Technoleg Iechyd Cymru
Health Technology Wales

Evidence Appraisal Report

Robot-assisted thoracic surgery

1. Purpose of the evidence appraisal report

This report aims to identify and summarise evidence that addresses the following question: Compared to open surgery or video-assisted thoracoscopic surgery, what is the clinical and cost effectiveness of robotic surgery for lung resection or anterior mediastinal mass excision?

Evidence Appraisal Reports are rapid systematic literature searches of published evidence to identify the best clinical and economic evidence on health technologies. Researchers critically evaluate this evidence. The draft Evidence Appraisal Report is reviewed by experts and by Health Technology Wales multidisciplinary advisory groups before publication.

2. Health problem

Thoracic surgery is concerned with conditions of the lungs, chest wall and diaphragm and is generally dominated by treatment of malignant disease: either lung cancer or, more rarely, tumours of the mediastinum, thymus or thorax. In 2017, there were 2,179 cases of lung cancer recorded in Wales (Royal College of Physicians 2019). Approximately 2% of patients diagnosed with small cell lung cancer (SCLC) and 16% of patients diagnosed with non-small cell lung cancer (NSCLC) undergo surgery to remove their primary tumour (Cancer Research UK 2018). Depending on the location, size, and stage of the tumour, surgery will consist of either removal of one lobe of the lung (lobectomy), removal of part of one or more lobes (wedge resection), removal of lung tissue as well as the associated airways and blood supply (segmentectomy), or occasionally removal of the entire lung (pneumonectomy) (EUnetHTA 2019).

The main indication for thoracic surgery is lung cancer. Symptoms for this disease do not often occur initially, so the majority of patients with lung cancer present with advanced disease. The cornerstone of treatment for potentially resectable lung cancer is surgical removal of the tumour. This can be done through either standard open thoracotomy, or a video-assisted thoracoscopic surgery (VATS) procedure. The European Society for Medical Oncology guidelines recommend that surgery is offered to all patients with stage I and II NSCLC, and specifically that VATS should be the approach of choice in stage 1 tumours. However this recommendation is only graded as level V (evidence from studies without control group, case reports, or expert opinion) and C (Insufficient evidence for efficacy). The NICE guideline *Lung cancer: diagnosis and management* recommends offering surgery (either open or thoracoscopic) to people with NSCLC who are well enough and for whom treatment with curative intent is suitable, and that surgery should be considered in people with early stage SCLC.

The treatment used for mediastinal tumours depends on the type of tumour and its location with thymic cancers and neurogenic tumours treated surgically. There is no recognised clinical staging system, although a system has been proposed (Detterbeck et al. 2014). The treatment strategy depends on whether it is possible to resect the tumour upfront or not. Minimally invasive surgery, including robotic approaches, is considered to be an option for presumed stage I and possibly stage II tumours (Girard et al. 2015).

3. Health technology

Robotic surgery is a form of minimally-invasive surgery whereby the instruments of the robotic system are controlled by a telemanipulator, which is a device for transmitting hand and finger movements to a remote robotic device, allowing the consequent manipulation of objects. The robot allows a higher degree of dexterity compared to the laparoscopic approach, which allows surgeons to operate in very tight spaces in the body (which would otherwise only be accessible through open surgery). Robot-assisted surgical systems in development include single-arm units designed to perform single-port surgery—also called single-incision surgery—and multi-arm systems typically used for multi-port, or multi-incision, procedures. Some manufacturers developing single-port systems designed to access the body via natural orifices describe their systems as allowing "scarless" surgery. A comparative potential benefit of multi-arm systems over single-arm systems is the ability to perform a broader range of surgical procedures due to their allowing for a larger surgical field with corresponding greater visualization of the surgical field and their versatility in positioning instruments, thus increasing surgeons' ability to access more anatomy with those instruments. Generally, single-port systems may be preferred for less complex surgery, whereas multi-port systems may be preferred for more technically challenging procedures.

The alternatives to robot-assisted thoracic surgery are other forms of minimally invasive surgery (laparoscopic surgery or VATS), or open surgery. Open surgery is a type of surgery in which an incision is made using a scalpel to fully expose the area of the body on which the operation will be performed. The surgeon inserts the instruments through the incision and conducts the surgery.

Minimally invasive approaches use an incision that is smaller than the usual open incision. It is also known as keyhole surgery. One incision is required to place the laparoscope (a viewing telescope attached to a camera and light source) that allows the surgeon to see the operative area on the video monitor; two or three other small incisions are made to place the surgical instruments. In laparoscopic surgery, the surgeon performs the procedure holding rigid instruments and views the surgical area through an endoscopic camera that is projected onto a monitor. In some cases, a surgery may start out as a minimally invasive procedure, but then convert to the larger open incision procedure if the surgeon needs more flexibility of movement or due to an adverse event. VATS is a type of minimally invasive surgery, comparable to laparoscopy, which does not require the formal thoracotomy incisions, especially the cuts through the ribs or breastbone (sternum). VATS is principally performed in the management of pulmonary, mediastinal, and pleural pathology. The instrumentation for VATS includes the use of a camera-linked optic scope and either conventional thoracic instruments or laparoscopic instruments (EUnetHTA 2019).

Between 2010 and 2015 the proportion of lung cancer surgery reported as undertaken by VATS in the UK and Ireland increased from 13.3% to 38.0% (The Society for Cardiothoracic Surgery in Great Britain & Ireland 2018). No more recent data is available, so the present proportion of thoracic surgery procedures conducted using open and minimally invasive techniques is not known.

There are four known manufacturers of commercially available robotic systems to aid in thoracic surgical procedures. These companies are Intuitive Surgical, Inc., Surgica Robotica S.p.A., TransEnterix and Freehand 2010 Ltd.

3.1. Intuitive Surgical: da Vinci®:

Intuitive Surgical currently offers four types of surgical systems, all of which are CE marked: da Vinci® Si, X, SP and Xi. Each system is composed of a master console and a mobile platform with boom-mounted robotic arms. The surgeon operates at a console (typically in the same room as the patient) while viewing a high definition 3D image from inside the patient's body to see anatomical structures in natural colours. The patient-side cart is a surgical robotic assistant, with multiple arms and detachable instruments, mounted on a cart that can be positioned at the surgical site. The system translates the surgeon's hand, wrist and finger movements into real-time movements of the wristed surgical instruments. Replaceable wristed instruments (EndoWrist®) are attached to the arms of the robot. The attached instruments have seven degrees of motion and every single instrument available is designed for a specific task (e.g. clamping, cutting, coagulating, dissecting, suturing). Another part of the surgical system is the Vision Cart: positioned tableside, the system's central processing unit component includes accessory equipment, a surgical video system, and a viewing monitor for the operating team. It is equipped with a high-definition, 3D endoscope (flexible tube with a camera and light) and image processing equipment that provides images of the patient's anatomy. This 3D HD endoscope is inserted through one of the small incisions and is held in place by one of the robotic arms (EUnetHTA 2019).

3.2. Surgica Robotica: Surgenius:

Surgica Robotica, an Italian company, offers one system: Surgenius Beta, with the Surgenius Gamma also in development. The Surgenius Beta is able to cover the entire torso (four abdominal quadrants) and has CE mark approval. The robotic tools reach nine degrees of freedom for the surgeon. Presently the company is developing the Surgenius Gamma (EUnetHTA 2019).

