Complications of robotic-assisted laparoscopic surgery distant from the surgical site

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Abstract

With the ever-increasing popularity of robotic-assisted laparoscopic surgery over the past decades, the literature reporting complications distant from the surgical site involving the use of this technology has also grown. The goal of this non-systematic review is to summarise these reports with a systems-based presentation of these complications. The most commonly observed complications were related to the peripheral nervous system and the most devastating occurring in cardiac and ophthalmic systems. There were no reports of patient complications directly related to the robot itself. While several of the reported complications are not unique to robotic surgery, they are included to maintain awareness of their possibility. The limitation of surgical time, judicious fluid administration, and constant vigilance of patient positioning are all recommended as possible preventative measures.

Key words: robotic surgical procedures; laparoscopic surgery; intraoperative complications; postoperative complications; patient safety

The inception of robotic-assisted surgery (RAS) has brought with it promises of an improvement upon the minimally invasive technique of conventional laparoscopic surgery through enhancements on the amount of control and mobility offered to the operator.1-3 The benefits associated with laparoscopic surgery such as decreased hospital stay, expedited recovery time, reduced postoperative pain, and improved cosmetic outcome translate naturally to RAS.5 However, it is controversial if RAS has truly produced an improvement. Overall it appears that for most surgeries, the robotic approach offers reduced blood loss, a reduced need for transfusion, and shorter hospital stay.6 However, a consistent benefit has not been shown regarding a reduction in morbidity or mortality, and there is an increased cost associated with robotic procedures.5 Furthermore, there has been discussion that the reduced hospital stay can offset some of the costs of RAS, but only if the initial investment in the robotic system is taken out of the equation.7

The unique logistics of the robotic surgical setup require extensive considerations such as specialised patient positioning combined with longer surgical times (i.e. tolerance of prolonged periods in the Trendelenburg position). In addition, patient characteristics such as morbid obesity, decreased cardiopulmonary reserve, vascular disease, ophthalmic disease, or pre-existing neurological disability, may increase the risk of complications and might be considered relative contraindications to RAS. This review article seeks to examine the complications and considerations unique to this novel field of surgery, with a focus on abdominal and pelvic procedures.

Methods

A literature search was carried out in two separate phases. The first was a literature search of PubMed, Embase, and SCOPUS utilising combinations of the keywords “robotic”, “robot-assisted”, “anesthetic”, “complications”, “Trendelenburg”, and “positioning”. Search exclusions were conference proceedings, and papers not in English or lacking English translations.
This yielded 1,738 citations, which were screened down (reviewers D.A.M., L.N.B.) to 78 articles. We catalogued complications and defined them as injuries not directly related to surgical action, which includes events such as haemorrhage, trauma to bowel, and postoperative urologic issues.

After this, a more focused search was performed on PubMed, Embase, and SCOPUS using keywords across all complications in order to ascertain more data regarding incidence, treatment, and recommendations for prevention. An additional 31 articles were selected with an emphasis on larger retrospective studies and prospective trials.

The complications found in the literature spanned essentially all organ systems. A systems-based approach was utilised to allow for a more organised presentation.

### Neurologic complications

Neurologic complications associated with both positioning and procedural factors were a significant portion of those reported. The most commonly reported complication was related to position-related injuries of the peripheral nervous system (Table 1).

#### Peripheral nervous system

Peripheral nerve injury is an uncommon yet debilitating complication of both robotic and laparoscopic-assisted surgery. In fact, 16% of ASA closed claims database complaints are because of injury of one or more nerves. One large retrospective series demonstrated a 0.16% incidence of peripheral nerve injuries in robotic-assisted laparoscopic prostatectomy (RALP) cases compared with a 0.1% incidence in non-robotic prostatectomies.

It is most often related to the steep Trendelenburg position required for robotic surgery and prolonged operative times when compared with traditional laparoscopic or open surgery. The possible mechanisms of nerve injury include compression, stretching, and ischaemia. Prolonged periods of compression can lead to Schwann cell damage and demyelination, leading to permanent nerve damage. Peripheral nerve injuries described in the literature include the lingual and buccal nerves, brachial plexus, lateral femoral cutaneous nerve, obturator nerve, femoral nerve, common peroneal nerve, and sciatic nerve.

#### Upper extremity injuries

Peripheral nerve injuries occur with an overall incidence of 0.25%, with brachial plexopathies accounting for 20% of all peripheral neuropathies reported to the ASA closed claims database. The most frequent site of upper extremity neuropathy is the ulnar nerve, followed by the brachial plexus and median nerve. These injuries are often attributed to excess pressure over the acromioclavicular joint. The role of shoulder bolsters in brachial plexus injuries is controversial, with some papers offering them as preventative measures and others classifying them as possible causes. In one case report by Devarajan and colleagues, three patients undergoing RALP suffered unilateral brachial plexopathies in abducted arms. These patients were all positioned in low lithotomy position on a beanbag, with the right arm abducted and left arm abducted at < 90 degrees, with both arms padded. All three patients experienced C5–C7 distribution numbness in the left upper extremity postoperatively. At six weeks postoperatively, two of the three patients had resolution of symptoms, but one patient had persistent pain, numbness, and grip weakness. This was thought to be because of the

