Introduction

Thyroidectomy is one of the most commonly performed surgical procedures and since the majority who undergo thyroidectomy are young females with excellent long-term prognosis, the main focus of the surgery has shifted from simply being safe or cure to improving quality-of-life and functional outcomes. Cosmetic outcome is one of the most important functional outcomes after thyroidectomy and this is particularly true in many parts of Asia. Although the traditional open thyroidectomy with a transverse cervical incision provides good exposure and is extremely safe in experienced hand, patients are left with a visible neck scar which at times could become hypertrophic or keloid and so not all patients are satisfied with the cosmetic results. For this reason, various minimal-access or endoscopic thyroidectomy techniques had been proposed and developed.

These approaches may be classified according to the site of incision in relation to the neck. The first is called the cervical approach which involves having a small transverse incision less than 2cm at neck area with endoscopic video-assistance to overcome the limited exposure of a small wound. The second is the extra-cervical approach (or remote-access) which involves making incisions away from neck leaving no neck scars. One popular example would be the gasless transaxillary approach. However, these techniques are generally challenging since they involve working in a limited space with the use of non-flexible endoscopic instruments and 2-D image representation. To overcome these problems, the da Vinci surgical robot system (Intuitive Surgical, Sunnyvale, CA, USA) was first applied by a South Korean group in 2007.

Despite higher cost, the robot provides a 3-D magnified surgical view, tremor-free handling and better dexterity in deep and narrow spaces, giving additional benefits such as better exposure and potentially easier lymph node (LN) dissection and tumor clearance. Since 2009, there has been growing enthusiasm over the world with several groups publishing their initial success with robotic-assisted thyroidectomy (RT).

However, it remains unclear whether the potential benefits of RT would translate into better clinical outcome. In October 2011, the FDA revoked the approval on the use of the robot for thyroidectomy which subsequently led to more questioning.

To date, growing number of publications are available which may shed light on this controversial issues. This review aims to summarize the current evidence of surgical and oncological outcome of RT, and its application in clinical practice.

Discussion

The authors have referenced some of their own studies in this review. These referenced studies have been conducted in accordance with the Declaration of Helsinki (1964) and the

Figure 1: Axillary incision for gasless TART.
protocols of these studies have been approved by the relevant ethics committees related to the institution in which they were performed. All human subjects, in these referenced studies, gave informed consent to participate in these studies.

**Surgical approaches in RT**

*Gasless transaxillary robotic-assisted thyroidectomy (TART)*

TART was one of the first robotic approaches to put into clinical practice. It starts with a vertical incision of axilla along the external margin of pectoralis major (PM) on the side of the lesion (Figure 1).

Dissection continues in the fascial layer of PM, up to the clavicle, under the platysma muscle, then entering through the space formed by the sternal and clavicular insertion of the sternocleidomastoid muscle (SCM), continued under the subhyoid muscles to the thyroid loggia (Figure 2). Working space is maintained with the help of a special, autostatic retractor, without gas insufflation.

For a single-incision TART, the 12 mm trocar with camera is placed in the central lowest part of incision with tip tilted upward. The 8mm trocar with ProGrasp forceps is placed on the right of camera as close as the retractor blade. The 5 mm trocar with Harmonic curved shears should be on the right side of the camera and the 5mm Maryland dissector is then positioned on the left of the camera (Figure 3). The Maryland dissector and Harmonic curved shears should be placed as far apart as possible.

For a double-incision TART, the ProGrasp forceps is placed in the second skin incision about 0.8 cm in length over the pre-pectoral, latero-sternal position of the same side instead, allowing easier traction for dissection.

Then the actual thyroidectomy could be performed under a similar operative view as that in open surgery. The upper and lower poles of thyroid and neck LNs are accessed easily, and from the lateral side parathyroid glands and recurrent laryngeal nerves are exposed clearly. However, exposing the contralateral thyroid lobe is difficult through a unilateral axillary approach.

**Bilateral axillo-breast approach (BABA)**

Compared to TART, BABA has several advantages. Firstly, it allows a much wider and symmetrical views of bilateral thyroid lobes and that in turn exposes clearly important structures such as the trachea, recurrent laryngeal nerve, parathyroid glands and the superior and inferior thyroid vessels. BABA starts with bilateral circumareolar incisions along the superomedial border of each areola, irrespective of the side of the lesion.

Anterior chest flap is made by blunt dissection above the breast parenchyma. A 12-mm camera port is inserted through the right breast incision and an 8-mm port through the left breast incision. The working space is insufflated with low pressure CO2 gas via the 12-mm port. The anterior chest flap is then extended to an area bounded superiorly by thyroid cartilage and inferiorly 2cm below clavicle and just beyond the medial border of the SCM laterally. Two 8-mm axillary incisions are made. The robot is docked and camera is inserted through the right breast incision and the energy dissection devices via the left breast. The graspers are inserted via the axillary ports. Then the console time begins, constituting the actual thyroidectomy in a manner similar to open thyroidectomy (Figure 4).