3.3. TransEnterix: Senhance™ Surgical System:

TransEnterix®, an American company, provides the Senhance™ Surgical System. This is a console type robotic platform consisting of a remote control station unit, manipulator arms, and a connection node. The Senhance system is available in a 3- or 4-arm set up, with each arm individually mounted on its own cart. It was designed to require only a minimal learning curve with familiar laparoscopic motion, trocars and approach. The surgeon sits at a console and telemanipulates the surgical robot. Furthermore, the surgeon has the ability to simultaneously control multiple robotic arms, instruments and a camera. Due to its open platform strategy, the Senhance™ System is compatible with other laparoscopic devices. Moreover, the surgical system provides eye-tracking that is intended to allow vision control during surgical operations without repositioning the camera: this is an evolution of current visualization technologies, such as the da Vinci Surgical System's binocular display controlled by foot-operated switches. Another feature is the haptic feedback that provides force feedback: this tactile force feedback translates sensation from an instrument's distal end to the surgeon's hand, contrasting da Vinci's feedback, which is displayed visually rather than felt by the controller (EUnetHTA 2019).)

3.4. Freehand 2010 Ltd: Freehand v1.2

Freehand 2010 Ltd is a company located in the United Kingdom. The company offers a robotic camera arm for minimally invasive surgery: this system is composed of a lockable articulating arm, an electronic control box, and a robotic motion assembly unit. Mounted on railings around the operating table, the camera can be moved in three dimensions, controlled via operator head movements and laser-pointed guidance. To select the direction of movement, the operator moves his/her head in the desired direction; an LED arrow with the selected direction is then displayed. In order to initiate movement, a foot switch is pressed until the camera is in the desired location; releasing the switch terminates movement (EUnetHTA 2019).

4. Usage and Welsh context

The manufacturer of the da Vinci® surgical system reports that since 2007, more than 5 million minimally invasive procedures have been performed worldwide. The system is used in over 4,400 hospitals worldwide and there are more than 43,000 da Vinci trained surgeons. As of June 2019, TransEnterix reported to have installed 23 Senhance systems worldwide (the majority in Europe and the USA) where surgeons continue to gather clinical data, with a goal of expanding FDA-cleared indications in the United States in coming years. In August 2017, the company established its first Senhance training and surgical innovation centre in the United States at Florida Hospital (Orlando, FL, USA) to train U.S. surgical teams on its robotic technology (EUnetHTA 2019).

In Wales, at the time of writing (May 2019) there is one Da Vinci Xi robotic surgery system available, at University Hospital of Wales, Cardiff. In 2017, 378 people had surgery for their lung cancer in Wales, representing 17.3% of all lung cancer cases (Royal College of Physicians 2019). No exact numbers for the number of mediastinal surgery cases in Wales are available, but based on the Society for Cardiothoracic Surgery audit data (covering Great Britain and Ireland), it is estimated that approximately 40 people in Wales require mediastinal surgery each year (The Society for Cardiothoracic Surgery in Great Britain & Ireland 2018).

NHS England published their Clinical Commissioning Policy *Robotic assisted lung resection for primary lung cancer* in 2016. This states that NHS England will not routinely commission robotic assisted lung resection for primary lung cancer. The policy concluded that there was not enough evidence to make the treatment available at the time it was compiled (NHS England Specialised Commisioning 2016).

5. Evidence search methods

The Population-Intervention-Comparator-Outcomes framework for the evidence appraisal is summarised in Appendix 1. This was developed with input from the Health Technology Wales (HTW) Assessment Group and UK experts. One amendment was made to the protocol during the development of this report: following expert consultation on an early draft, nodal upstaging and lymph node yield were added as outcomes of interest.

Initial exploratory searches identified the existence of a Rapid Evidence Assessment (REA) by the European Network for Health Technology Assessment (EUnetHTA), assessing the use of robotic surgery in thoracic and visceral indications (REA OTCA14) (EUnetHTA 2019). This was published in June 2019; prior to this HTW were granted access to a pre-publication draft. This report was assessed using the EUnetHTA adaption toolkit, and information on the technology's use, clinical effectiveness, and safety was deemed suitable for adaptation within this assessment. REA OTCA14 covers relevant evidence published up to June 2018, and includes evidence from prospective controlled studies only. HTW conducted our own supplementary searches in May 2019 to identify more recently published prospective evidence, any suitable evidence from retrospective studies, and any evidence on the cost effectiveness of this intervention. This search was re-run on 9 July 2019 to identify any evidence published during the production of this report. The search strategy used is available on request.

6. Clinical effectiveness

In addition to EUnetHTA REA OTCA14, three other recent systematic reviews were identified that studied the clinical effectiveness of robot-assisted surgery compared to video-assisted and open surgery. One review focussed on thymectomy (O'Sullivan et al. 2019b); two focussed on lung resection (Ng et al. 2019, O'Sullivan et al. 2019a). The characteristics of the systematic reviews and the outcomes reported by each review are summarised in Appendix 3.

HTW also searched for relevant randomised trials or prospective non-randomised trials published subsequent to the last search date of EUnetHTA REA OCTA14, with the aim of updating the findings

of this report to include the most recent evidence. No randomised trials were identified, but three recent observational studies were identified: all studied the use of RATS for lobectomy; two compared RATS to VATS (Duclos et al. 2018, Worrell et al. 2019) and the third study compared RATS to VATS and open surgery (Nelson et al. 2019).

6.1. Clinical effectiveness outcomes

The following section lists the evidence identified for each relevant outcome. Table 1 summarises outcomes comparing RATS to open surgery; Table 2 summarises outcomes comparing RATS to VATS.

Table 1. Summary of all outcome data, robot-assisted thoracic surgery (RATS) vs open thoracic surgery

Outcome	Evidence source	Study and patient characteristics	Absolute effect	Relative effect (interpretation)
Mortality				
30-day mortality	O'Sullivan 2019a, meta-analysis of published systematic reviews and database studies	Lobectomy, any pathology. Five studies (all retrospective), 94,342 patients	139/13,923 (1.0%) deaths following RATS; 1,857/80,419 (2.3%) deaths following open surgery	OR 0.53, 95% CI 0.33–0.85, P = 0.008 (favours RATS)
Intraoperative mortality	EUnetHTA 2019, systematic review of prospective studies	Mediastinal mass excision, one study, 36 patients	Zero deaths in both groups	N/A
30 day mortality	O'Sullivan, 2019b, meta-analysis of observational studies	Thymectomy, six studies, 295 patients	Zero deaths in both groups	N/A
3 year survival	Nelson, 2019, prospective observational study	Lobectomy for NSCLC; one study; 530 patients	yp Stage 0-1: 89% vs 85% yp Stage 2: 71% vs 77% yp Stage 3: 72% vs 68%	No statistically significant difference between groups
Duration of hospital stay	EUnetHTA 2019, systematic review of prospective studies	Mediastinal mass resection, one study, 36 patients	Mean 9.6 days RATS; 11.8 days open	No statistically significant difference between groups
	O'Sullivan 2019a, meta-analysis of published systematic reviews and database studies	Lobectomy, any pathology. Five studies (all retrospective), 118,945 patients	N/R	Weighted mean difference -1.4 days, 95% CI -1.96 to -0.85, P < 0.00001, (favours RATS)
	Ng 2019, systematic review/meta-analysis	Lobectomy/NSCLC (stages I-III), two studies, 7,516 patients	N/R	Mean difference -0.82 days, 95% CI -1.07 to – 0.57; P < 0.0001 (favours RATS)
	O'Sullivan, 2019b, meta-analysis of observational studies	Thymectomy, 13 studies, 1,313 patients	N/R	Weighted mean difference −2.78 days, 95% CI: −3.22, −2.33, P<0.00001 (favours RATS)
Duration of surgery	O'Sullivan 2019a, meta-analysis of published	Lobectomy, any pathology, two studies (21,259 patients)	N/R	weighted mean difference 65.56 min, 95% CI 53.66–