| Table 1 Summary of neurological complications of robotic-assisted laparoscopic surgery |
|-------------------------------|-----------------|-----------------|-----------------|
| Category                      | Complication    | Incidence       | Risk Factors    | Prevention                  |
| Peripheral nervous system     | Upper extremity nerve injury | 0.25-1.8% | Shoulder bolsters causing excess pressure over acromioclavicular joint | Padding of shoulder bolsters  |
|                               |                  |                 | Bean bag use    | Discontinuation of bean bag use |
|                               |                  |                 | Abduction of arms > 90 degrees | Adduction of arms         |
|                               |                  |                 |                 | Gel foam and egg crate padding (no difference) | |
|                               | Lower extremity nerve injury | 0.3-2% | Low BMI | Not listed |
|                               |                  |                 | Prolonged time spent in lithotomy position | |
|                               |                  |                 | Insufficient padding of leg supports | |
|                               | Unspecified positioning injuries | 0.4-6.6% | Prolonged operative time | Not listed |
|                               |                  |                 | One or more medical comorbidities | |
|                               | Cerebral oedema | Not listed | Income < $35,000 annually | Limit time in steep Trendelenburg  |
|                               |                  |                 | Steep Trendelenburg | Restrict steep Trendelenburg to 30 degrees maximum  |
|                               |                  |                 | Prolonged operative time | Fluid restriction  |
|                               |                  |                 | Prolonged Steep Trendelenburg | Limit operative time  |
|                               |                  |                 | CO2 peritoneum of 16 mm Hg | Limit intra-abdominal insufflation pressure to 8 mm Hg  |

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application of shoulder restraints, which depress the acromioclavicular joint and clavicle relative to the torso and increase the angle of abduction to > 90 degrees. After discontinuing the use of beanbags and adducting both arms, the authors’ institution had no further brachial plexopathies across 2,674 cases.

A retrospective study by Mills and colleagues reviewed 334 robotic urologic cases and found 22 neuropraxic injuries, with 13 of 22 involving the upper extremity. The injuries were unilateral in at least nine of 13 cases with eight of 13 involving both arms being tucked, however, this was also the most popular position choice in the study (183 of 334 patients). The remaining four of 13 upper extremity injuries were bilateral and occurred in all position variations described. Incidence of injury correlated strongly with increasing case time and increasing ASA classification. One month postoperatively, 59% of injuries had resolved, and 23% persisted at six months. Beanbag use was not associated with these injuries.

Most reports citing brachial plexus injuries described no long-term sequelae. One case report describes a patient undergoing RALP who demonstrated a pure motor deficit in the right shoulder abduction (C5–C6 innervation), with a power grading of four of five and a weakness in elbow flexion (C5–C6 innervation) with a power grading of three of five. This deficit had resolved by postoperative day five and showed continued resolution two weeks postoperatively. In another retrospective review, a patient undergoing robotic gynaecologic surgery had a brachial plexus injury with no long-term sequelae. Oksar and colleagues published a prospective study of 53 patients undergoing RALP, and a unilateral sensory and motor neuropraxia was observed in one patient with resolution after three days.

A retrospective cohort review of 831 robotic gynaecologic cases by Ulm and colleagues showed an overall rate of positioning injuries of 6.8% per case. Of these seven patients experienced a brachial plexopathy that resolved by two weeks postoperatively without intervention. Transient neuropathy was also reported in three of 305 patients in a prospective study of RALP.

Although most studies attributed these peripheral neuropathies to complications of positioning, one study evaluated the utility of gel foam vs egg crate padding to prevent slide and positioning injuries. Wechter and colleagues looked at 61 patients undergoing robotic gynaecologic procedures, of which five experienced transient shoulder or neck pain. No significant difference was appreciated between gel pad and egg crate foam in prevention.

A retrospective study performed by Nakamura and colleagues demonstrated an association of Clavien I and II complications with higher ASA scores (III–IV), and found only one case of extremity numbness in a retrospective review of 293 patients having RALP.

Lower extremity injuries

Most robotic urological procedures require steep Trendelenburg with lithotomy position. Compression of the peroneal nerve can easily occur between the head of the fibula and leg supports, and compression of the saphenous nerve at the medial tibial condyle. Lower BMI seems to be a risk factor for lithotomy positioning injuries. Additionally, each h of lithotomy increases the risk of motor neuropathy 100-fold. Prolonged periods in this position can lead to lower extremity neuropathies involving the lateral femoral cutaneous nerve, common peroneal nerve, obturator nerve, and sciatic nerve if adequate precautions are not taken. Lower extremity neuropathy incidence as a complication ranges from 0.3–5.1%. In a review article of robotic prostatectomies by Awad and colleagues, 0.3% of patients experienced a sensory deficit and one in 4,500 experienced a motor nerve deficit in the common peroneal nerve distribution. The obturator nerve had a 0.5% injury rate. A sensory deficit occurred in 0.3–2% and motor deficit occurred in one in 25,000 in the sciatic nerve distribution. Femoral nerve injury had a one in 50,000 chance of persistent motor neuropathy.

The study by Ulm and colleagues demonstrated two cases of lower extremity neuropathy (including one obturator nerve injury) that were attributed to positioning. There was no significant risk factor identified.

As mentioned previously, lateral femoral cutaneous nerve injury can occur as a result of lithotomy position. One case of lateral femoral cutaneous neuropathy was observed in the study by Wechter and colleagues, which was not associated with intraoperative slide and resolved by postoperative week 10.

