Robotics in general surgery: A systematic cost assessment

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Abstract

The utilisation of robotic-assisted techniques is a novelty in the field of general surgery. Our intention was to examine the up to date available literature on the cost assessment of robotic surgery of diverse operations in general surgery. PubMed and Scopus databases were searched in a systematic way to retrieve the included studies in our review. Thirty-one studies were retrieved, referring on a vast range of surgical operations. The mean cost for robotic, open and laparoscopic ranged from 2539 to 57,002, 7888 to 16,851 and 1799 to 50,408 Euros, respectively. The mean operative charges ranged from 273.74 to 13,670 Euros. More specifically, for the robotic and laparoscopic gastric fundoplication, the cost ranged from 1534 to 2257 and 657 to 763 Euros, respectively. For the robotic and laparoscopic colectomy, it ranged from 3739 to 17,080 and 3109 to 33,865 Euros, respectively. For the robotic and laparoscopic cholecystectomy, ranged from 1163.75 to 1291 and from 273.74 to 1223 Euros, respectively. The mean non-operative costs ranged from 900 to 48,796 from 8347 to 8800 and from 870 to 42,055 Euros, for robotic, open and laparoscopic technique, respectively. Conversions to laparotomy were present in 34/18,620 (0.18%) cases of laparoscopic and in 22/1488 (1.5%) cases of robotic technique. Duration of surgery robotic, open and laparoscopic ranged from 54.6 to 328.7, 129 to 234, and from 50.2 to 260 min, respectively. The present evidence reveals that robotic surgery, under specific conditions, has the potential to become cost-effective. Large number of cases, presence of industry competition and multidisciplinary team utilisation are some of the factors that could make more reasonable and cost-effective the robotic-assisted technique.

Key words: Costs, general surgery, healthcare economics, outcomes, robotics, training

INTRODUCTION

The evolution of robotic technology during the last decade has facilitated the realisation of a great variety of operations in various surgical fields. The robotic-assisted technique has an important position among the other minimally invasive methods in general surgery. Several are the main advantages of robotic-assisted surgery, such as three-dimensional view of the operating field, low intraoperative blood loss, the precision of movements due to the elimination of surgeon tremor, utilisation of wristed instruments that improve dexterity and facilitate suturing, have made possible even the most complicated operations such as robotic pancreaticoduodenectomy. In contrast to the above-mentioned advantages, the absence of tactile feedback of the surgeon and the cost are the main weak points of the robotic technique.

Nowadays, the only commercially available robotic equipment “(da Vinci®, Intuitive Surgical Inc.; CA, USA) is characterised by...
elevated cost, including the cost of acquisition, training, and equipment-instrument cost, as well as that of maintenance of the robotic system (with an annual service contract, over 100,000 US dollars). This high cost can explain the reasons that decreased the widespread use of robotic-assisted surgery.\(^{[4]}\) According to van Dam et al., to amortise the initial capital for the acquisition of robotic devices, the technique should be applied on more than 300 surgical procedures per year for 7 years, equivalent to an amount of over 1000 Euros per patient.\(^{[4]}\) As a result, it can be easily understood that the robotic technology refers exclusively to surgical centres with a large volume of patients to achieve the per case charges as low as possible. The robotic instrumentation that has increased the cost of acquisition (almost over 1500 Euros per instrument), as well as a limited number of use (10 uses per instrument), represent another financial burden.\(^{[9]}\) Moreover, the reimbursement to the hospital for utilisation of the robot is in direct correlation with the type of health insurance and the health system itself, favouring the countries without universal health coverage.

The purpose of this review is to evaluate the till now available literature on the cost assessment of robotic technology in the field of general surgery.

**METHODS**

**Data sources**

A systematic search was held in PubMed (16 November 2015) and Scopus (16 November 2015) databases. The same search strategy was implemented in both PubMed and Scopus databases, consisted of a sequence of keywords: (Robot OR robotic OR telesurgery) AND (general surgery OR bariatric OR colorectal resection OR cholecystectomy OR appendicectomy OR pancreatectomy OR splenectomy OR fundoplication OR pancreaticoduodenectomy) AND (cost OR cost analysis). The references of each included study were also searched.