Outcome	Evidence source	Study and patient characteristics	Absolute effect	Relative effect (interpretation)
	systematic reviews and database studies			77.46, P < 0.00001 (favours open)
	O'Sullivan, 2019b, meta-analysis of observational studies	Thymectomy, 12 studies, 774 patients	N/R	Weighted mean difference 6.73 min, 95% CI -21.2 to 34.7
Rate of complications/AEs				
Blood transfusion rates	O'Sullivan 2019a, meta-analysis of published systematic reviews and database studies	Lobectomy, any pathology, one study	0.9% vs 5.0% (intraoperative), p = 0.07; 0.9% vs 7.8% (postoperative), p = 0.002	N/R
Frequency of postoperative complications	EUnetHTA 2019, systematic review of prospective studies	Mediastinal mass resection, one study, 36 patients	3/14 (22%) and 2/22 (9%)	N/R; no significant difference between groups
	O'Sullivan, 2019b, meta-analysis of observational studies	Thymectomy, 13 studies, 824 patients	N/R	OR: 0.37; 95% CI: 0.22, 0.60, P<0.0001 (favours RATS)
	O'Sullivan, 2019b, meta-analysis of observational studies	Thymectomy, 6 studies, 190 patients	3 events recorded in each treatment arm	N/R
Rate of disease recurrence after surgery (follow up not specified)	EUnetHTA 2019, systematic review of prospective studies	Mediastinal mass resection, one study, 36 patients	1/22 vs 0/14 patients experienced recurrence	N/R
Positive surgical margins	O'Sullivan, 2019b, meta-analysis of observational studies	Thymectomy, nine studies, 2,701 patients	16/391 events vs 289/2310 events	Risk difference −0.04; 95% CI: −0.07, −0.01, P=0.01 (favours RATS)
Lymph node yield	O'Sullivan 2019a, meta-analysis of published systematic reviews and database studies	Lobectomy, any pathology, two studies, number of patients not reported	N/R	Standardised mean difference 0.09, 95% CI -0.09 to 0.27, P = 0.31
Quality of life (Measured by EORTC-QLQ-C30, 1 month follow up)	EUnetHTA 2019, systematic review of prospective studies	Mediastinal mass resection, one study, 36 patients	Deterioration of 1/10 QOL/symptom subscales vs deterioration of 5/10 subscales	N/R
Patient satisfaction	No evidence identified			

Outcome	Evidence source	Study and patient characteristics	Absolute effect	Relative effect (interpretation)
CI: confidence interval; N/R: not reported; NSCLC: non-squamous cell lung cancer; OR: odds ratio; QOL: quality of life; RATS: robot-assisted thoracic surgery				

Table 2. Summary of all outcome data, robot-assisted thoracic surgery (RATS) vs video-assisted thoracic surgery (VATS)

Outcome	Evidence source	Study and patient characteristics	Absolute effect	Relative effect (interpretation)
Mortality during surgery or in hospital	EUnetHTA 2019, systematic review of prospective studies	Lobectomy, three studies, 164 patients	Zero and three deaths in the RATS and VATS groups respectively	N/R
30 day mortality	O'Sullivan 2019a, meta-analysis of published systematic reviews and database studies	Lobectomy, any pathology. Nine studies, 223,073 patients.	N/R	OR 0.61, 95% CI 0.45–0.83, P = 0.001 (favours RATS)
2-year survival	Ng 2019, systematic review/meta-analysis	Lobectomy/NSCLC (stages I-III), one study, 2,059 patients	N/R	OR 1.18; 95% CI, 0.55 to 2.50, P = 0.68 (favours neither treatment)
3 year survival	Nelson, 2019, prospective observational study	Lobectomy for NSCLC; one study; 407 patients	yp Stage 0-1: 89% vs 94% yp Stage 2: 71% vs 76% yp Stage 3: 72% vs 81%	No statistically significant difference between groups
5 year survival	Ng 2019, systematic review/meta-analysis	Lobectomy/NSCLC (stages I-III), one study, 313 patients	N/R	OR 1.26; 95% CI, 0.75 to 2.13, P = 0.38 (favours neither treatment)
5 year survival	Worrell et al 2019, prospective observational study	Lung resection, one study, 98 patients	74% vs 74%	No statistically significant difference between groups
Duration of hospital stay	EUnetHTA 2019, systematic review of prospective studies	Lobectomy, three studies, 164 patients	N/R	No statistically significant difference between groups

Outcome	Evidence source	Study and patient characteristics	Absolute effect	Relative effect (interpretation)
Duration of hospital stay	O'Sullivan 2019a, meta-analysis of published systematic reviews and database studies	Lobectomy, any pathology, 12 studies (282,884 patients)	N/R	No pooled analysis reported; no statistically significant difference between groups in 11/12 studies
Duration of hospital stay	Ng 2019, systematic review/meta-analysis	Lobectomy/NSCLC (stages I-III), six studies, 7,752 patients	N/R	Mean difference −0.16 days, 95% CI -0.84 to 0.48 (favours neither treatment)
Duration of hospital stay	O'Sullivan, 2019b, meta-analysis of observational studies	Thymectomy, 5 studies, 380 patients	N/R	Mean difference -0.81, 95% CI -2.22 to 0.59 (favours neither treatment)
Duration of surgery	EUnetHTA 2019, systematic review of prospective studies	Lobectomy, three studies, 164 patients	N/R	No pooled analysis reported; one study reported significantly longer duration of surgery with RATS; two studies reported no significant difference
Duration of surgery	O'Sullivan 2019a, meta-analysis of published systematic reviews and database studies	Lobectomy, any pathology, seven studies (209,392 patients)	N/R	Weighted mean difference 4.98 min, 95% CI 2.61–7.36, P < 0.001 (favours VATS)
Duration of surgery	O'Sullivan, 2019b, meta-analysis of observational studies	Thymectomy, six studies, 533 patients	N/R	Weighted mean difference 8.99 min, 95% CI -10.5

Outcome	Evidence source	Study and patient characteristics	Absolute effect	Relative effect (interpretation)
				to 28.5 (favours neither treatment)
Rate of complications/AEs				
Frequency of postoperative complications	EUnetHTA 2019, systematic review of prospective studies	Lobectomy, three studies, 164 patients	N/R	No statistically significant difference between groups
Frequency of postoperative complications	O'Sullivan, 2019b, meta-analysis of observational studies	Thymectomy, 5 studies, 464 patients	N/R	OR: 0.74; 95% CI: 0.19, 2.85, P=0.66 (favours neither treatment)
Frequency of intraoperative complications	O'Sullivan, 2019b, meta-analysis of observational studies	Thymectomy, 3 studies, 219 patients	N/R	OR: 1.18; 95% CI: 0.48, 2.91, P=0.71 (favours neither treatment)
Frequency of any complications	Ng 2019, systematic review/meta-analysis	Lobectomy/NSCLC (stages I-III), six studies, 999 patients	Twenty-five percent (138/545) of VATS patients experienced complications compared to 24% (108/454) of patients in the RATS group	(OR 1.28; 95% CI, 0.75 to 2.17; P = 0.37) (favours neither treatment)
Rate of conversion to open surgery from minimally invasive surgery	O'Sullivan 2019a, meta-analysis of published systematic reviews and database studies	Lobectomy, any pathology, four studies (81,100 patients)	N/R	OR 0.80, 95% CI 0.56–1.15, P = 0.22 (favours neither treatment)
Rate of conversion to open surgery from minimally invasive surgery	O'Sullivan, 2019b, meta-analysis of observational studies	Thymectomy, four studies, 341 patients	1 patient in RATS groups and 2 patients in VATS group converted to open surgery	N/R