Unspecified positioning injuries

A net 6.6% incidence of positioning injuries was observed in a retrospective review of 334 robotic-assisted urologic surgeries conducted by Mills and colleagues, with 23% of these injuries persisting beyond six months. On further analysis, four of 10 retroperitoneal lymph node dissections and one of six adrenalectomies had positioning injuries. Radical prostatectomy and partial nephrectomy had an injury incidence of 7%. Median case time for patients with positioning injuries was 328 min and 240 min for patients without injury. Once adjusted for case times, i.v. fluid administration and beanbag use were not associated with injury.

In another retrospective study of 61,656 patients undergoing RALP, 0.4% (249 of 61,656) experienced positioning injury. The authors found that patients with one or more medical comorbidities had two times the chance of positioning complication than patients with no comorbidities. They also found that patients with annual income of <$35,000 annually were more likely to have a positioning complication. Furthermore, a positioning injury was the strongest predictor of a prolonged length of stay with a three-fold greater likelihood. Also, one review article suggests the use of an additional time out to assess for optimal positioning.

Central nervous system

Cerebral oedema occurred in three cases (case report and case series) in patients who underwent RAS, and described as a concern in robotic cases that could lead to postoperative agitation in four cases total. The cases reported varied from depressed mental status necessitating reintubation in the postanaesthesia care unit, with CT scan findings consistent with cerebral oedema to delayed extubation with a normal CT. The two cases with confirmed radiologic evidence of cerebral oedema underwent treatment with dexamethasone and diuretics with ultimate resolution of symptomatology. The aetiology is thought to be secondary to an increase in central venous pressure from the combination of Trendelenburg position and pneumoperitoneum with resultant increase in intracranial pressure and capillary leak. Preventative strategies suggested included limiting time in steep Trendelenburg, fluid restriction, limiting intra-abdominal insufflation pressure to 8 mm Hg, and limiting operative time when possible.
Complications of robotic laparoscopic surgery

Non-neurological complications

Complications were not just limited to the nervous system, but occurred in various other organ systems as well (Table 2). Overall, those reported were primarily related to combinations of Trendelenburg position, abdominal insufflation, and prolonged procedure time. No cases were reviewed where a patient suffered injury directly related to the robot, with the exception of robot failure necessitating conversion to an open surgery which had a reported incidence of 0.6% in one retrospective review.35

Ophthalmic and otologic complications

Ischaemic optic neuropathy (ION)

ION has an estimated incidence across all procedures of 0.05% and is encountered with robotic abdominal and pelvic surgeries.36 Posterior ION was reported in a case report involving two patients undergoing prostatectomy, with one using a robotic technique and the other laparoscopic.37 The specifically reported cases described bilateral loss in visual acuity (as severe as complete blindness) and varied regarding the specific visual fields.8 35 Postoperative follow-up generally demonstrated some degree of recovery, but with varying degrees of stable visual deficit, with continued optic disc pallor on exam at the three-month postoperative period.8 35

Visual loss of unclear aetiology

Varying degrees of visual field deficit and blindness were reported across seven papers. The majority of papers were represented by case reports and case series, but one larger retrospective study reported an incidence of one in 256 cases.38 A smaller prospective study that followed visual acuity in RALP patients demonstrated visual loss without clear aetiology in seven total eyes examined across seven of 25 subjects with complete resolution of the loss at three months.39 Case reports and case series described loss ranging from progressive bilateral visual field deficits to blindness, and each described resolution at three months postoperatively, with case length possibly playing a role.40 41 Duration of surgery, especially procedures exceeding six hours, were noted to have an increased association with the incidence of visual loss.52 One possible way to mitigate the risk is a “break period” with a return to supine position during procedures utilizing steep Trendelenburg. One small prospective trial demonstrated a significant decrease in intraocular pressure towards baseline when a five to seven-min break was taken at the 90-min or 120-min mark of surgery.35 Increased awareness of ophthalmic complications relating to steep Trendelenburg, resulted in a report of two open-angle glaucoma patients having a robotic case rescheduled as open after ophthalmic consultation.43

Corneal abrasions (CA)

CA is the most common ocular complication of robotic surgery.44 45 Among non-ocular surgeries, larger studies have indicated an incidence of 0.013 to 0.17%.46 Among retrospective studies that contained more than five hundred cases, the range of incidence for CA in robotic cases was 0.13% to 3%.47–49 The largest retrospective study examined (>100,000 cases) did not demonstrate a significant difference in incidence of CA in open versus robotic prostatectomy, but did demonstrate a significant increase when comparing open hysterectomy (0.03% incidence) with laparoscopic (0.136%) and robotic (0.297%) hysterectomies.47 None of the cases reported long-term deficit or clinical sequelae in affected patients. The tendency of eyes to incompletely close during general anesthesia predisposes patients to this risk.50 Other risk factors included conjunctival oedema and lack of covering eye tape, fluid administration greater than two litres,51 and robotic versus purely laparoscopic cases.52 Potential causes also included direct contact with patient eyes by the patient or provider50 and monitoring cables in proximity to the eyes.51 Smaller follow-up reports included preventative interventions of fluid restriction less than two litres, transparent occlusive dressing, and actively warning patients not to touch their eyes, which resulted in no further incidence of CA in this group.51 The use of protective eye and bio-protective dressings has been described in other articles.53