**Study selection criteria**

All comparative articles providing information regarding the cost evaluation of robotic technology in general surgery were regarded as valid for this review. Only articles published in English, German, French, Italian, Spanish and Greek were involved in this review. Abstracts, reviews, letters to the editor, short surveys, commentaries and editorials were not included in this review.

**Definitions**

Operative charges are constituted of the medical costs referred exclusively to operation (e.g. operating theatre, anaesthesia and surgical supply). Non-operative charges are constituted of all the costs not referred exclusively to the operation but to preoperative procedure and postoperative recuperation (e.g., postoperative medication, hospital stay, laboratory, and radiology). Total costs are constituted of the sum of operative and non-operative charges. All costs are calculated in Euros.

A total of 175 and 656 studies were retrieved, respectively, in PubMed and Scopus search among which 31 studies that have met the inclusion criteria of our systematic review.\(^{[6]-[36]}\) Three additional studies were included through hand-searching of included references.\(^{[11,23,25]}\) Figure 1 represents the followed search strategy (flow diagram).

The principal characteristics of the included studies in our review (demographics, type of operation, number of patients, total costs, operative charges, non-operative charges, robot charges included to the total costs, surgical equipment costs, operating theatre costs, length of hospital stay, number of conversions to laparotomy, duration of the operation and blood loss) are presented in Table 1.

**Statistical considerations**

Nonparametric statistical techniques were applied in this study. These methods are appropriate because the studies' data did not present normal distributions. Kruskal–Wallis test was used to test the differences in the median between the three surgical techniques (OP, LA, and RO) applied in various types of operations. The value of \(P < 0.05\) denoted statistical significance.

**RESULTS**

Among the 31 studies included, 7 referred to gastric fundoplication, 5 to adrenalectomy, 5 to colectomy, 4 to cholecystectomy, 3 to Roux-en-Y gastric bypass, 2 to pancreatectomy, 2 to rectal resection, 2 to splenectomy, 1 to positioning of adjustable gastric banding, 1 to sigmoidectomy, 1 to gastroenterostomy, 1 to rectopexy, 1
to sleeve gastrectomy and 1 to adhesiolysis. The median cost for adhesiolysis ranged from 21,995 to 32,020, and the weighted median average was 30,309.38 for 405,068 patients, regardless of the type of operation. The median cost for adrenalectomy ranged from 13,197 to 32,712 and the weighted median average was 38,093.38 for 20,465 patients, regardless of the type of operation. The median cost for cholecystectomy ranged from 23,307 to 23,561, and the weighted median average was 23,560.83 for 731,879 patients, regardless of the type of operation. The median cost for splenectomy ranged from 1898 to 5077, and the weighted median average was 3487.50 for 90 patients, regardless of the type of operation [Figure 2]. There was a significant difference between adhesiolysis, adrenalectomy and cholecystectomy as well (P < 0.01). Seven studies had 3 arms comparing robotic to open to laparoscopic, 2 studies had 2 arms comparing robotic to open while 22 studies compared robotic with the laparoscopic technique. Of the 31 studies listed, 14 had no surgical equipment or operating room costs. Of these 14, further 7 were not analysing any operative charges or non-operative charges but only total costs. 184,431 patients were operated by the open method, 1,006,285 patients with laparoscopic and 37,814 with robotic. The mean cost for robotic, open and laparoscopic ranged from 2539 to 57,002, 7888 to 16,851 and 1799 to 50,408 Euros, respectively. The mean operative charges ranged from 900 to 48,796, from 8347 to 8800 and from 870 to 42,055 Euros, for robotic, open and laparoscopic technique, respectively. The mean operative costs for splenectomy was 5075 Euros for robotic technique and 2992 Euros for laparoscopic technique. In twelve studies, the robotic costs were included in the estimation of operative charges. Surgical equipment costs varied between 644 and 6639 Euros. Operating theatre costs ranged from 636 to 4468 Euros per surgical case. Regarding adhesiolysis, adrenalectomy and cholecystectomy, the weighted median average costs were 29,703.10 for operative charges, 25,703.10 for laparoscopic charges and 22,122.32 for robotic charges. There was a significant difference between these three types of operations P < 0.05 [Figure 2].

