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Title

Exploring public opinion about liability and responsibility in surgical robotics with the iRobotSurgeon survey

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ABSTRACT

As robotic systems become more autonomous, it gets less straightforward to determine liability when humans are harmed. This is an important emerging challenge, with legal implications, in the field of surgical robotic systems. The iRobotSurgeon survey (www.iRobotSurgeon.com) explores public opinions about questions of responsibility and liability in the area of surgical robotics.

MAIN TEXT

Advances in machine learning have enabled the development of increasingly autonomous robotic systems which can capture sensor information about their environment, make decisions independently of human supervision, and learn from experience. The increased autonomy of robots poses a legal challenge in determining liability. This is a particularly acute issue for surgical robotic systems, due to the inherent risks and potential for harm in surgery. We believe there is a need to explore public attitudes to these questions and have developed the iRobotSurgeon Survey (www.iRobotSurgeon.com). The survey presents five hypothetical scenarios **(Table 1)** where the patient comes to harm and the respondent needs to determine who they feel is mostly responsible: the surgeon, the robot manufacturer, the hospital, or another party **(Figure 1)**.

Classification of surgical robotic systems

A six-level classification system for autonomy exists for surgical robotic systems, based on the level of involvement of the operator[1]: **Level 0 (No autonomy**): these include systems under complete command of the operator which include tele-operated robotic systems; **Level 1 (Robot assistance)**: the robot provides guidance to the operator who maintains control of the system. This include smart devices (such as intelligent endoscopes) that provide feedback on important anatomical structures; **Level 2 (Task autonomy)**: the robotic system is autonomous for specific tasks such as suturing skin which are initiated by the operator; **Level 3 (Conditional autonomy)**: the system generates task strategies that the operator then selects and the robot can perform without close oversight; **Level 4 (High autonomy)**: the robot can make medical decisions but under the supervision of a qualified doctor; **Level 5 (Full autonomy)**: the robotic system is able to perform an entire surgical procedure without supervision. Other classification systems have also been proposed such as based on the level of surgeon-robot interaction[2].

For the purpose of the iRobotSurgeon survey, we put forward a simple three stage classification system designed to be easy to understand for the public but also encompass the full range of robotic systems:

1) **Human-controlled robotic system**: these systems include robots that are completely controlled by the surgeon who can sometimes be in a different place to the surgery (telesurgical robot). Other robots are integrated within handheld instruments and may, for example, warn the doctor when they are operating close to important parts of the body (handheld robot).
2) **Robot-assisted system**: these systems helps the surgeon carry out specific tasks. This could be stitching wounds, inserting a needle into the brain, or inserting a screw to fix a broken bone. The surgeon is present and supervises the robot.
3) **Autonomous robotic system**: this system can conduct entire surgical procedures with minimal or no human supervision.

Current state of surgical robotic systems and the legal landscape

There are a number of human-controlled robotic systems on the market, of which the DaVinci system (Intuitive Surgical, California, USA) is the best known. These systems are used for a range of different operations including prostatectomy and hysterectomy. They are under complete control of the surgeon who are either within the operating room or tele-controlling the system in another location. In recent years, more advanced systems have been released including robot-assisted endoscopes that help surgeons navigate the gut or robotic arms that help direct the insertion of pedicle screws into the spine[3,4]. Robot-assisted systems that can undertake specific tasks are under development including those capable of drilling the base of the skull or undertaking autonomous suturing of soft tissues[5]. Given the rapid pace of progress, a fully autonomous 'Robot Surgeon' may emerge over the professional lifetimes of currently practising surgeons. [**author: this seems to contradict the 'science fiction' statement – if we can expect fully autonomous robot surgeons in the next 20-30 years?]**

There is legal precedent with harm to individuals caused by non-autonomous robots, mainly in the manufacturing industry[6]. These cases have typically been determined by looking at whether the robot was defective in some way (product liability), whether there was culpability on behalf of the employer (through inadequate training, for example) or if the employee placed themselves in harm's way by not abiding by safety guidelines. In *Jones vs W+M Automation Inc*, an employee was struck by a robotic gantry causing a head injury[7]. The robotic system had been installed by General Motors without an interlock system which stopped the machine when employees were within the danger zone of the machine. The plaintiff sued the robot manufacturer for negligence, but the court held the summary judgement under the 'component part' doctrine which states that the manufacturer of a non-defective component cannot be held liable if this component is installed into another defective product. Within autonomous robotics, the 'component part' doctrine indicates that if a robotic system were being controlled by an algorithm developed by a third party, liability may lie with the software developers if the robotic hardware was not defective.

[author: is this a likely scenario, that robots in surgery and software come from different parties?]