Miscellaneous ophthalmic complications

A single case of retinal tear after RALP was noted postoperatively after visual changes, no long term sequelae was reported.51 Overt retinal detachment was reported in one patient and thought to be as a result of intraocular pressure changes in the Trendelenburg position.26

Otoxic complications

Otorrhagia resulting from aetiologies including tympanic membrane perforation and ear canal haematoma were noted in case reports, with no sequelae at one month after treatment with antibiotic and steroid otic drops.54–56

Cardiovascular complications

Ultimately, very few cardiovascular complications were found in the literature, with the search yielding two case reports, one review article, and two retrospective analyses. Complications reported did not appear to be unique to RAS of the abdomen and pelvis and had no greater incidence. Bradycardia in response to insufflation was noted in one study to occur in seven of 575 (1.2%) of patients, with one episode progressing to asystole with recovery after a brief period of chest compressions and administration of atropine and epinephrine.57 An additional retrospective study demonstrated a cardiac event in two of 182 (1%) patients who underwent a robotic procedure, with one patient developing atrial fibrillation with resultant cardiogenic pulmonary oedema, and the other developing ischaemic changes on EKG.52 Myocardial infarction as a result of in-stent thrombosis was described in a case report, where a patient developed a new left bundle branch block and was ultimately taken to the cardiac catheterization lab.54 One case report described a patient with significant cardiac risk factors who underwent cardiac arrest likely because of hypercarbia upon extubation who was subsequently successfully resuscitated,59 and an additional case report described intraoperative cardiac arrest and death in a patient with significant coronary artery disease.60

Pulmonary complications

Pulmonary complications described in the literature were not especially unique to RAS or the Trendelenburg position. A literature review yielded eight review articles, three case reports, and three prospective studies. Complications included right mainstem intubation on assumption of the Trendelenburg position and inability to maintain adequate ventilation for periods exceeding six hours, were noted to have an increased association with the incidence of visual loss.52 One possible way to mitigate the risk is a “break period” with a return to supine position during procedures utilizing steep Trendelenburg. One small prospective trial demonstrated a significant decrease in intraocular pressure towards baseline when a five to seven-min break was taken at the 90-min or 120-min mark of surgery.35 Increased awareness of ophthalmic complications relating to steep Trendelenburg, resulted in a report of two open-angle glaucoma patients having a robotic case rescheduled as open after ophthalmic consultation.43