The mean hospital stay (in days) for robotic, open and laparoscopic techniques ranged from 1.8 to 51, from 3 to 220 and from 2.3 to 11, respectively. More specifically, in robotic, open and laparoscopic gastric fundoplication, it ranged from 2.3 to 4, 6.1 to 7.9 and 2.3 to 5.2 days, respectively. For robotic and laparoscopic adrenalectomy, it ranged from 1.8 to 6.4 and 2 to 6.2 (median) days, respectively. For robotic, open and laparoscopic colectomy, it ranged from 5.2 to 7.46, 5 to 32 and 5.5 to 8.3, respectively. For robotic and laparoscopic cholecystectomy, it ranged from 2.7 to 4.58 and 2.3 to 4.84, respectively. In Roux-en-Y gastric bypass, for robotic, open and laparoscopic technique, it ranged from 3 to 7.8, 5 to 220 and from 3.3 to 11, respectively. In pancreactectomy, it ranged from 4 to 7.1, 3 to 25 and 6 to 7.3, respectively. In rectal resection, it ranged from 4 to 51, 4 to 24 and 10.8 ± 8.6, respectively. In splenectomy, it ranged from 5 to 11 and 4 to 7, respectively for the robotic and the laparoscopic technique. Conversions to laparotomy were performed in 34/18,620 (0.18%) cases of laparoscopic and in 22/1488 (1.5%) cases of robotic technique. The mean duration of robotic, open and laparoscopic techniques ranged from 54.6 to 328.7, 129 to 234 and from 50.2 to 260 min, respectively. Blood loss in robotic, open and laparoscopic ranged from 8.4 to 279, from 120 to 681 and from 12 to 667 ml, respectively.

**DISCUSSION**

The introduction of innovative and less invasive technologies in surgical fields has been adopted with great difficulty from

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**Figure 2:** Estimated total costs in correlation of the surgical technique used in three types of operations