In Tort law, negligence is the legal term used to describe behaviour that leads to unreasonable risk or harm to an individual or property[8]. A negligent action is one that departs from what a 'reasonably prudent' person would not do. The difficulty in using this standard with autonomous robots is defining what is 'reasonably prudent', particularly with robotic systems that learn and develop new techniques through machine learning algorithms. One of the key parts of negligent liability is foreseeability; as these systems move further away from predetermined instructions, they are likely to display unforeseen behaviours which poses challenging dilemmas to the issue of negligent liability. Under current legal frameworks, robots, even if autonomous, cannot be held liable for any damage or harm it causes[9].

Parallels with autonomous vehicles and the moral crumple zone

A good parallel to consider is that of liability with autonomous vehicles. Surveys of public opinion have found concerns about the issue of determining liability with autonomous vehicles[10]. This is unsurprising given the incremental shift of control and decision-making away from the human driver and towards the robotic system. Jeffrey Gurney suggests a simple model, where in most cases of accidents while a vehicle is in autonomous mode, the manufacturer should be held liable. In the case where the driver had some aspect of control, and could have prevented the collision, then they should be held liable[11]. There is, however, concern that human actors may shoulder a disproportionate burden of responsibility in the event of damages involving complex automated systems. Madeleine

Elish dubbed this the ‘Moral Crumple Zone’ to describe humans bearing the brunt of legal responsibility in complex human-robot systems which they have limited control over[12]. Elish uses, among others, the example of the crash of Air France Flight 447 which led to the death of all 228 passengers on board. In this tragic accident, a technical failure set off a chain of events that led to the crash. A sensor malfunction led to a shift from autopilot to a human-controlled flight mode. A viscous cycle of increasing flight crew panic and feedback mechanism alarms led to the crash. An analysis concluded that the crash was multi-factorial including both technical failures alongside the human factors of loss of cognitive control and communication breakdown. However, the media narrative focused on the human factors and the role of the pilots in the crash.

The iRobotSurgeon Survey

There have been efforts to ascertain public expectation and attitudes to the difficult ethical and moral dilemmas in self driving cars[13]. The iRobotSurgeon Survey (www.iRobotSurgeon.com) aims to explore public opinion towards the issue of liability with robotic surgical systems. The survey has been developed through an iterative approach with input from clinicians, patients, ethicists, and public engagement professionals. The scenarios (Table 1) are designed not to have a clear culpable actor and aim to get the respondent to provide an answer based upon their instinct on who they feel shoulders the most responsibility. The survey aims to understand whether there is a perceived onus of responsibility still placed on the human surgeon even as robotic systems become increasingly autonomous. Coupled to this, we aim to determine whether there are geographical differences in attitudes towards liability that may be underpin by cultural ethical variation. Collectively, we hope the survey will shed light onto this thorny issue and provide useful insights for regulators and policy makers, as well as direct future research.

Author Contributions

AABJ: conceived idea for article, lead writing of manuscript, reviewed and agreed on final manuscript

AMAJ: contributed to manuscript writing, reviewed and agreed on final manuscript

HJM: conceived idea for article, contributed to manuscript writing, reviewed and agreed on final manuscript

Competing Interests statement

The authors have no conflicts of interest to declare

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TABLE

Case 1	A world-leading heart surgeon (Surgeon A) operates remotely on a patient in a different country using a telesurgical system. During the operation, a major blood vessel is cut open. Surgeon A cannot stop the bleeding using the robot. A support surgeon in the operating room (Surgeon B) steps in and controls the bleeding. Despite this, the patient loses blood and is harmed.
Case 2	A surgeon uses a robotic telescope while operating on a patient. Its purpose is to inform the surgeon about the location of an important blood vessel. The surgeon plans to use this information and their knowledge of anatomy to perform the operation safely. During surgery, the robot malfunctions. It gives the surgeon inaccurate information. The blood vessel is cut and the patient is harmed.
Case 3	A patient has an operation where screws are inserted into the bone of their spine by a robot. A surgeon pre-programmes the robot with directions for the screws to be fixed. The robot then carries out the operation independently as the surgeon supervises. After the operation, the patient wakes up and cannot move their legs. A follow-up scan shows a screw has been put into the wrong place, causing spinal injury. An investigation finds the surgeon had correctly programmed the robot, directing the screws away from the spinal cord.
Case 4	A surgeon recommends a hip replacement operation for a patient. A robot carries out the surgery independently and the surgeon, who supervises,

	does not intervene. The operation is technically successful and follow-up scans show that the hip was repaired as planned. However, the patient is left with worse hip pain which badly affects their quality of life.
Case 5	An intelligent robot develops a new surgical technique to treat pancreatic cancer. Research through clinical trials shows the new technique is better than existing treatments. A surgeon refers a patient with newly diagnosed pancreatic cancer for the procedure. During the operation, the robot cannot manage a complication in the surgery and the patient is harmed.

Table 1: Five scenarios describing robotic surgical systems of increasing autonomy

FIGURES

Figure 1: iRobotSurgeon survey poses five scenarios to respondents and asks them to decide who they feel is most liable: the surgeon, robot manufacturer, hospital or another party