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<table>
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<td>Ophthalmic</td>
<td>Ischaemic optic neuropathy&lt;sup&gt;36,37&lt;/sup&gt;</td>
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<td>Trendelenburg position&lt;sup&gt;34&lt;/sup&gt;</td>
<td>Limit time in steep Trendelenburg&lt;sup&gt;3&lt;/sup&gt;</td>
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<td>Increased i.v. fluids&lt;sup&gt;38&lt;/sup&gt;</td>
<td>Avoid excessive i.v. fluid administration&lt;sup&gt;8&lt;/sup&gt;</td>
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<td>Pneumoperitoneum&lt;sup&gt;9&lt;/sup&gt;</td>
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<td>Prolonged operative time&lt;sup&gt;39&lt;/sup&gt;</td>
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<td>Corneal abrasion&lt;sup&gt;40-42,53&lt;/sup&gt;</td>
<td>0.2–3%</td>
<td>Tendency of eyes to incompletely close&lt;sup&gt;40&lt;/sup&gt;</td>
<td>Fluid restriction &lt; 2 L&lt;sup&gt;41&lt;/sup&gt;</td>
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<td>Lack of eye tape&lt;sup&gt;40&lt;/sup&gt;</td>
<td>Transparent occlusive dressing and protective eye coverings&lt;sup&gt;51-53&lt;/sup&gt;</td>
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<td>Fluid administration &gt; 2 L&lt;sup&gt;21&lt;/sup&gt;</td>
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<td>Patient or provider contact with patient eyes&lt;sup&gt;40&lt;/sup&gt;</td>
<td>Verbal warning to patients to avoid touching their eyes&lt;sup&gt;52&lt;/sup&gt;</td>
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<td>Monitoring cables in close proximity to the eyes&lt;sup&gt;51&lt;/sup&gt;</td>
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<td>Unclear</td>
<td>Ophthalmology consultation in patients with intraocular pathology or increased IOP at baseline&lt;sup&gt;56&lt;/sup&gt;</td>
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<td>Retinal detachment&lt;sup&gt;36&lt;/sup&gt;</td>
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<td>Bradycardia&lt;sup&gt;57&lt;/sup&gt;</td>
<td>1.20%</td>
<td>Insufflation&lt;sup&gt;77&lt;/sup&gt;</td>
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<td>Atrial fibrillation&lt;sup&gt;52&lt;/sup&gt;</td>
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<td>Case report</td>
<td>Pre-existing coronary artery disease&lt;sup&gt;59&lt;/sup&gt;</td>
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<td>Hypercarbia on extubation&lt;sup&gt;59&lt;/sup&gt;</td>
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<td>Mainstem intubation&lt;sup&gt;30-34,36,38&lt;/sup&gt;</td>
<td>Not listed</td>
<td>Steep Trendelenburg position</td>
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<td>Pulmonary oedema&lt;sup&gt;51&lt;/sup&gt;</td>
<td>Case report</td>
<td>Prolonged pneumoperitoneum and intra-abdominal pressures of 20 mm Hg&lt;sup&gt;1&lt;/sup&gt;</td>
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<td>Aspiration&lt;sup&gt;19,63&lt;/sup&gt;</td>
<td>6.3–15%</td>
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<td>Atelectasis&lt;sup&gt;55,59&lt;/sup&gt;</td>
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<td>Pneumoperitoneum causing exaggerated superior ascension of the diaphragm and decreasing FRC&lt;sup&gt;55,59&lt;/sup&gt;</td>
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<td>Pneumothorax</td>
<td>One case report in RALP patient&lt;sup&gt;66&lt;/sup&gt;</td>
<td>Theoretically caused by changes in lung compliance as a result of pneumoperitoneum and steep Trendelenburg&lt;sup&gt;6&lt;/sup&gt;</td>
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<td>Acute kidney injury&lt;sup&gt;22,72,73&lt;/sup&gt;</td>
<td>0.4–5.8%</td>
<td>Increased intra-abdominal pressure with pneumoperitoneum causes increased renal vascular resistance and decreased renal blood flow&lt;sup&gt;60,72&lt;/sup&gt;</td>
<td>Aggressive fluid therapy titrated to urine output &gt; 200 mL h&lt;sup&gt;-1&lt;/sup&gt;&lt;sup&gt;72&lt;/sup&gt;</td>
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<td>(Serum Creatinine increase ≥0.3 mg dl&lt;sup&gt;-1&lt;/sup&gt; or ≥ 1.5-fold from baseline)</td>
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<td>Or (Urine Output &lt;0.5 mL&lt;sup&gt;-1&lt;/sup&gt; kg&lt;sup&gt;-1&lt;/sup&gt; for &gt;6h)</td>
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<td></td>
<td>Oliguria&lt;sup&gt;10&lt;/sup&gt;</td>
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<td>Direct mechanical compression because of carbon dioxide insufflation&lt;sup&gt;20&lt;/sup&gt;</td>
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<td>Case report</td>
<td>Pneumoperitoneum with insufflation pressures of 14 mm Hg\textsuperscript{10, 74}</td>
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<td>Vascular</td>
<td>Gas embolism\textsuperscript{7, 75–78}</td>
<td>0–100%</td>
<td>Pneumoperitoneum\textsuperscript{75}</td>
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<td>Deep vein thrombosis\textsuperscript{92, 79–80}</td>
<td>0.5–0.6%</td>
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<td>Reposition the lower extremities every 2 h\textsuperscript{72}</td>
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<td>Compartment syndrome\textsuperscript{22, 72, 82–86, 87–90}</td>
<td>0.03–0.3%</td>
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<td>Avoid constant compression (from stockings or wraps) in patients in lithotomy position for a prolonged period of time\textsuperscript{72}</td>
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<td>Rhabdomyolysis\textsuperscript{14, 26, 72, 91, 93}</td>
<td>0.67–0.95%\textsuperscript{63, 95}</td>
<td>Compartment syndrome\textsuperscript{2, 91}</td>
<td>Increased vigilance during patient positioning\textsuperscript{72, 93}</td>
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<td>Musculoskeletal/</td>
<td>Digit injury\textsuperscript{71}</td>
<td>6.30%</td>
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<td>Integumentary</td>
<td>Cervical and lumbar strain\textsuperscript{26}</td>
<td>Case report</td>
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<td>Decompression of stomach by oro/naso-pharyngeal tube, and keeping the patient’s face visible during surgery\textsuperscript{72}</td>
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<td>Oral ulcerations and conjunctival burns\textsuperscript{91}</td>
<td>Not listed</td>
<td>Steep Trendelenburg causing reflux of stomach acid onto face\textsuperscript{79}</td>
<td>Prolonged time spent in steep Trendelenburg\textsuperscript{91, 93}</td>
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<td>Contusions and ecchymoses\textsuperscript{13}</td>
<td>0.36%</td>
<td>Prolonged time in Trendelenburg leading to vascular stasis\textsuperscript{13}</td>
<td>Transport from OR table to stretcher\textsuperscript{13}</td>
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<td>Pressure lesions\textsuperscript{91}</td>
<td>35%</td>
<td>Overextension of patients in supine position\textsuperscript{72}</td>
<td>Dedicate particular care to the vacuum mattress in the gluteal region with additional padding\textsuperscript{82}</td>
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<td>Oedema</td>
<td>Subcutaneous emphysema\textsuperscript{5, 61, 14, 23}</td>
<td>0.3–3.3%\textsuperscript{57, 59, 65, 94, 95, 98}</td>
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<tr>
<td></td>
<td>Chemosis and conjunctival oedema\textsuperscript{6}</td>
<td>43.8%\textsuperscript{63}</td>
<td>Operative time &gt; 200 min\textsuperscript{74}</td>
<td>Not listed</td>
</tr>
<tr>
<td></td>
<td>Airway oedema\textsuperscript{5, 6, 10, 14–16, 18, 19, 23, 26, 38}</td>
<td>0.7–26%\textsuperscript{57, 58, 103–104}</td>
<td>EtCO2 &gt; 5.3 kPa\textsuperscript{26}</td>
<td>Use of more than 6 surgical ports\textsuperscript{74}</td>
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<td></td>
<td></td>
<td></td>
<td>Use of more than 6 surgical ports\textsuperscript{74}</td>
<td>Steep Trendelenburg\textsuperscript{15, 102}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Abdominal insufflation of CO2\textsuperscript{15, 102}</td>
<td>Pneumoperitoneum causing venous outflow obstruction in steep Trendelenburg\textsuperscript{15, 19, 98, 108}</td>
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</table>
position, with resultant decline in pulse oximetry saturation reading that resolved with withdrawal of the tracheal tube and no noticeable sequelae.59 10 14 16 30