**Robotic facelift thyroidectomy (RFT)**

Besides TART and BABA, other approaches of RT had been described. Terris et al. reported their initial experiences on robotic facelift thyroidectomy (RFT). The facelift incision is made adjacent to the postauricular crease, and crossing over the occipital hairline under cover of the ear, and extending inferiorly 1cm within the occipital hairline to ensure the scar will be invisible.

The dissection proceeds through identifying of SCM, going superficial to greater auricular nerve and reflecting or dividing the external jugular vein. Then a triangular space bounded by the anterior surface of SCM, the posterior sternohyoid muscle and the superior border of the omohyoid muscle is encountered. The omohyoid is reflected ventrally, and the anteromedial surface of SCM is fully dissected down to the clavicle. Once the operative field is maintained by placing a customized retractor blade underneath the strap muscles, robot is deployed. Three arms are directed along the axis of the fixed retractor system including the camera, grasper and harmonic device. Then thyroidectomy proceeds.

Table 1 shows the advantages and disadvantages of different RT approaches. Currently there is no evidence to suggest which technique is superior to the other and the choice is based on expertise and patient’s preference. Unlike TART and BABA, more experience of RFT is pending. Terris et al. reported RFT in 10 patients.
patients, and when compared to 5 patients with TART, the results favoured robotic facelift in terms of ease of surgery and operative time\textsuperscript{15}.

**Surgical and oncological outcome when compared to conventional open thyroidectomy**

Conventional open thyroidectomy (OT) remains the gold standard of thyroid surgery. To date, there has been no randomized trial comparing outcomes between RT and OT, while several meta-analyses were available for this issue. Lang et al.\textsuperscript{17} recently reported a meta-analysis aimed to compare surgical complications between RT (TART and BABA) and OT, which comprised 11 studies totalling 2375 patients (35.3% underwent RT and 64.7% underwent OT). RT was significantly associated with longer operating time by an average of 55.8 minutes (\(p < 0.001\)), hospital stay (\(p = 0.023\)) and higher temporary RLN injury (3.8% vs. 1.3%, \(p = 0.016\)). Other parameters such as permanent RLN palsy, temporary and permanent hypocalcaemia, haematoma and overall morbidity were comparable\textsuperscript{17}.

Similarly, in the meta-analysis by Jackson et al. comparing TART and OT\textsuperscript{18}, the operative time of RT was longer than that of the open approach (95% CI: 29.23, 54.87), but operation risks were similar in both groups\textsuperscript{18}. A recently published meta-analysis and systemic review by Sun et al.\textsuperscript{19} in 2014, including 11 studies with 726 patients undergoing RT (TART and BABA) and 1205 OT, also confirmed a significantly longer operation time in RT, exceeding OT by 76.7 minutes, while length of stay and other complications including haematoma, seroma, RLN injury and hypocalcaemia had no significant difference. Other outcome such as voice, pain and paraesthesia were similar, and the robotic cohort reported higher cosmetic satisfaction\textsuperscript{19}. To summarize, RT is significantly associated with a higher patient satisfaction in cosmesis, but with a longer operative time. The long term morbidity were similar to that of OT but in short term, the risk of temporary RLN may increase\textsuperscript{17}.

Moreover, there is concern about potential new complications that were not usually found in OT, such as brachial plexus injury, flap numbness and fibrosis, chyle leak and oesophageal perforation\textsuperscript{20}. Although the incidences of such complications were low, patients need to be informed about the potential risks before deciding on the surgical approach.

Regarding to oncological outcomes, due to the scarce long-term follow up data in literature, most of the outcome parameters measure post-operative thyroglobulin (Tg) level, TSH-stimulated Tg and RAI uptake at first RAI ablation in order to compare tumour clearance between RT and OT. Tae et al.\textsuperscript{21} studied 245 patients with papillary thyroid carcinoma (PTC) who underwent TT (62 with RT, 183 with OT), and found that the mean TSH-stimulated thyroglobulin (Tg) at first RAI ablation was significantly higher in the robotic group (\(p <0.001\)), but the TSH-stimulated Tg after RAI ablation did not differ. Similarly, in another study of 94 PTC patients who underwent TT and also central neck dissection (43 with TART, 51 with OT), the RAI uptake ratios at whole body scan before RAI ablation were significantly higher in the RT group but the RAI uptake ratios during follow-up scan after ablation were similar between RT and OT\textsuperscript{22}.