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Journal of Minimal Access Surgery | ??? | ??? | ???
| First author, year[a] | Type of operation | Number of patients (%) | Total costs | Operative charges | Non-operative charges | Robot cost included (Y/N) | Surgical equipment costs | Operating room costs | Length of hospital stay (days) | Conversion to laparotomy (%) | Duration of surgery (min) | Blood loss (mL) |
|-----------------------|-------------------|------------------------|-------------|-------------------|----------------------|--------------------------|------------------------|------------------|-------------------------------|--------------------------|--------------------------|--------------------------|
| Aghesioiysis, Salman, 2013[31] | OP 165,078/226,445 (16.3) | Median: 32,020 NR | NR | NR | NR | NR | NR | Median: 5.7 | NR | NR | NR | |
| | LA 205,813/1,162,790 (17.7) | Median: 30,318 NR | NR | NR | NR | NR | Median: 4.7 | NR | NR | NR | |
| | RO 34,177/37,270 (91.7) | Median: 21,995 NR | NR | NR | NR | NR | Median: 4.9 | P<0.05 | NR | NR | NR | |
| Adrenalectomy, Salman, 2013[31] | OP 16,530/226,445 (7.3) | Median: 39,692 NR | NR | NR | NR | NR | NR | Median: 6.7 | NR | NR | NR | |
| | LA 3,488/1,162,790 (0.3) | Median: 31,207 NR | NR | NR | NR | NR | Median: 4.7 | P<0.05 | NR | NR | NR | |
| | RO 447/37,270 (1.2) | Median: 32,712 NR | NR | NR | NR | NR | Median: 6.7 | P<0.05 | NR | NR | NR | |
| Brunaud, 2008[11] | LA - | Mean: 1,799 NR | NR | NR | NR | NR | NR | Mean (SD): 6.4 (3) | 5/100 (5) | Mean (SD): 99 (35) (40-275) | NR | NR | |
| | RO 100 | Mean: 4,102 NR | NR | NR | NR | NR | Mean: 1.8 | NR | NR | NR | |
| Prewitt, 2008[29] | OP - | NR | NR | NR | NR | NR | NR | - | NR | NR | NR | |
| | RO 16 | Mean: 6,942 NR | NR | NR | NR | NR | Mean: 1.8 | NR | NR | NR | |
| Winter, 2006[36] | OP 20/95 (21) | Median: 13,383 Median: 6,942 | NR | NR | NR | NR | Mean: 1.8 | NR | NR | NR | |
| | LA 45/95 (47) | Median: 13,197 Median: 6,334 | NR | NR | NR | NR | Mean: 2 | 0/30 | NR | NR | |
| | RO 30/95 (32) | Median: 15,842 Median: 9,508 | NR | NR | NR | NR | Median: 2 | 0/30 | Median (range): 185 (130-295) | NR | NR | |
| Morino, 2004[22] | LA 10/20 (50) | Mean: 2,005 Mean: 1,027 Mean: 991 Mean: 598 | Mean: 991 | Mean: 428 | Mean: 5.4 | Mean: 5.7 | Mean (range): 0/10 | Mean (range): 5.4 (4-8) | Mean (range): 5.7 (4-9) | Mean (range): 169 (136-215) | P<0.01 | |
| | RO 10/20 (50) | Mean: 2,539 Mean: 1,510 Mean: 1,046 | Mean: 873 Mean: 636 Mean: 3 (2-4) Mean: 3 (2-4) | Mean (range): 0/10 | Mean (range): 5.4 (4-8) | Mean (range): 5.7 (4-9) | Mean (range): 0/10 | Mean (range): 5.4 (4-8) | Mean (range): 5.7 (4-9) | Mean (range): 169 (136-215) | P<0.01 | |
| Adjustable gastric banding, Muehlmann, 2003[34] | LA 10/20 (50) | Mean: 4,587 Mean: 4,587 | Mean: 1,089 Mean: 1,089 | Mean (range): 3 (2-4) Mean (range): 3 (2-4) | Mean (range): 0/10 | Mean (range): 5.4 (4-8) | Mean (range): 5.7 (4-9) | Mean (range): 0/10 | Mean (range): 5.4 (4-8) | Mean (range): 5.7 (4-9) | Mean (range): 169 (136-215) | P<0.01 | |
| | RO 10/20 (50) | Mean: 6,964 Mean: 1,089 | Mean (range): 97 (60-140) | Mean (range): 3 (2-4) Mean (range): 3 (2-4) | Mean (range): 0/10 | Mean (range): 5.4 (4-8) | Mean (range): 5.7 (4-9) | Mean (range): 0/10 | Mean (range): 5.4 (4-8) | Mean (range): 5.7 (4-9) | Mean (range): 169 (136-215) | P<0.01 | |