Outcome	Evidence source	Study and patient characteristics	Absolute effect	Relative effect (interpretation)
Rate of disease recurrence after surgery (2 years follow up)	Ng 2019, systematic review/meta-analysis	Lobectomy/NSCLC (stages I-III), one study, 313 patients	N/R	No statistically significant difference between groups
Rate of disease recurrence after surgery (5 years follow up)	Ng 2019, systematic review/meta-analysis	Lobectomy/NSCLC (stages I-III), one study, 313 patients	N/R	No statistically significant difference between groups
Positive surgical margins	O'Sullivan, 2019b, meta-analysis of observational studies	Thymectomy, three studies, 563 patients	12/178 events vs 17/385 events	Risk difference 0.02; 95% CI: −0.02, 0.07, P=0.3 (favours neither treatment)
Lymph node yield	O'Sullivan 2019a, meta-analysis of published systematic reviews and database studies	Lobectomy, any pathology, four studies, number of patients not reported	N/R	Standardised mean difference -0.12, 95% CI -0.15 to -0.09, P < 0.00001, favours VATS
Number of dissected lymph nodes	Ng 2019, systematic review/meta-analysis	Lobectomy/NSCLC (stages I-III), five studies, 7,814 patients		Mean difference −0.82; 95% CI, −2.69 to 1.04; P = 0.39
Frequency of nodal upstaging	Ng 2019, systematic review/meta-analysis	Lobectomy/NSCLC (stages I-III), six studies, 18,216 patients	8% (1,258/14,724) of VATS patients were upstaged compared to 10% (355/3,492) of RATS patients	OR 1.02; 95% CI, 0.85 to 1.22; P = 0.87
Quality of life, assessed using EORTC questionnaire, median follow up 65 months	Worrell et al 2019, prospective observational study	Lung resection, one study, 98 patients recruited, data only available for 29 patients	N/R	Global health status and symptom scale median scores were similar to the general population

Outcome	Evidence source	Study and patient characteristics	Absolute effect	Relative effect (interpretation)
				and did not significantly differ between groups
Patient satisfaction	No evidence identified			
CI: confidence interval; N/R: not reported; NSCLC: non-squamous cell lung cancer; OR: odds ratio; QOL: quality of life; RATS: robot-assisted thoracic surgery; VATS: video-assisted thoracic surgery				

6.1.1. Mortality/survival

Lobectomy
EUnetHTA OTCA14 included three prospective observational studies (164 patients in total) that considered mortality during surgery or in-hospital post-surgery of RATS and VATS (Gonde et al. 2017, Rinieri et al. 2016, Augustin et al. 2013). There were no deaths amongst RATS-treated patients; there were three deaths in the VATS-treated patients (EUnetHTA 2019).

O'Sullivan (2019a) combined results from previous meta-analyses and database studies and reported that RATS is superior with respect to 30-day mortality compared to VATS (OR 0.61, 95% CI 0.45–0.83, P = 0.001) and open approaches (OR 0.53, 95% CI 0.33–0.85, P = 0.008). This was based on meta-analysis of five studies (94,342 patients) comparing RATS and open surgery, and nine studies (223,073 patients) comparing RATS and VATS. All data was from retrospective studies.

Ng (2019) evaluated evidence on long-term survival after RATS and VATS. One study (313 patients) comparing RATS to VATS reported on 5-year survival rates. At 5 years, 73% (103/141) of VATS patients were alive compared to 77% (133/172) of RATS patients (OR 0.79; 95% CI, 0.47 to 1.33, P = 0.38). This study also reported on disease-free survival at 5 years. Sixty-five percent (92/141) of VATS patients had no recurrence of cancer at 5 years compared to 73% (125/172) of patients in the RATS group (OR 0.71; 95% CI, 0.44 to 1.14; P = 0.16). Two studies (2,059 patients) reported on 2-year survival rates. At 2 years, 86% (934/1,082) of VATS patients were alive compared to 86% (838/977) of RATS patients (OR 1.18; 95% CI, 0.55 to 2.50, P = 0.68). One study reported on disease-free survival at 2 years. Eighty-three percent (131/158) of VATS patients had no recurrence of cancer at 2 years compared to 92% (49/53) of patients in the RATS group (OR 0.40; 95% CI, 0.13 to 1.19; P = 0.10).

None of the systematic reviews identified reported long-term survival rates after RATS compared to open surgery, but HTW identified one study reporting 3-year survival after lobectomy by RATS or open surgery. There was no statistically significant difference in survival between people having RATS or open surgery (Nelson et al. 2019).

Mediastinal mass excision/thymectomy
EUnetHTA OTCA14 included one prospective observational study (36 patients) that compared RATS and open surgery (Balduyck et al. 2011). 100% intraoperative survival was reported in both groups (EUnetHTA 2019).

O'Sullivan (2019b) reported 30-day mortality data from six studies (795 patients) comparing RATS and open surgery. There were no deaths reported in the RATS-treated group and only one death in patients treated with open surgery. A further six studies (295 patients) compared 30-day mortality in RATS to VATS: no deaths were recorded in either treatment arm.

6.1.2. Duration of hospital stay

Lobectomy
Three prospective studies reported length of hospital stay in patients undergoing lobectomy or segmentectomy using RATS or VATS. In all cases there was no statistically significant different between groups: one study reported marginally longer length of stay with RATS; in two studies the time in hospital was marginally shorter for RATS than VATS.

O'Sullivan (2019a) identified five studies (118,945 patients) measuring length of stay in RATS vs open surgery: pooled analysis suggests length of stay is significant shorter after RATS compared to open surgery (weighted mean difference -1.4 days, 95% CI -1.96 to -0.85, P < 0.00001). Data from 12 studies (282,884) was identified comparing length of stay in RATS and VATS, but no pooled

analysis was reported: in the majority of studies, there was no significant difference in length of stay between RATS and VATS.

Ng (2019) analysed length of hospital stay in six studies (7,752 patients) comparing RATS and VATS: there was no significant different between groups (mean difference −0.16 days (95% CI -0.84 to 0.48). In the same systematic review, a pooled analysis of two studies including 7,516 patients showed that RATS patients had a significantly reduced length of hospital stay compared to open lobectomy. The mean hospital stay for RATS patients was 0.82 days less than open lobectomy patients (95% CI -1.07 to – 0.57; P < 0.0001).

Mediastinal mass excision/thymectomy
One prospective study reported no significant different in length of hospital stay after robot-assisted mediastinal mass resection and open surgery. Mean length of stay was 9.6 days in the RATS group and 11.8 days in the open surgery group.

O'Sullivan (2019a) reported a shorter hospital stay (weighted mean difference −2.78 days, 95% CI: −3.22, −2.33, P<0.00001) after robotic thymectomy than open surgery, based on pooled analysis of 13 studies (1,313 patients).

6.1.3. Duration of surgery

Lung resection
No prospective studies were found comparing duration of surgery for RATS to open lung resection. Three studies reported duration of RATS compared to VATS: no pooled analysis was reported. In one study RATS duration was statistically significantly longer than VATS in one study (mean 215 min for RATS; mean 183 min for VATS, p<0.05); in the remaining two studies there was no significant different in surgery time.

Analysis of retrospective data by O'Sullivan (2019a) found that duration of surgery was longer for RATS than for VATS or open surgery (RATS vs. VATS; weighted mean difference 4.98 min, 95% CI 2.61–7.36, P < 0.001, robotic vs. open, weighted mean difference 65.56 min, 95% CI 53.66–77.46, P < 0.00001). This was based on analysis of two studies (21,259 patients) comparing RATS to the open approach, and seven studies (209,392 patients) comparing RATS to VATS.

Mediastinal mass excision/thymectomy
EUnetHTA OTCA14 found one prospective study comparing duration of surgery for RATS to open surgery for mediastinal mass resection. There was no significant difference between the two types of surgery: mean duration was 224 min in the RATS group and 244 min in the open group. No prospective studies compared RATS to VATS for this outcome.