Pulmonary oedema

A single case report described episodes of pulmonary oedema in a patient undergoing a RALP with no prior reports found in the literature.61 The patient developed pulmonary oedema requiring reintubation and received therapy with mechanical ventilation and furosemide with no prolonged sequelae described.61

Aspiration

Overt witnessed aspiration historically has a low reported incidence of 0.01-0.04% in general anaesthetic cases and smaller studies indicating a potential of 7-8% incidence of silent or subclinical regurgitations.62 Regurgitation events with concern for subclinical aspiration were reported with a similar incidence in two small studies, with an incidence of 6.3% (16 patients) and 15% (53 patients) in each study respectively, with no reports of a major aspiration event.60 63 The steep Trendelenburg position required for most cases is thought to increase the likelihood of regurgitation occurrence.64

Atelectasis

The combination of prolonged Trendelenburg position and abdominal insufflation results in an increased incidence of atelectasis, as a result of an exaggerated superior ascension of the diaphragm, because of pneumoperitoneum.59 65 The increased intra-abdominal pressure decreases functional residual capacity to the point that it approaches closing volume, resulting in increased atelectasis formation.59 65 No severe complications were directly linked to atelectasis in any of the studies reviewed, but it was implicated in reports of gradual desaturation.

Pneumothorax

A single case report described an instance of pneumothorax during a RALP, that was discovered incidentally on postoperative chest x-ray without significant clinical signs during the case.66 One theorized mechanism is because of changes in lung compliance during the combination of insufflation and steep Trendelenburg position.67

Renal

Complications involving the renal and collecting system were described in four review articles, six retrospective analyses, and one prospective animal study. Complications ranged from minor increases in creatinine to acute kidney injury (AKI).

Acute kidney injury

The incidence of renal injury as it relates to open vs laparoscopic vs robotic technique is controversial. Eleven papers mentioned AKI as a complication with varying degrees of severity and morbidity. Three studies specifically examined the incidence of AKI across the differing techniques and included analysis of diagnostic studies.68–70 AKI occurred in these three studies conforming to the acute kidney injury network stage-1 criteria regarding increase in serum creatinine (either absolute increase of \( \geq 0.3 \text{mg} \cdot \text{dL}^{-1} \) or \( >1.5\)-fold increase from baseline), or decrease in urine output (<0.5 mL kg\(^{-1}\) h\(^{-1}\) for >6 h) with a reported incidence of 5.5-6.5% across robotic cases.59–70 Among the studies examined there was no clear relationship regarding the incidence of AKI with surgical technique, with some studies finding a lowered incidence in robotic cases, that was thought to relate to decreased blood loss and blood transfusions administered.68 70 One paper mentioned a total of 17 in 293 cases (5.8%) without reference to specific criteria.22 The proposed aetiology was an increase in intra-abdominal pressure, resulting in an increased renal vascular resistance with consequent decrease in creatinine clearance.65 Incidence of urogenital events focusing on kidney injury was reported in one retrospective study as 0.4% and noted acute tubular necrosis as a presumptive aetiology as a result of low blood flow.71 This was considered to be more significant in the elderly, who may not possess the reserve to recover their renal function postoperatively as seen in younger subjects.65 One case involved a non-oliguric renal failure, possibly because of rhabdomyolysis from compartment syndrome.72 A suggested preventative strategy was aggressive fluid therapy titrated to a urine output of >200 mL h\(^{-1}\).72 Likely aetiologies in robotic cases include the reduction in renal blood flow seen with insufflation pressures around 15 mm Hg.73

Oliguria

Oliguria with no clinical sequelae was described in two papers with the theorized aetiology being renal compression.9 10

Gastrointestinal and hepatobiliary complications

Few complications were described relating to the gastrointestinal system and only one report involved the liver. There were no specific complications associated with robotic cases, but the lack of tactile feedback was theorized as a possible risk for surgical injuries.64

Hepatobiliary

The review yielded one case report of acute liver injury that was ultimately believed to be as a result of ischaemia and vascular congestion, relating to insufflation pressures of 14 mm Hg obstructing portal blood flow.10 14

Vascular complications

Among vascular complications reported in patients undergoing procedures, lower extremity compartment syndrome was the most common, followed by surgical bleeding necessitating transfusion and postoperative deep vein thrombosis.

Gas embolism

Arterial gas embolism was described in two articles, with one case that presented as a pure motor quadriplegia that was subsequently treated with a steroid bolus and hyperbaric oxygen.9 77 No long-term sequelae were observed.