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| First author, year[ref] | Type of operation | Number of patients (%) | Total costs | Operative charges | Non-operative charges | Robot cost included (Y/N) | Surgical equipment costs | Operating room costs | Length of hospital stay (days) | Conversion to laparotomy (%) | Duration of surgery (min) | Blood loss (mL) |
|-------------------------|-------------------|------------------------|-------------|-------------------|----------------------|--------------------------|-------------------------|---------------------|-------------------------------|---------------------------|--------------------------|----------------|
| **Cholecystectomy**     |                   |                        |             |                   |                      |                          |                         |                     |                               |                           |                          |               |
| Buzat, 2013[12]         | LA                | 10/30 (33)             | NR          | NR                | NR                   | N                        | Mean: 945               | NR                  | 0/10                          | Mean (SD): 85.5 (11.8) | Mean (SD): 12 (7.5) |               |
|                         | RO                | 20/30 (67)             | NR          | NR                | Mean: 935            | NR                       |                         | NR                  | 0/20                          | Mean (SD): 84.6 (20.5) | Mean (SD): 8.4 (7.3) | P=0.2289 |
| **Salman, 2013[31]**    |                   |                        |             |                   |                      |                          |                         |                     |                               |                           |                          |               |
|                         | LA                | 731,395/1,162,790 (62.9) | NR          | NR                | NR                   | NR                       | Median‡: 23,561         | NR                  | 0/10                          | Mean (SD): 85.5 (11.8) | Mean (SD): 12 (7.5) |               |
|                         | RO                | 484/37,270 Median: 1,307 | NR          | NR                | NR                   | NR                       | Median‡: 23,307         | NR                  | 0/20                          | Mean (SD): 84.6 (20.5) | Mean (SD): 8.4 (7.3) | P=0.2289 |
| **Breitenstein, 2008[10]** |                   |                        |             |                   |                      |                          |                         |                     |                               |                           |                          |               |
|                         | LA                | 50/100 (50) Mean (SD): 4,581 (1,433) | Mean: 1,223 | Mean: 3,390       | Y                    | NR                       | Mean: 1,291             | Mean: 4,598          | 0/50                          | Mean (SD): 4.84 (2.2)  | Mean (SD): 50.2 (29.2) | NR         |
|                         | RO                | 50/100 (50) Mean (SD): 5,861 (1,290) | Mean: 1,291 | Mean: 4,598       | NR                   | NR                       | Mean (SD): 4.58 (1.9)  | Mean (SD): 54.6 (31.6) | P=0.54                     | Mean (SD): 1.30††      | Mean (SD): 1.55††    | NR         |
| **Heemskerk, 2005[18]** |                   |                        |             |                   |                      |                          |                         |                     |                               |                           |                          |               |
|                         | LA                | 12/24 (50) Mean: 2,148.45 P<0.001 | Mean: 273.74 | Mean: 1,874.71 Y | -                    | NR                       | Mean: 1,163.75         | Mean: 2,165.32       | 0/12                          | Mean (SD): 2.3          | Mean (SD): 1.30††    | NR         |
|                         | RO                | 12/24 (50) Mean: 3,329.07 P<0.001 | Mean: 2,571 | Mean: 2,596       | Y                    | NR                       | Mean: 889.18           | Mean: 165.32         | 0/12                          | Mean (SD): 2.7          | Mean (SD): 1.55††    | P=0.17    |
| **Colectomy**           |                   |                        |             |                   |                      |                          |                         |                     |                               |                           |                          |               |
| Keller, 2013[21]        | LA                | 17,265/1,809 (95.9)    | Mean: 31,970 | Mean: 2,571       | Y                    | Mean: 2,252              | Mean: 29,399           | Mean: 2,596          | 0/17,265                     | Mean (SD): 6.13         | Mean (SD): 201        | NR         |
|                         | RO                | 744/18,099 (4.1)       | Mean: 39,160 | Mean: 3,572       | P<0.001              | Mean: 3,588             | Mean: 3,777            | Mean: 7.46           | 0/744                        | Mean (SD): 261          | Mean (SD): 0.001      | P=0.211   |
| Park, 2012[28]          | LA                | 35/70 (50) Mean (SD): 7,561 (1,178) | Mean: 5,014 | Mean: 2,596       | Y                    | Mean (SD): 4,468 (4.91) | Mean (SD): 8.3 (4.2)   | Mean (SD): 0.35       | Mean (SD): 130 (43)         | Mean (SD): 56.8 (31.3) | Mean (SD): 35.8 (26.3) | MEAN (SD): 35.8 (26.3) |
|                         | RO                | 35/70 (50) Mean (SD): 8,964 (1,998) | Mean: 7,451 | Mean: 1,572       | Y                    | Mean (SD): 6,639 (979)  | Mean (SD): 7.9 (4.1)   | Mean (SD): 0.13       | Mean (SD): 195 (41)         | Mean (SD): 35.8 (26.3) | Mean (SD): 35.8 (26.3) | MEAN (SD): 35.8 (26.3) |

