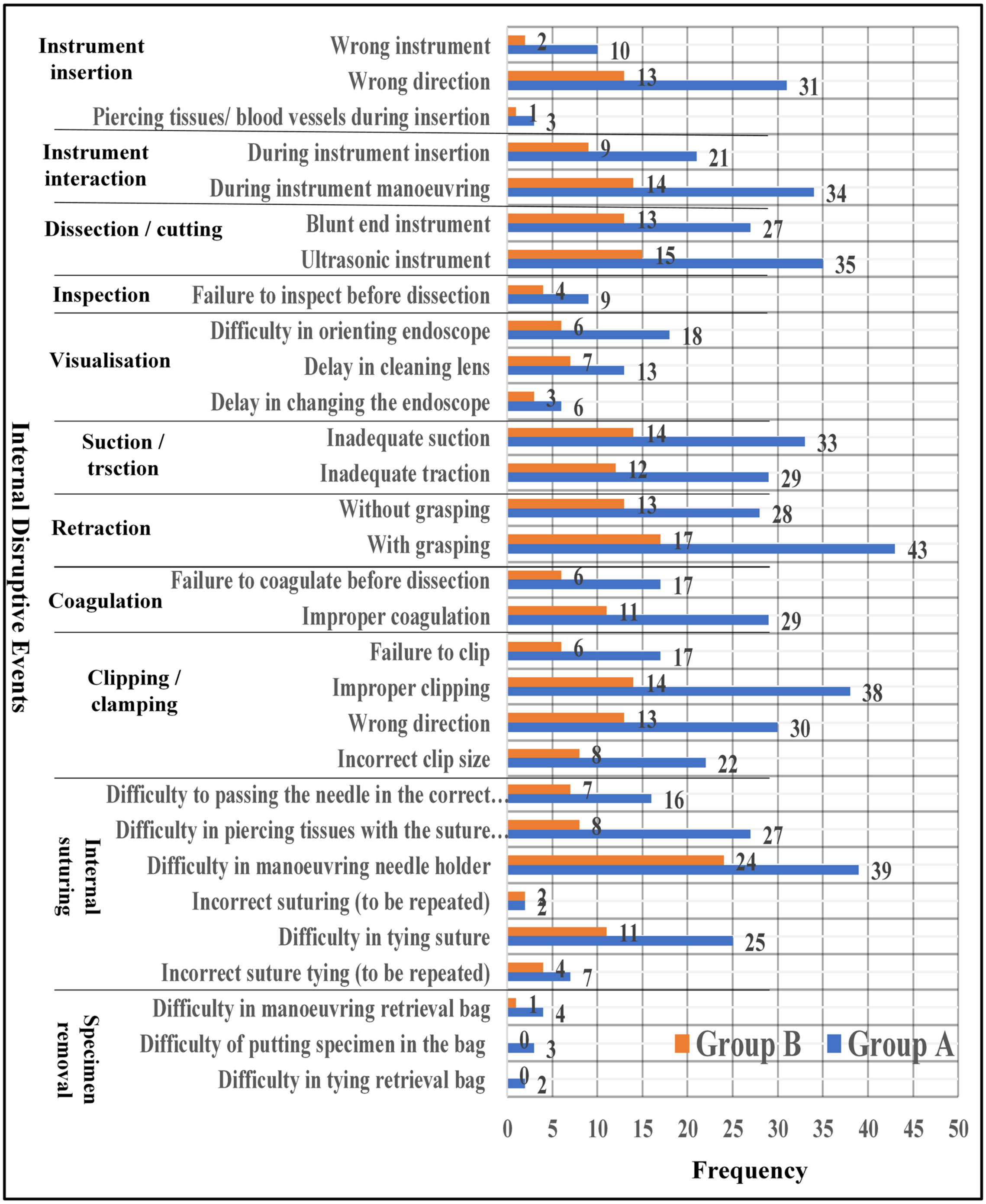


**Fig. 4** Frequency of internal disruptive events for groups A and B

A study conducted in cooperation with the European Association for Endoscopic Surgery reveals that 89% of the surgeons surveyed were unaware of the ergonomics, though all of them stated they find ergonomics important [33]. Our discussion with surgeons and assistants reflects similar unawareness of ergonomics. The surgeons welcome suggestions and tools that ease their musculoskeletal problems and enhance their concentration on performing complex tasks and performance. The assistants are mainly residents with limited experience and inadequate educational background on ergonomics.

One may consider the external and internal disruptive events listed in this study (Figs. 3, 4) are minor events and may have limited effect on the operative time. Disruptive