Venous gas embolisms (VGEs) were encountered more commonly in the literature. The incidence of VGEs in abdominopelvic laparoscopic procedures ranged from seven-100% in individual studies; however, no studies reviewed reported haemodynamic consequences to even “severe” VGEs.76–78 One prospective study (51 subjects) directly evaluated the incidence of VGE between open vs RALP and demonstrated a lower incidence of VGE in the robotic group compared with open (38 vs
Deep vein thrombosis (DVT)

The incidence of DVT was reported as 0.5-0.6% in robotic prostatectomy patients, compared with a 0.0-0.5% in laparoscopic prostatectomy patients in papers where incidence was reported.27 79 80 The majority of literature referencing DVT incidence focused on prostatectomies and did not demonstrate the surgical technique (open vs laparoscopic vs robotic) to have a significant effect on the incidence of DVT.27 81 82 A retrospective study of robotic nephrectomy patients demonstrated a pulmonary embolus incidence of 1.3% postoperatively.83

Lower extremity compartment syndrome

Lower extremity compartment syndrome was reported in 14 papers with no mortalities. Lower extremity compartment syndrome has an incidence of 0.028% described across abdominal and pelvic surgeries.72 A multicentre study examining 3,110 RALPs demonstrated an incidence of 0.28% regarding compartment syndrome, with seven cases undergoing subsequent fasciectomy and no mortalities, rhabdomyolysis, or AKI reported.92 The cases described used a spectrum of therapies ranging from fluid resuscitation and analgesic skin grafting, and no mortalities were reported.93 94 95 96 Significantly less common was gluteal compartment syndrome, which was reported in two cases. These patients underwent subsequent bilateral fasciectomy without permanent sequelae.92 93 Changes in compartment pressure can occur from elevating the legs and calf compression in the lithotomy position combined with decreased lower extremity blood flow, exacerbated by the Trendelenburg position.92 89 90

Rhabdomyolysis

Most commonly occurring in association with compartment syndromes, rhabdomyolysis was reported as a complication in eight papers, in the setting of both upper and lower extremity compartment syndromes.72 91 The overall incidence reported in the literature ranged from 0.67% to 0.95% in retrospective studies.81 90 One prospective study monitored serum creatine kinase assays at timed intervals on 60 patients undergoing RALP and demonstrated creatine kinase concentrations >5,000U L^-1 in ten patients, who were then treated with hypervolaemic fluid therapy and no development of postoperative renal injury.93 The authors noted that positioning injuries were implicated in all cases of elevated creatine kinase and were most commonly seen in the gluteal area, and subsequently recommended special care in positioning to provide adequate gluteal cushioning.93 Additional reported risk factors were high BMI, operative time, and time in Trendelenburg position, with respect to elevations in serum creatine kinase concentrations.91 93 Hypervolaemic fluid therapy was the most commonly encountered treatment strategy, with the targeted goal of urine output levels ranging from 60 ml h^-1 to 200 ml h^-1.93 94 The majority of studies noted no long-term sequelae and minimal delays to patient discharge in patients reported rhabdomyolysis.81 92 The most common morbidity associated with rhabdomyolysis in the reviewed literature was AKI, with a prolonged hospital course requiring some form of renal replacement therapy, in one noted instance it required a 90-day hospitalization.72 92 Preventative strategies focused mainly on vigilance during patient positioning and an emphasis on proper cushioning and pressure relief for the gluteal area, and adequate hydration in patients with suspected rhabdomyolysis.72 93

Musculoskeletal and integumentary complications

Complications including superficial trauma, non-neuropathic positioning injuries, oedema, and connective tissue injuries were grouped into a combination of musculoskeletal and integumentary complications.

Trauma

Digit injuries and resultant arthralgias were reported in one prospective study, with an incidence of 16 in 254.94 95 Cervical and lumbar strain were reported in a single case report with no long term sequelae.96 Other studies reported incidence of oral ulcerations and conjunctival burns.97 Contusions of the head, left thigh, and flank were reported in three patients who underwent robotic gynaecologic surgery.91 Different degrees of pressure lesions were reported in one paper with the most common being redness of the gluteal region, followed by induration and increased erythema, and one case with a burn and accompanying leg weakness and paresthesia.93 The use of a vacuum mattress in the gluteal region was recommended as a way to prevent pressure-induced sores in prolonged procedures.93 Overall, no distinction was made between robotic and laparoscopic procedures in the degree of risk of soft tissue injury; however, longer operative times did seem to increase this risk.

Subcutaneous emphysema

Ten papers reported subcutaneous emphysema as a complication occurring during robotic cases.9 11 14 23 37 59 65 94 95 Five of the ten papers reported extension of CO2 into the mediastinum, resulting in a pneumomediastinum with no reported long term complications.9 11 14 15 96 Additionally, major subcutaneous emphysema was reported in a case series of three patients who underwent robotic sacrocolpopexy and was believed to have an association with a valveless trocar system that was used in all three cases.97 The reported incidence is a range of 0.3-3.9%.94 98 Risk factors reported included an operative time > 200 min, a measured end tidal CO2 > 5.3 kPa and the use of more than five separate surgical ports.94 97 98 A twenty-seven patient prospective study conducted on patients undergoing laparoscopic cholecystectomy, demonstrated subcutaneous emphysema in 56% of postoperative patients with no clinical sequelae.99 Laparoscopic literature demonstrated an incidence of 0.3-2.3%, which fell within the range observed for robotic cases.100 101 Treatment strategies included return to supine position with hyperventilation of the pCO2 back to normal range, and no permanent sequelae were observed.