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| First author, year[8] | Type of operation | Number of patients (%) | Total costs | Operative charges | Non-operative charges | Robot cost included (Y/N) | Surgical equipment costs | Operating room costs | Length of hospital stay (days) | Conversion to laparotomy (%) | Duration of surgery (min) | Blood loss (mL) |
|----------------------|-------------------|------------------------|-------------|------------------|----------------------|-------------------------|------------------------|---------------------|----------------------------|-----------------------------|-----------------------------|---------------------|
| Bertani, 2011[8]     | OP                | 45/109 (41.3)          | Mean: 7,888 | NR               | NR                   | Y                      | Mean: 1,694             | Mean: 795           | Median (range): 6 (5-32) | -                           | Median (range): 133        | Median (range): 150      |
|                      | LA                | 30/109 (27.5)          | Mean: 7,968 | NR               | NR                   |                        | Mean: 2,066             | Mean: 1,128           | Median (range): 5 (3-12) | 2/30 (6.7)                  | Median (range): 210 (150-360) | Median (range): 110 (50-300) |
|                      | RO                | 34/109 (31.2)          | Mean: 10,027| NR               | NR                   |                        | Mean: 3,166             | Mean: 1,011           | Median (range): 5 (4-17) | 2/34 (5.9)                  | Median (range): 194 (130-301) | Median (range): 170 (80-1,000) |
| de Souza, 2010[4]    | LA                | 135/175 (77.1)         | Median (range): 9,057 | Median (range): 5,458 | NR                   | NR                      | Mean (SD): 6,816 (3,743) | Mean (SD): 3,200 (639) | Mean (SD): 5.5 (3.4) | 1/135 (0.74)                | Median (SD): 118.08 (38.1) | Median (SD): 50 (100-600)  |
|                      | RO                | 40/175 (22.9)          | Median (range): 11,131 | Median (range): 6,816 | NR                   | NR                      | Mean (SD): 2,176 (350) | Mean (SD): 4,294 (669) | Mean (SD): 5.2 (5.8) | 1/40 (2.5)                  | Median (SD): 158.93 (36.69) | Median (SD): 50 (10-240)   |
| Rawlings, 2007[30]   | LA                | 15/32 (46.9)           | Mean (SD): 5,954 (2,069) | NR               | NR                   | NR                      | Mean (SD): 1,358 (382) | Mean (SD): 3,200 (639) | Mean (SD): 5.5 (3.4) | 2/15 (13.3)                 | Median (SD): 169.2 (37.5) | Median (SD): 66.3 (50.7)  |
|                      | RO                | 17/32 (53.1)           | Mean (SD): 6,825 (3,743) | NR               | NR                   | NR                      | Mean (SD): 2,176 (350) | Mean (SD): 4,294 (669) | Mean (SD): 5.2 (5.8) | 0/17                         | Median (SD): 218.9 (44.6) | Median (SD): 40 (24.9)    |
| Sigmoideotomy       | Rawlings, 2007[30]| LA                      | 12/25 (48) | Mean (SD): 7,889 (8,642) | NR               | NR                   | NR                      | Mean (SD): 1,650 (698) | Mean (SD): 3,668 (1,177) | Mean (SD): 6.6 (8.3) | 0/12                         | Median (SD): 199.4 (44.5) | Median (SD): 65.4 (52.1)  |
|                      | RO                | 13/25 (52)             | Mean (SD): 9,097 (8,989) | NR               | NR                   | NR                      | Mean (SD): 2,330 (470) | Mean (SD): 4,468 (903) | Mean (SD): 6.0 (7.3) | 2/13 (15.4)                 | Median (SD): 225.2 (37.1) | Median (SD): 90.4 (60)    |
| Rectal resection     | Baek, 2012[7]     | LA                      | 150/304 (49.3) | Mean (SD): 7,311 (2,600) | Mean (SD): 5,634 | Y                      | Mean (SD): 2,457 (544) | Mean (SD): 10.8 (8.6) | -                           | Median (SD): 219.7 (71.2) | Median (SD): 126.2 (267.7) |
|                      | RO                | 154/304 (50.7)         | Mean (SD): 10,731 (2,800) | Mean (SD): 6,483 (1,167) | Mean (SD): 4,248 |                       | Mean (SD): 644 (7,194) | Mean (SD): 11.1 (7.0) | -                           | Median (SD): 285.2 (69.1) | Median (SD): 167.8 (26.1) |
| Bertani, 2011[8]     | OP                | 34/86 (39.5)           | Mean (SD): 9,858 | NR               | NR                   | Y                      | Mean: 2,511             | Mean: 954             | Median (range): 7 (4-24) | Q/34                        | Median (range): 164 (100-350) | Median (range): 120 (50-2,000) |
|                      | RO                | 52/86 (60.5)           | Mean: 11,214 | NR               | NR                   |                        | Mean: 3,140             | Mean: 1,417           | Median (range): 6 (4-51) | 2/52 (4)                    | Median (range): 260 (190-370) | Median (range): 100 (50-1,000) |