In their systematic review of retrospective studies, O'Sullivan (2019a) identified 12 studies (774 patients) comparing RATS to open surgery for people undergoing thymectomy. Duration of surgery was longer with RATS but the difference between groups was not statistically significant (weighted mean difference 6.73 min, 95% CI -21.2 to 34.7). Similarly, pooled analysis of six studies (533 patients) comparing RATS and VATS reported a longer, but non-significant, duration of surgery with RATS (weighted mean difference 8.99 min, 95% CI -10.5 to 28.5).

6.1.4. Complications/morbidity/adverse events

Lobectomy
In EUnetHTA OTCA14, three observational studies of lobectomy all reported non-statistically significant differences in total postoperative complications between RATS and VATS. None of these studies reported on intraoperative complications.

Augustin et al reported significantly more blood loss in the RATS group, but no-significant difference in drain duration. Gonde et al did not report on blood loss and found non-statistically significant differences in operation time and drain duration between the groups. Rinieri et al however found a statistically significant difference in blood loss between the groups, with the robot-assisted surgery group associated with significantly less blood loss (median 50ml for RATS compared with median 100ml for VATS); there were no statistically significant differences in drain duration in this study.

In the systematic review of lung resection by O'Sullivan (2019b), one study reported lower intraoperative (0.9% vs 5.0%, P = 0.07) and postoperative (0.9% vs 7.8%, P = 0.002) blood transfusion rates for RATS versus open surgery (P = 0.002). Comparing RATS and VATS, the percentage of patients requiring blood transfusions was reported in two studies, both of which demonstrated no difference in the incidence between RATS and VATS. In the review by Ng (2019), a pooled analysis of six studies including 999 patients showed no statistically significant difference in complications between VATS and RATS. Twenty-five percent (138/545) of VATS patients experienced complications compared to 24% (108/454) of patients in the RATS group (OR 1.28; 95% CI, 0.75 to 2.17; P = 0.37).

Mediastinal mass resection/thymectomy
One prospective study of mediastinal surgery reported non-statistically significant differences rates of postoperative complications between RATS and open surgery: 3/14 (22%) and 2/22 (9%) of RATS and open-treated patients experienced postoperative complications, respectively. Both RATS and open surgery resulted in increased thoracic pain at 1 month; this persisted only in the open surgery group at the 3 month point. Open surgery but not RATS was associated with increased fatigue at 1 month after surgery ($p<0.01$). The robot-assisted group showed an increase in shoulder pain/dysfunction at 3 months, which was not observed in the open surgery group ($p<0.05$). (EUnetHTA 2019).

The systematic review by O'Sullivan (2019a) analysed incidence of postoperative complications from 13 studies (824 patients), finding a significantly lower postoperative complication rate in RATS thymectomy compared to the open approach (OR: 0.37; 95% CI: 0.22, 0.60, $P<0.0001$). Intraoperative complications, pooled from six studies (190 patients) did not differ significantly between RATS and open surgery (only 3 events were recorded in each treatment arm). Comparing RATS and VATS, there was no significant difference in rates of intraoperative (3 studies; 219 patients; OR: 0.74; 95% CI: 0.19, 2.85, P=0.66) or postoperative complications (5 studies; 464 patients; OR: 1.18; 95% CI: 0.48, 2.91, P=0.71).

6.1.5. Conversion to open surgery

Lung resection
Three prospective studies compared the rate of conversion to open surgery in RATS and VATS. One study reported a statistically significant difference in conversion to laparoscopic or open surgery, with conversion occurring more often in VATS (IG 2% vs. CG 16%, $p<0.01$). In the other two studies, there was no significant difference in conversion rates (EUnetHTA 2019).

The systematic review by O'Sullivan (2019b) included a pooled analysis of conversion rates from four studies (81,100 patients); this reported no significant difference in conversion rates between RATS and VATs (OR 0.80, 95% CI 0.56–1.15, P = 0.22).

Thymectomy/mediastinal mass resection
EUnetHTA OTCA14 did not identify any prospective studies reporting this outcome. O'Sullivan (2019a) included data on conversion rates from four retrospective studies (341 patients): only a single patient in the RATS group and 2 patients in the VATS group underwent conversion to open surgery.

6.1.6. Disease recurrence

Lung resection
No prospective studies reported the incidence of disease recurrence after lung resection by RATS, VATS or open surgery.

Ng (2019) reported rates of disease recurrence with RATS and VATS after 5 years (one study, 313 patients), 2 years (one study, 211 patients); neither study found a significant difference in rates of disease recurrence after RATS and VATS.

Thymectomy/mediastinal mass resection
The only source of evidence found was a single prospective study (36 patients) comparing RATS and open surgery, included in EUnetHTA OTCA14 (Balduyck et al. 2011, EUnetHTA 2019). Recurrence occurred in 1/22 patients in the open group and none in the RATS group.

6.1.7. Surgical margins

Lung resection
No prospective studies reported the incidence of positive or negative surgical margins in people who had undergone lung resection by RATS, VATS or open surgery.

Thymectomy/mediastinal mass resection
No prospective studies reported the incidence of positive or negative surgical margins in people who had undergone mediastinal mass resection by RATS, VATS or open surgery.

O'Sullivan (2019b) pooled data on the rate of positive surgical margins from nine studies (2,701 patients) comparing RATS and open surgery. Margins were positive in 14/391 patients treated with RATS and 289/2310 patients treated with open surgery (Risk difference −0.04; 95% CI: −0.07, −0.01, P=0.01). The same review also identified three studies (563 patients) comparing this outcome for RATS and VATS. There was no significant difference in the rate of positive margins after RATS or VATS (Risk difference 0.02; 95% CI: −0.02, 0.07, P=0.3)

6.1.8. Nodal upstaging/nodal yield

Lung resection
The systematic review by O'Sullivan (2019a) identified two studies that compared the lymph node yield obtained with open surgery and RATS. The total number of patients included was not reported. There was no significant difference between lymph node yield using RATS and open surgery (Standardised mean difference 0.09, 95% CI -0.09 to 0.27, P = 0.31). The review by O'Sullivan (2019a) also identified four studies (number of patients included not reported) comparing lymph node yield obtained with RATS and VATS. This analysis found that lymph node yield is slightly higher with VATS than RATS (Standardised mean difference -0.12, 95% CI -0.15 to -0.09, P < 0.00001), but it is not clear if this represents a clinically significant difference. Ng 2019 pooled data from five studies (7,814 patients) reporting the number of lymph nodes dissected in RATS and VATS cases. This analysis did not find any significant difference in the number of lymph nodes dissected between these types of surgery (mean difference −0.82; 95% CI, −2.69 to 1.04; P = 0.39). The same review also reported no difference in the frequency of nodal upstaging between RATS and VATS (pooled analysis of six studies/18,216 patients; OR 1.02; 95% CI, 0.85 to 1.22; P = 0.87)

Thymectomy/mediastinal mass resection
We did not identify any comparative evidence reporting these outcomes in thymectomy or mediastinal mass resection.

6.1.9. Quality of life

Lung resection
No existing systematic reviews identified data on quality of life after lung resection. HTW identified one study (98 patients) that collected health-related quality of life data from patients after RATS or VATS (median time after surgery was 65 months; no baseline date reported). The EORTC questionnaire was used to assess quality of life. Only 29 patients completed the questionnaire. Global health status and symptom scale median scores were similar to the general population and did not significantly differ between groups (Worrell et al. 2019).

Thymectomy/mediastinal mass resection
EUnetHTA OTCA14 included quality of life outcomes from a single prospective study of 36 patients who underwent mediastinal mass resection by RATS or open surgery. After 1 month, the open surgery group showed deterioration on 5 out of 10 QoL/ symptom subscales; in the robot-assisted surgery group there was deterioration on only 1 out of 10 subscales. Functioning deteriorated in the open group at 1 month (but not thereafter); no deterioration was observed in the RATS group (EUnetHTA 2019).