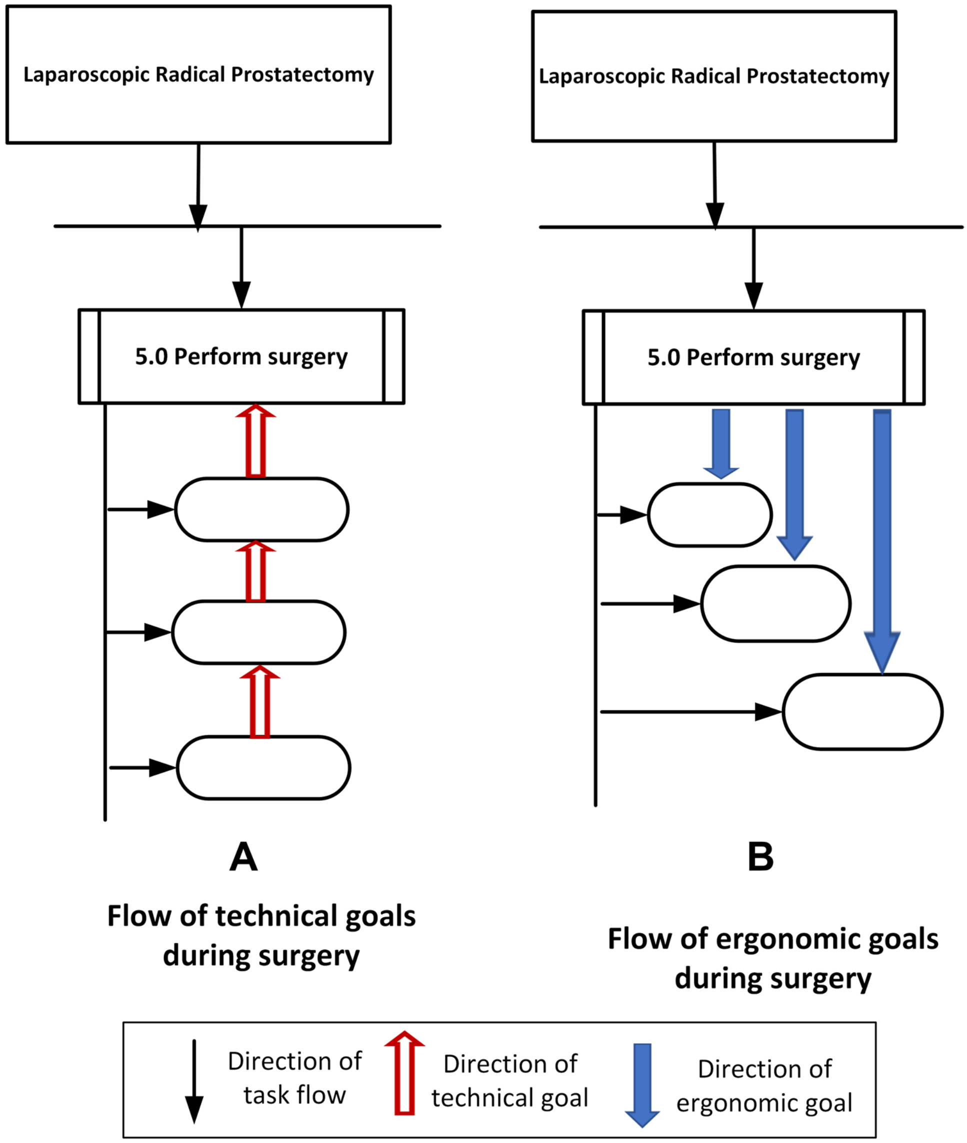


**Fig. 5** Hierarchical flows of technical and ergonomic goals

events may require additional corrective actions. For example, division of a blood vessel before coagulation may lead to bleeding, which may increase time taken in haemostasis. Successive disruptive events may force surgeons to slow down and subsequently increase operative time. The overall impact of these small events on the surgeons pace and performance is difficult to measure [16]. In addition, the accumulation of these events may predispose surgeons to serious errors leading to adverse events, such as dissecting the wrong plane.

It is worth noting that some multiple, often repetitive minor events usually considered in the literature as destructive affecting performance, for example, irrelevant conversations [41] may be quite common in an OR and not have a significant impact on surgeon performance [42]. Other events may have a positive impact on surgeon performance. For example, if the surgeon allows the assistant to perform surgical operations during the final quarter of the procedure, for short time, to ease musculoskeletal pain resulting from long-period static posture, could have a positive impact on the surgeon's performance.

Our developed HTA could form a good material for guiding resident surgeons, nurses, students, and trainees to comprehend technical and ergonomic requirements for low-level tasks of complex surgery, gives clear indication on the impact of managing adequately the ergonomic goals and features, enhances coordination within the surgical team, and helps in the reduction of disruptive events intra-operatively.

Our developed HTA can also be used as a checklist for assessing or self-appraising the performance of surgical teams. Few researchers have attempted similar checklists. Sarker et al. [11, 12], Peyre et al. [14], and Sarker and Deancy [13] used HTA as a procedural checklist assessment instrument by listing the technical tasks and determining the number of not performed tasks. However, their works consider the surgeon as the sole agent involved in conducting a procedure rather than the surgical team. They also evaluated the implementation of surgery tasks in isolation from ergonomic considerations. Consequently, a surgeon may pass the assessment by performing all technical tasks despite also producing a significant number of errors in the process that may have post-operative consequences. We believe our approach is superior in that it combines both technical and ergonomic considerations and incorporates teamwork. Peyre et al. [14] stress that expert surgeons automate their knowledge, "making difficult to teach incremental steps" of the complex procedures, and by "capturing automated knowledge in checklist form, we can scaffold resident learning and improve feedback for advanced laparoscopic case". These comments provide further validity of our developed HTA as a training aid.

## Limitations

There are several approaches to LRPs as well as to each of its task, and we illustrated only one path. Accordingly, our list of main tasks and detailed subtasks are not comprehensive and do not provide a "one size fits all" mould.

The number of observations is relatively small, and accordingly, we may miss some low-level subtasks or potential disruptive events in our lists of HTA. In addition, our study can only focus on what we observed during procedures. Some external erroneous events observed during procedures may be the consequences of other factors. These could include coordination failures between various theatre teams before the start of the procedure. Workload, and stress and fatigue factors significantly affect the surgical team performance. The contribution of these factors on the rate of disruption events was not assessed.

Finally, patient preparation, information flow and coordination between various departments, and surgeon's workload may differ between hospitals and may affect how surgical teams work. Our current study did not investigate the effect of these aspects on surgical team performance. Our developed HTA appears to have some utility, but needs larger studies. We intend to cover these issues in future research.

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## Compliance with ethical standards

**Disclosures** The authors Latif Al-Hakim, Ming Wang, Jiaquan Xiao, Dennis Gyomber, and Shomik Sengupta have no conflicts of interest or financial ties to disclose.

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