Lee J et al.\textsuperscript{23} reported a study involving 128 patients with PTC and also lateral neck node metastasis underwent TT with modified radical neck dissection (62 with TART and 66 with OT) which showed that the results of radioactive iodine scans and postoperative serum Tg concentrations did not differ significantly. Similar findings were also seen when BABA was compared to OT\textsuperscript{24}. In summary, current data suggested that RT may have similar surgical completeness versus OT. Even in studies which showed higher TSH-stimulated Tg in RT group, TSH-stimulated Tg after RAI ablation remains similar between RT and OT which may suggest that remnant thyroid tissue could be successfully ablated by RAI.

**Surgical and oncological outcome when compared to endoscopic thyroidectomy**

Since RT essentially belongs to the category of remote-access thyroidectomy, one of the contentious issues is whether there are measurable advantages with RT over non-robotic endoscopic thyroidectomy (ET). In November 2012, Lin et al.\textsuperscript{25} reported a meta-analysis comprising 6 studies with 2048 patients (978 underwent RT and 1070 underwent ET), and showed that RT was associated with more complications (WMD = 1.51, 95% CI 1.18 to 1.94) and greater amount of drainage fluid (WMD = 17.10, 95% CI 5.69 to 28.51). Other outcomes

<table>
<thead>
<tr>
<th>Table 1: Comparison of thyroidectomy techniques.</th>
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<tbody>
<tr>
<td>Hidden incisions</td>
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<tr>
<td>Size of scar</td>
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<tr>
<td>Extent of dissection</td>
</tr>
<tr>
<td>Bilateral access</td>
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<tr>
<td>Gas insufflation</td>
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<tr>
<td>Drains required</td>
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<tr>
<td>Outpatient procedure</td>
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<tr>
<td>Size of thyroid</td>
</tr>
<tr>
<td>Difficulty in learning</td>
</tr>
<tr>
<td>Cost</td>
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</tbody>
</table>

*, ++, +++; from least to most

Abbreviations: OT, open thyroidectomy; TART, transaxillary robotic thyroidectomy; BABA, Bilateral axillo-breast approach; RFT, robotic facelift thyroidectomy

including operating time, conversion, post-operative hospital stay and the number of LNs harvested were similar.

One year later, Lang et al.26 analysed 6 studies with a total of 3510 patients (61.7% underwent TART or BABA and 38.3% underwent ET). In contrast to the previous meta-analysis, this study showed that the RT group had significantly less temporary RLN injury (2.6% vs. 3.3%, p = 0.035) and shorter length of hospital stay (3.4 days vs. 3.5 days, p = 0.030). Again, higher drain output was observed in the RT group. There were no significant differences in total operating time when the robot was used irrespective of the extent of thyroidectomy and surgical approach (i.e. TAA or BABA). The number of LN harvest between RT and ET was again not significantly different.

Recently in 2014, Jackson et al.18 compared the efficacy of RT via TART with ET in a meta-analysis comprising 9 studies, totalling 2881 patients (1122 underwent RT and 1759 underwent ET), and found that the operative time tend to be shorter in RT group than ET group, which might be due to reduced operating time with better surgical manipulations in RT despite extra time for docking and undocking of the robot. This study again showed that RT had similar surgical risks to ET.

Incidence of complications including brachial plexus injury and skin flap paraesthesia, and also cosmetic satisfaction appeared similar between the RT and ET as expected27,28. RT may be associated with a higher pain score immediately after operation than ET9, but after the first day, postoperative pain appears similar between the two groups29.

Oncological outcome between RT and ET was not adequately studied in the current literature, partly because post-operative follow-up period was relatively short. Also most thyroid carcinoma had good tumour risk; only a significantly large cohort with long follow-up period would have enough power to truly evaluate any long term difference.

Nonetheless with limited data, in the meta-analysis by Lang et al. both RT and ET groups had comparable postoperative TSH-stimulated Tg level (0.8ng/mL vs. 1.1ng/mL, p = 0.456)26, suggesting completeness of tumour removal was similar.

Table 2: Summary of publications regarding robotic thyroidectomy in Graves’ disease.

<table>
<thead>
<tr>
<th>First author (year)</th>
<th>Region</th>
<th>Approach</th>
<th>No. of patients</th>
<th>Thyroid volume</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>RT</td>
<td>OT</td>
</tr>
<tr>
<td>Kandil E (2011)</td>
<td>USA</td>
<td>TART</td>
<td>5</td>
<td>16.6 ± 3.2 (ml)</td>
<td>-</td>
</tr>
<tr>
<td>Giannopoulos G</td>
<td>South Korea</td>
<td>TART</td>
<td>7</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Kwon H (2013)</td>
<td>South Korea</td>
<td>BABA</td>
<td>30</td>
<td>36.6 (7.8-123.0) g</td>
<td>-</td>
</tr>
<tr>
<td>Nouraeidine SI (2013)</td>
<td>USA</td>
<td>TART</td>
<td>12</td>
<td>62.3 ± 47.8 ml</td>
<td>147.3 ± 153.6 ml</td>
</tr>
<tr>
<td>Park JH (2013)</td>
<td>South Korea</td>
<td>TART</td>
<td>7</td>
<td>77.4 ± 12.3 g</td>
<td>85.6 ± 20.4g</td>
</tr>
</tbody>
</table>

Abbreviations: RT, robotic thyroidectomy; OT, open thyroidectomy.