6.1.10. Patient satisfaction

No evidence was identified comparing patient satisfaction after RATS, VATS or open thoracic surgery.

6.2. Ongoing trials

Initial scoping searches highlighted the existence of ongoing randomised trials of RATS. Given the substantial body of non-randomised evidence already available HTW only searched for ongoing randomised trials. Three trials were identified; all compared RATS and VATS in people undergoing lobectomy. Their design and characteristics are outlined in Table 3. No ongoing trials evaluating RATS in mediastinal surgery were identified.

Table 3. Ongoing randomised trials of robot-assisted thoracic surgery

Study name, reference	Setting and design	Eligibility criteria	Interventions	Outcomes	Expected completion
ROMAN; NCT02804893	Prospective, randomized, multicentre study	Early stage (I-II) lung cancer where lobectomy or anatomical segmentectomy is indicated	RATS; VATS. Total planned recruitment = 300 patients	Conversion; complication rate; duration of surgery; length of stay; quality of life; local and distance recurrence; disease-free survival (planned follow-up: 2 years)	March 2023
NCT02617186	Prospective, randomized, study; number of centres not reported	Non-small cell lung cancer stage I, II or IIIa suitable for lobectomy	RATS; VATS. Total planned recruitment = 186 patients	Health-related quality of life; cost effectiveness	January 2021

Study name, reference	Setting and design	Eligibility criteria	Interventions	Outcomes	Expected completion
NCT03134534	Prospective, randomized, study; number of centres not reported	Pulmonary neoplasms, stages I-III, suitable for lobectomy	RATS; VATS. Total planned recruitment = 300 patients	3-year overall survival and disease free survival; positive margin rate; duration of surgery; 30-day mortality; length of hospital stay; intraoperative and postoperative complications; quality of life	January 2020

7. Economic evaluation

7.1. Cost Consequence Analysis

The economic considerations between the three surgical approaches have been evaluated in the literature multiple times and to varying degrees. The evaluation of RATS to VATS and open surgery is characterised by two costing periods, the initial intervention and the longer-term costs, this analysis will focus on the former. The uncertainty surrounding the long-term clinical impact of the alternative approaches favours a cost consequence analysis (CCA) structure. This review takes a UK NHS perspective with a focus on initial intervention costs. Costs are listed in 2018 GBP.

7.1.1. Duration of surgery

RATS is characterised by high capital costs when compared to the surgical alternatives evaluated within this report. Capital costs are applied according to attribution of time under the assumption of full capacity with a 7-year work life duration. Costs are applied to procedure components from the literature with NHS specific costs preferred. The literature includes a wide range of methodologies, outcomes and location settings. A recent meta-analysis (Agzarian et al. 2016) was central to the model built for this rapid review. Agzarian et al. (2016) estimated the pooled average for operative time and for length of hospital stay. The Operative time for RATS was 190 minutes, this was higher than that seen in open surgery and VATS. The extent to which RATS and VATS differ in operative time is discussed in O'Sullivan et al. (2019a) who state a minor increase of 5 minutes. Open surgery is associated with a weighted mean difference of 66 minutes when compared to RATS, this results in an operative time of 124 minutes. This weighted mean different approach was used due to the lack of reported baseline figures offered by the most recent systematic review. Theatre time is reported on an hourly cost basis as £930 per hour by the Information services division (ISD) Scotland report of 2018 (Information services division Scotland 2018).

7.1.2. Bed days

Duration of hospital stay is estimated to be insignificantly different between RATS and VATS. RATS have a consistently lower duration of hospital stay compared to the open procedure. The model uses the figures from Agzarian (2016) of 4.88 for RATS and VATS and 6.85 for open. The excess bed day cost of £346 is an average of the major thoracic procedure inpatient excess bed days tariff cost reported by the national schedule of reference costs 2017-18.

7.1.3. Capital and variable costs

Kajiwara et al. (2018) present the structure of capital attribution and maintenance considerations for the Da Vinci Si. The Da Vinci Si model X single console has a supplier reported price of £1.1m. The nature of this rapid review means that the scope was unable to include the alternative robotic systems or to evaluate the veracity of the capacity potential. Maintenance costs are applied at a rate of £120,000 per year, system costs over the 7 years is £1,940,000. To estimate a per procedure system cost the traditional method is to estimate how many procedures are to be undertaken using the capital asset, here we have a situation where the robot may be used for alternative procedures. This modelling takes the form of an allocated capacity approach which applies costs according to a portion of the machine time being used, not the method which directly assess values according to fixed costs divided by the number of RATS procedures. The base case approach assumes two procedures can be undertaken each day, RATS constitutes part of this workload. The fixed costs applied per RATS procedure is £533. The VATS fixed costs used is an inflation adjusted figure from Ramsay et al. (2012). Open lobectomy incurs no direct fixed cost.

The variable costs associated with each of the procedures include multi-use and single use items. The rapid review process undertaken here uses an adaption of the literature with input from expert costing knowledge. Currently there are no micro-costing evaluations of the three approaches which use an NHS setting. The 2012 report by Ramsey et al. exhibits the variable costs for the comparative approaches for prostate surgery. The micro-costing approach identifies the differences in consumables to be characterised by the additional drapes required for RATS and the Harmonic shears used in VATS. The reported variable figures are assessed in the context of current prices identified by experts, the approach taken here is to update the Ramsey et al. 2012 figures using the BOE inflation calculator to offer 2018 GBP prices. Increased competition within the surgical devices sector may lead to a decrease in the price of specialist items. The variable cost of the open lobectomy follows the approach adopted by Kajiwara et al. (2018) in assuming a general equality of costs, here this equates to the average between the two alternatives (£1,674).

Table 4. Cost estimates across comparative surgical approaches

	RATS	VATS	Difference: RATS minus VATS	Open lobectomy	Difference: RATS minus Open lobectomy
Capital costs	£533	£120	£413	-	£533
Consumables cost	£1,620	£1,727	-£107	£1,674	-£54
Theatre time	£2,945	£2,868	£77	£1,922	£1,023
Bed days cost	£1,688	£1,688	£0	£2,370	-£682
Total cost	£6,786	£6,403	£383	£5,966	£820

RATS: robot-assisted thoracic surgery; VATS: video-assisted thoracic surgery

The cost comparison totals show that the cheapest approach undertaken was that of the open lobectomy. The RATS approach costs £383 and £820 more than VATS and open approach respectively. VATS estimated costs are £437 more than open lobectomy. Costs included in this approach follow the broad trend shown in the literature, the main difference occurs due to the capital cost capacity approach taken for RATS. The robot cost for RATS is lower in this structure

than is typically seen as this analysis assumes that other procedures will be undertaken using the equipment.

7.1.4. RATS vs. Open

The clinical outcomes suggest that RATS may improve the level of short-term mortality and reduce the duration of hospital stay following surgery. The clinical improvement comes at an incremental cost of £820. In a setting where capital costs are not applied, due to the existence of available capacity, RATS remain more expensive than the open approach (£287). The cost difference is driven mainly by theatre duration costs.

7.1.5. RATS vs. VATS

The clinical outcomes achieved through using the VATS approach are comparable to those from RATS. The higher cost associated with RATS compared to VATS of £383 is primarily driven by capital costs. In the situation where machinery has available capacity, costs are broadly similar between the two approaches.