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| First author, year | Type of operation | Number of patients (%) | Total costs | Operative charges | Non-operative charges | Robot cost included (YN) | Surgical equipment costs | Operating room costs | Length of hospital stay (days) | Conversion to laparotomy (%) | Duration of surgery (min) | Blood loss (mL) |
|-------------------|-------------------|------------------------|-------------|-------------------|----------------------|------------------------|-------------------------|---------------------|-----------------------------|-----------------------------|---------------------------|-----------------|
| **Gastroenterostomy** | | | | | | | | | | | | |
| Wormer, 2013[31]  | LA                | 29.677/29.959 (99.1)  | Mean (SD): 31,317 (17,120) | NR     | NR     | NR     | NR     | NR     | Mean (SD): 2.2 (1.5) | NR | NR | NR |
|                   | RO                | 282/29.959 (0.9)      | Mean (SD): 44,574 (21,165) | NR     | NR     | NR     | NR     | NR     | Mean (SD): 2.5 (2.4) | P<0.05 | NR | NR | NR |
| **Fundoplication** | | | | | | | | | | | | |
| Owen, 2014[27]    | OP                | 2,168/12,079 (18)    | Mean (SD): 9,353 (10,244) | NR     | NR     | NR     | NR     | NR     | Mean (SD): 6.1 (7.2) | P<0.05 | NR | NR | NR |
|                   | LA                | 9,572/12,079 (79.2)  | Mean (SD): 5,838 (5106)    | NR     | NR     | NR     | NR     | NR     | Mean (SD): 2.8 (3.6) | P<0.05 | NR | NR | NR |
|                   | RO                | 339/12,079 (2.8)     | Mean (SD): 7,799 (4,426)   | P<0.05 | NR     | NR     | NR     | NR     | Mean (SD): 3 (3.5) | P<0.05 | NR | NR | NR |
| **Wormer, 2013[31]** | LA                | 7,484/7,756 (96.5)  | Mean (SD): 24,139 (17,622) | NR     | NR     | NR     | NR     | NR     | Mean (SD): 2.3 (2) | NR | NR | NR |
|                   | RO                | 27,727,756 (3.5)     | Mean (SD): 27,576 (15,484) | P<0.05 | NR     | NR     | NR     | NR     | Mean (SD): 2.3 (2) | NR | NR | NR |
| **Nakadi, 2010[26]** | LA                | 11/20 (55)           | Mean (SEM): 5,907 (168)    | Mean (SEM): 1,525 (35) | Mean: 4,382 | N     | Mean: 76 | NR     | Mean (SEM): 4.1 (0.3) | 0/11 | Mean (SEM): 96 (5) | NR |
|                   | RO                | 9/20 (45)            | Mean (SEM): 27,561 (99)    | Mean (SEM): 1,553 (40) | Mean: 26,008 | N     | Mean: 1,214 | P<0.001 | Mean (SEM): 4.4 (0.2) | 1/9 (11.1) | Mean (SEM): 137 (12) | P=0.01 |
| **Andeberg, 2009[26]** | OP                | 10/34 (29.4)        | Mean: 10,521               | NR     | Mean: 8,347 | N     | NR     | NR     | Mean (SD): 7.9 (2.8) | NR | Mean (SD): 129 (43) | NR |
|                   | LA                | 10/34 (29.4)        | Mean: 8,982                | NR     | Mean: 5,494 | NR     | NR     | NR     | Mean (SD): 5.2 (3.0) | NR | Mean (SD): 207 (52) | NR |
|                   | RO                | 14/34 (41.2)        | Mean: 9,584                | NR     | Mean: 4,015 | Mean: 2,081 | NR | NR     | NR     | Mean (SD): 3.8 (1.9) | P=0.002 | Mean (SD): 207 (47) | P=0.003 |
| **Heemskerk, 2007[29]** | LA                | 11/22 (50)        | Mean: 3,376.35             | NR     | NR     | NR     | NR     | NR     | Mean: 4 | 0/11 | Mean: 135 | NR |
|                   | RO                | 11/22 (50)        | Mean: 4,363.82             | P=0.033 | NR     | NR     | NR     | NR     | Mean: 4 | 0/11 | Mean: 176 | P=0.094 |
| **Mueller-Stich, 2007[35]** | LA                | 20/40 (50)       | Mean (SD): 2,743 (483)     | Mean (SD): 763 (115) | NR     | NR     | NR     | NR     | Mean (SD): 3.3 (0.8) | 0/40 | Mean (SD): 102 (19) | NR |
|                   | RO                | 20/40 (50)       | Mean (SD): 3,244 (512)     | Mean (SD): 1,534 (111) | NR     | NR     | NR     | NR     | Mean (SD): 2.9 (0.8) | 0/40 | Mean (SD): 88 (18) | NR |
Table 1: Contd...