Applying RT in Graves’ disease

Unlike the management for thyroid cancer and nodular goiter, application of RT for Graves’ disease (GD) remains challenging and some would even consider it as a relative contra-indication because of the technical difficulties resulting from a larger gland size and increased vascularity. Table 2 summarized the current literature on the application of RT in GD. Kandil et al. reported their successful experience of TART in 5 GD patients8, while in another study with 7 GD patients Giannopoulos G et al. commented that RT for GD should be reserved20. On the other hand, experience from Kwon H et al.31 about BABA for GD with mean thyroid volume of 36.6g was positive. When compared to OT, a retrospective study with 25 GD patients undergoing total thyroidectomy (12 with RT and 13 with OT) found that the thyroid volume appeared to be smaller in RT group (62.3 ml in RT and 147.3ml in OT, p = 0.08) and the surgical outcome were actually similar, suggesting that RT may be applicable to GD only if thyroid size is small32. While in a series of 16 GD patients (7 with RT and 9 with OT), RT and OT group had similar thyroid volume and surgical outcome, but the operative time in RT was significantly longer33. Currently the reported studies included only a small number of subjects. More studies are warranted to evaluate the application of RT in GD.

Cost analysis

Significantly higher direct medical cost is an obvious disadvantage with RT when compared to ET or OT. A cost-analysis by Cabot et al. showed that the total cost for OT, transaxillary ET, and TART were USD$9,028 ± $891, USD$12,505 ± $1,222, and USD$13,670 ± $1,384 respectively34. When compared to OT, one study estimated the cost of RT as operative time plus anaesthesia fees plus consumables plus the robotic system, and compared only those aspects of the procedure that would differ between RT and OT, a 2.2 times (217%) increase in costs related to the use of the robotic system to perform thyroidectomy was observed35.

When compared to ET, the cost was significantly higher in RT group when both the endoscopic equipment depreciation cost and complications cost had been added together36,37.
Learning curve
One potential advantage of RT was the shorter learning curve than ET which is relevant for a surgeon who would like to learn either procedure.\textsuperscript{27,28} When measured by the number of cases required before reaching a plateau in operating time, RT required 35 to 45 cases while ET required 55 – 60 cases\textsuperscript{27,28}.

Conclusion
Technologic advances are paramount in improving medical care for patients. However the proposed benefits of a new technique have to be weighed accurately against its risks and significantly higher cost. When compared to conventional OT, RT provides a superior cosmetic outcome without visible cervical scars.

Drawbacks are that RT requires significantly higher cost and longer operation time. To date, most studies reported similar surgical risks between OT and RT with one meta-analysis showing increased risk of temporary RLN palsy in RT. Moreover it may also introduce new complications which were not found in OT. Although current data suggest that the completeness of tumour removal by RT is similar to that by OT, the follow-up time has been too short to truly assess the oncologic outcome.

For patients who are motivated to completely avoid a neck scar, the additional use of robots showed similar cosmetic results to ET. RT has comparable operation time and surgical risks to ET, if not less as recent evidence showed that RT is associated with lower risk of temporary RLN injury and shorter operation time than OT. Other potential benefits of RT include shorter learning curve and better surgeon ergonomics. So far there are still many unresolved questions such as the long-term outcome in patients with thyroid carcinoma treated with RT, selection criteria for patients to undergo RT and cost-effectiveness of RT relative to OT or ET. To date, there has been no randomized trial comparing outcomes between RT and OT and a multi-centre trial is also not available. RT may be an alternative to OT in centres with adequate resources and expertise, but its application should be carefully and thoroughly discussed before one decides on the procedure.

Abbreviations list
RT, robotic thyroidectomy; OT, open thyroidectomy; ET, endoscopic thyroidectomy; TART, transaxillary robotic-assisted thyroidectomy; BABA, bilateral axillo-breast approach; RFT, robotic facelift thyroidectomy; GD, Graves’ disease; RLN, recurrent laryngeal nerve; LN, lymph node; 2-D, two dimension; 3-D, three dimension; FDA, US Food and Drug Administration; TSH, thyroid stimulating hormone; Tg, thyroglobulin; PTC, papillary thyroid carcinoma; RAI, radio-active iodine; WMD, weighted mean differences; CI, confidence interval; SCM, sternocleidomastoideus muscle; PM, pectoralis major

References
18. Jackson NR, Yao L, Tufano RP, Kandil EH. Safety of robotic thyroidectomy approaches: Meta-