7.1.6. Scenario Analyses

The uncertainty surrounding the number of procedures undertaken using the robotic device favours the use of scenario analyses to include all available information and to develop a range of plausible approaches. The initial set of scenarios develops a range of capacity estimates around a surgeries per day estimate. A high and low capacity estimate is used around the base case level, three and one procedures respectively. Yearly totals are based on a 5-day working week and 52 weeks per year. The second range of scenarios is developed around the annual capacity suggested by expert knowledge of a major robot assisted surgery centre in England of 260 procedures. A high estimate of 260 and a lower 160 level are included. Results can be seen in Table 5.

Table 5. Scenario analysis: Capacity level

Scenario capacity	Procedures (per duration)	Fixed cost allocation
Low capacity	200 (per year)	£1,386
England RAS centre	290 (per year)	£956
High capacity	400 (per year)	£693
Low level	1 (per day)	£1,066
Base case level	2 (per day)	£533
High level	3 (per day)	£355

The scenario analyses demonstrate the high variability of fixed cost allocation according to usage levels. The base case estimate reflects a broadly high usage level and low fixed cost per procedure whilst still totalling a higher cost of RATS compared to both VATS and Open. The lowest fixed costs can be seen for highest level of usage, the 3 procedures per day approach reduces the fixed cost to £355. At the optimal usage level, the RATS approach continues to be higher cost than both VATS and Open. At lower usage levels the fixed cost allocation increases to £1,386.

The variable costs of each procedure present an area of uncertainty. Variation in resource use due to individual surgeon preference and cost reductions achieved through optimisation or price

change may lead to a change in overall costs. A threshold analysis approach estimates the required reduction in RATS related consumables cost of approximately 24% to be cost equal to VATS and 51% for Open.

Whilst robot assisted surgery has been undertaken for a significant amount of time, the possible improvement to capacity and reduction in cost is mentioned in expert consultation consistently. Reduction in fixed costs per procedure may be achieved through the development of dedicated RAS staff/theatres, extension of active working times, and block times in theatres. The da Vinci system is reported to be available on a rental and leasing basis. Alternative robotic surgery systems may reflect a more cost-effective approach to RATS but were not included in the current scope due to the rapid review process and the relative availability of evidence.

8. Organisational issues

As of May 2019, there is a single Da Vinci Xi system available in Wales, at University Hospital Wales, Cardiff. If robot-assisted thoracic surgery were to be carried out using this existing system, access to treatment would be more difficult for people living outside of South East Wales. People in North Wales already travel to England for robot-assisted surgery where this is indicated. In November 2018, it was agreed that adult thoracic surgery services should be located at a single site at Morriston Hospital, Swansea (Welsh Health Specialised Services Committee 2018). An outline commissioning plan to implement this is being developed. As the only established robotic surgery system in Wales is located at University Hospital Wales, Cardiff, consideration would need to be given to any deployment of RATS in the context of this service reorganisation.

According to the manufacturers consulted as part of EuNetHTA's rapid evidence assessment, the personnel required for robot-assisted surgery is the same as for an open or VATS intervention. However, additional training and learning is required to operate all robotic systems. Extensive, highly specialized training and an adequate volume of cases are required for surgeons and their surgical teams to maintain proficiency. The surgical team requires training to learn how to set-up the system and how to make any necessary adjustments during a procedure. Studies evaluating the learning curve with RATS have identified longer surgical times, increased blood loss, and increased frequency of conversion to open surgery as possible factors associated with relative inexperience (Arnold et al. 2019, Gallagher et al. 2018). Estimates of the number of cases undertaken to complete learning curve vary considerably; systematic evaluation of learning curve is beyond the scope of this report, but a minimum of 20 cases is commonly reported (Veronesi et al. 2018). There is some limited evidence that longer initial surgery times with RATS may be counteracted once a surgeon has gained experience, and with experience surgery times may shorten, but it has not been possible to quantify this: none of the evidence discussed in Section 6 allows for subgroup analysis according to level of surgeon experience, for example.

No consensus or recognized standards exist regarding optimal training programs for robot-assisted surgery. The European Society of Thoracic Surgeons and European Association for Cardio-Thoracic Surgery are in the process of defining procedures to optimise robotic training of thoracic surgeons and producing learning material to support this (Veronesi et al. 2018).

Other issues associated with robot-assisted surgery are the need for additional pre- and postoperative procedures related to preparing, cleaning, and maintaining the system and proprietary instrumentation. TransEnterix has stated that switching the reusable surgical instruments for its Senhance system is a quick and simple process and that the Senhance system offers per-procedure costs comparable to those of conventional laparoscopic surgery (EUnetHTA 2019).

One postulated advantage of robotic surgery is the potential reduction in short- and long-term fatigue experienced by surgeons. Traditional surgery often involves surgeons standing in poor ergonomic positions for long periods of time, increasing mental and visual fatigue in the short term and potentially causing musculoskeletal problems in the long term. Robotic surgery, which involves more time with the surgeon seated at the robotic console, has the potential to alleviate these issues (Zhou et al. 2018), but more evidence is needed to quantify these potential advantages.

The robotic systems typically consist of a surgeon's console and a patient-side cart with three to four interactive robotic arms controlled from the console. The arms are for tools that hold objects and can also act as scalpels, scissors, or graspers. The surgeon uses the console's master controls to manoeuvre the patient-side cart's robotic arms. The robotic surgical system is large and although it may fit in most operating room suites, renovation or new construction of operating rooms may be needed in some cases (EUnetHTA 2019).

9. Patient issues

None of the studies identified included any information on patients' perspectives or experiences of undergoing thoracic surgery. No equality issues were identified.

10. Conclusions

There is a large body of evidence assessing the clinical effectiveness of thoracic surgery using RATS compared to VATS or open surgery. However, all the evidence identified is from non-randomised trials, and evidence is not available for all outcomes. The majority of evidence reported here is drawn from four existing systematic reviews, none of which reported any formally quality assessment of their results

Overall, the evidence suggests that RATS may be beneficial compared to open surgery in terms of short-term mortality, duration of hospital stay after surgery and the rate of positive surgical margins. However, the evidence suggests that duration of surgery may be longer with RATS than open surgery. Furthermore, the scarcity of evidence on survival data beyond 30 days comparing these two interventions is a major limitation of the evidence: we identified a single study reporting longer term survival; this found no statistically significant difference in overall survival between RATS and open surgery after 3 years of follow-up.

Evidence comparing RATS and VATS found no statistically significant difference between types of surgery for most outcomes, including long-term (up to five years) overall and disease-free survival.

Robotic systems suitable for thoracic surgery are available from at least four different manufacturers (see Sections 3.1 to 3.4 for details). It was not possible to determine the robotic system used for surgery in all the sources of clinical effectiveness evidence. However, the sources of evidence that did include this information all used a Da Vinci robotic system. We did not identify any sources of evidence that reported using surgical systems from other manufacturers. More evidence on the clinical effectiveness of different robotic surgical systems is likely to be available in the future, allowing for clearer comparison of different systems.

The health economic evaluation was conducted using the Da Vinci X system for costing purposes. Due to the lack of clinical evidence on alternative robotic surgical systems, it has not been possible to evaluate the cost of these. The analysis found RATS to be more costly than both open surgery and VATS based on any measured differences in short-term outcomes. The comparative long term outcomes associated with each type of surgery are uncertain.

11. Further research

Prospective, randomised trials of thoracic robotic surgery are ongoing; but results of these are not yet available.

12. Contributors

This topic was proposed by M Kornaszewska, Consultant Thoracic Surgeon, Cardiff and Vale University Health Board.

The HTW staff and contract researchers involved in writing this report were:

- H Britton: project-managed report production; co-ordinated expert reviewer input.
- D Jarrom: reviewed clinical and cost-effectiveness evidence; primary author of report.
- J Washington: developed search strategy and carried out literature searches.
- T Winfield: synthesised cost effectiveness evidence and developed cost model.