Oedema

Clinically significant oedema of various body regions was reported in eight papers.9 31 35 23 28 63 107 109 The incidence of head and neck oedema was reported to be 12.5%.91 Such oedema was severe enough to delay extubation until postoperative day two.
in one case,28 and has been reported to be severe enough to necessitate reintubation in 0.7% of cases.6 Chemosis and conjunctival oedema are considered common effects of prolonged steep Trendelenburg, with no demonstrated clinical consequence and had an incidence of 33–43.8%.15 19 63 102 However, retrospective studies report an association between presence of chemosis and the development of increased upper airway resistance. To that effect, the degree of chemosis has been used as a warning sign of possible airway oedema.4 15 63

Airway oedema was the most prominent type observed, making up 16 of the 28 articles reporting oedema as a complication.5 19 28 38 57 58 63 102–104 Overall, airway oedema was reported to have an incidence ranging from 0.7–26% in the articles reviewed.56 63 103 105 Reported incidences of specific aspects of airway oedema after prolonged Trendelenburg position for RAS in one paper included 15.1% for glossal oedema, 13.2% for generalized head and neck oedema, hyperaemia in 5.7%, and “loud inspirations” in 13.2%.15 The most commonly reported complication resulting from airway oedema was the need for reintubation,6 19 72 102 followed by delayed extubation (3.5% incidence in one prospective study105), and ventilator assistance in patients where oedema was recognized before extubation.19 105 Some studies have advised an airway leak test; however, the sensitivity and specificity of this test is unclear. One small prospective trial demonstrated a sensitivity of 75% and a specificity of 59%, but a negative predictive value >90%.26 106 107 Others have less feasibly advised the addition of laryngeal fiberoscopy to evaluate the level of oedema.105 Treatment for airway oedema outside of delayed extubation and mechanical ventilation included head up position, CPAP, a nasopharyngeal airway,108 and a combination of head up extubation at the end of the case followed by diuretics.19 There was no significant data available for comparison from the laparoscopic literature, but one could surmise that upper body oedema would likely be worsened in robotic cases, because of the degree of Trendelenburg required and the propensity for longer surgery times.

Conclusions

Robotic surgery is a continuously evolving technique of surgery that is growing in prevalence and use. Our review yielded a number of complications that providers should be aware of when providing anaesthetic and perioperative care for these patients (Tables 1 and 2). As with any new technique, there is a learning curve for both the surgeon and the anaesthetist; therefore, proper training by and observation of experienced providers might decrease the incidence of these complications.109 Consideration of appropriate alternative therapies, in patients with possible relative contraindications, should be discussed amongst the patient and their providers with the goal of choosing a safe and efficacious therapy. With the exceptions of generally prolonged surgical times and rare cases of significant blood loss, there were no direct complications related to the robot itself or changes in aspects of the procedure. The most commonly observed complications were peripheral neuropathies, followed by corneal abrasions, vascular complications, and the effects of oedema both generalized and system specific.

Ultimately, the combination of Trendelenburg position with insufflation and longer procedural times results in a necessity for a higher level of vigilance and planning that often goes hand-in-hand with longer cases. Positioning must be precise and take into account not only maintaining adequate exposure for docking of the robot, but also maintaining patient safety and minimizing risk for positioning injury. A few specific risk factors consistently emerged from review of the literature, including obesity and ~240 min operative time. Additionally, a pre-existing neurologic condition was a notable risk factor for positioning injuries. Because of these considerations, it is imperative that the anaesthetist be intimately involved in the specifics of patient positioning and of the use of assistive devices such as beanbags and shoulder bolsters. Inadequate attention to positioning and lack of use of assistive devices was directly attributed to positioning injuries in a number of papers. The prolonged time spent in Trendelenburg positions leaves patients at increased risk for oedema formation secondary to venous engorgement, and more restrictive fluid administration was suggested for reducing the degree of oedema. Corneal abrasions were found to result from a combination of proptosis and poor lid closing as a result of oedema, and direct injury from hanging wires and drapes. Increased care when dealing with the head and neck region of the patient, along with proper eye protection is essential, especially with an ever-increasing number of drapes and warmers that prevent easy visualization of patients. Overall, comparing robotic-assisted cases to purely laparoscopic cases did not reveal complications unique to robotic surgery. However, the increased surgical times seen in robotic-assisted surgery do make these cases a higher-risk variant of laparoscopic procedures, although this was not consistently validated.

As with most aspects of patient care, the best way to address these issues and reduce the incidence of such complications is to balance these competing factors as best we can. Restrictive fluid administration can help reduce oedema formation, but can also result in increased incidence of acute kidney injury. Increased use of assistive devices and special attention to patient positioning can help prevent injuries, but also adds to the duration of already prolonged operative times. Ultimately, what matters most is a constant vigilance throughout the perioperative period. Preoperative evaluation for risk factors and adjustment of the anaesthetic plan accordingly, intraoperative attention to vital signs and proper patient positioning, and postoperative surveillance for adverse events are essential in providing excellent patient care and reducing the complications associated with robotic surgery.

Authors’ contributions

Study design/planning: D.M.G.
Study conduct: D.A.M., L.N.B, D.M.G.
Data analysis: D.A.M., L.N.B, D.M.G.
Writing paper: all authors
Revising paper: all authors

Declaration of interest

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