The HTW Assessment Group advised on methodology throughout the scoping and development of the report.

A range of clinical experts from the UK provided material and commented on a draft of this report. Their views were documented and have been actioned accordingly. All contributions from reviewers were considered by HTW's Assessment Group. However, reviewers had no role in authorship or editorial control, and the views expressed are those of Health Technology Wales.

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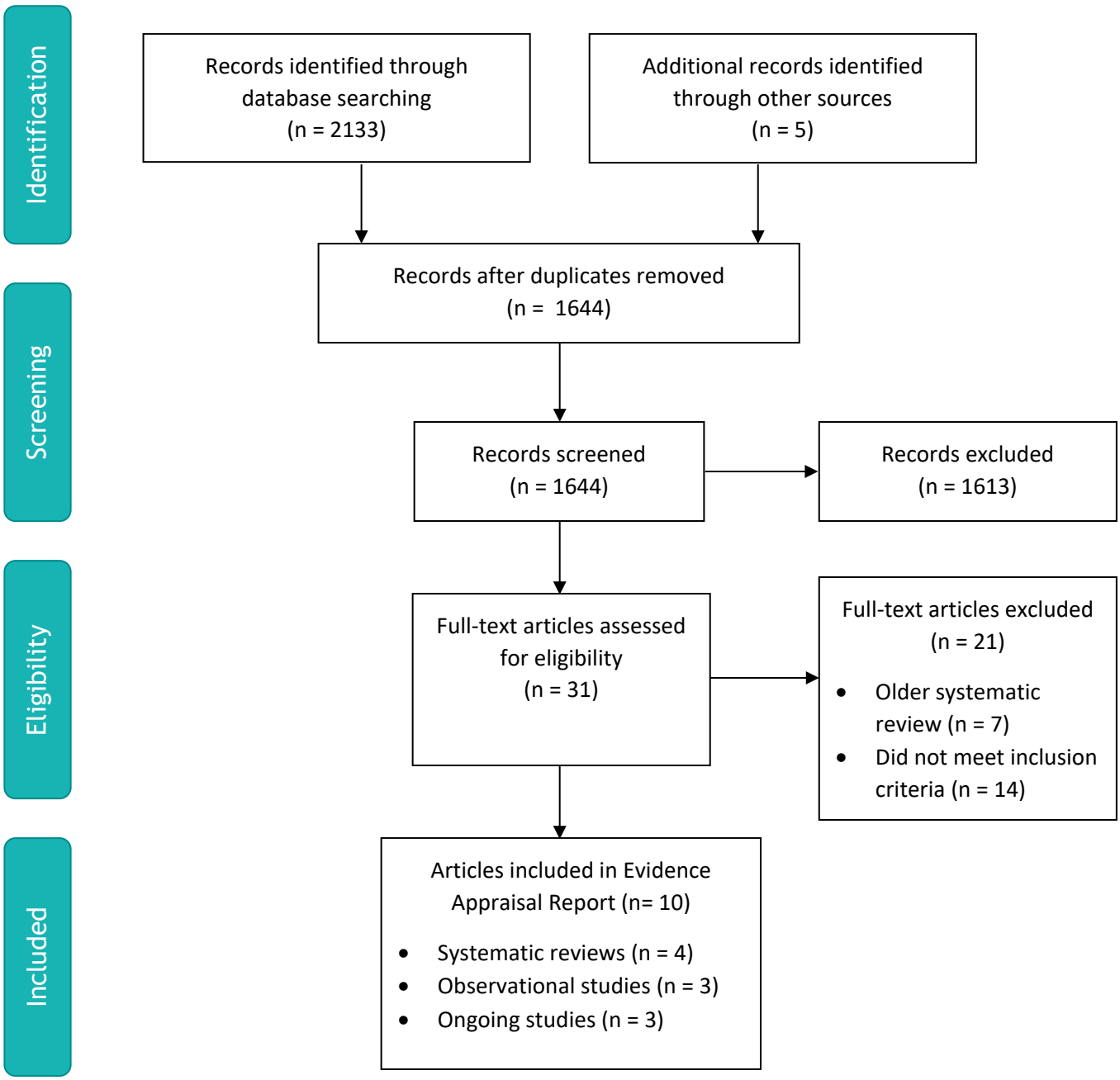
Appendix 1. Research question and PICO

Research Question	Compared to open surgery or video-assisted thoracoscopic surgery, what is the clinical and cost effectiveness of robotic surgery for lung resection or mediastinal mass excision?

	Selection criteria
Population	People in whom thoracic surgery is indicated (lobectomy; lung segmentectomy/wedge resection; mediastinal mass/lesion excision)
Intervention	Robotic or robot-assisted thoracic surgery
Comparison/ Comparators	Open surgery Video-assisted thoracoscopic surgery
Outcome measures	Survival/mortality Duration of hospital stay Duration of surgery Rate of complications/adverse events (intraoperative or postoperative) Rate of conversion to open/thoracoscopic surgery from robot-assisted surgery Rate of disease recurrence after surgery Positive surgical margins Lymph node yield/nodal upstaging Quality of life Patient satisfaction
Study design	We will include the following clinical evidence in order of priority: • Systematic reviews. • Randomised or non-randomised trials. • Non-randomised trials for outcomes. We will only include evidence for "lower priority" evidence where outcomes are not reported by a "higher priority" source. We will also search for economic evaluations or original research that can form the basis of an assessment of costs/cost comparison.
Search limits	The EUNETHTA Rapid Assessment Report OTCA14 "Robotic surgery in thoracic and visceral indications" will be used to identify prospective clinical effectiveness evidence published up to June 2018. We will conduct our own searches to identify prospective evidence published after this date. We will conduct our own searches to identify and evidence on cost effectiveness from any time period.

Appendix 2 - PRISMA flow diagram outlining selection of evidence



Appendix 3. Systematic review characteristics. Green indicates outcomes reported; amber indicates outcomes searched for but no or very limited evidence identified; red indicates outcomes not reported.

Author, year	Selection criteria (type of surgery/disease/any other notable criteria)	Date of literature search	Comparison(s)	Outcomes reported									
				Survival/mortality	Duration of hospital stay	Duration of surgery	Complications/adverse events	Conversion to open surgery	Disease recurrence	Surgical margins	Nodal upstaging/yield	Quality of life	Patient satisfaction
EUnetHTA 2019	Any thoracic surgery/any pathology/prospective studies only	June 2018	RATS vs VATS	Yes	Yes	Yes	Yes	Yes	*Yes*	*Yes*	No	*Yes*	*Yes*
EUnetHTA 2019	Any thoracic surgery/any pathology/prospective studies only	June 2018	RATS vs open	*Yes*	*Yes*	*Yes*	*Yes*	N/A	*Yes*	*Yes*	No	*Yes*	*Yes*
O'Sullivan 2019b	Thymectomy/thymoma; myasthenia gravis	2 Jul 2018	RATS vs VATS	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	No
O'Sullivan 2019b	Thymectomy/thymoma; myasthenia gravis	2 Jul 2018	RATS vs open	Yes	Yes	Yes	Yes	N/A	No	Yes	No	No	No
O'Sullivan 2019a	Lobectomy/any pathology/systematic reviews or database/registry studies	December 2017	RATS vs VATS	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No	No
O'Sullivan 2019a	Lobectomy/any pathology/systematic reviews or database/registry studies	December 2017	RATS vs open	Yes	Yes	Yes	Yes	N/A	No	No	Yes	No	No
Ng 2019	Lobectomy/NSCLC (stages I-III)	28 Jan 2018	RATS vs VATS	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes	No
Ng 2019	Lobectomy/NSCLC (stages I-III)	28 Jan 2018	RATS vs open	No	Yes	No	*Yes*	N/A	*Yes*	No	No	Yes	No