| First author, year[ref] | Type of operation | Number of patients (%) | Total costs | Operative charges | Non-operative charges | Robot cost included (Y/N) | Surgical equipment costs | Operating room costs | Length of hospital stay (days) | Conversion to laparotomy (%) | Duration of surgery (min) | Blood loss (mL) |
|-------------------------|-------------------|------------------------|-------------|------------------|----------------------|--------------------------|-------------------------|---------------------|-------------------------------|--------------------------|--------------------------|------------------|
| Morino, 2006[23]        | LA                | 25/50 (50)             | Mean: 1,527 | Mean: 657         | Mean: 870            | N                        | Mean: 100               | Mean: 557            | Mean (range): 2.9 (2-6)      | 0/25                     | Mean (SEM): 11.1 (10.6) | NR               |
|                         | RO                | 25/50 (50)             | Mean: 3,157 | Mean: 2,257       | Mean: 900            | P<0.001                  | Mean: 1,454             | Mean: 803            | Mean (range): 3 (2-7)       | 1/25 (4)                 | Mean (SEM): 131.3 (18.3) | P<0.001          |
| Pancreatectomy Kang, 2011[20] | LA                | 25/45 (55.6)           | Mean (SD): 2,829 (1,263) | Mean (SD): 1,628 (460) | NR                    | Y                        | NR                      | NR                  | Mean (range): 7.3 (3.0)   | NR                      | Mean (SD): 258.2 (118.6) | NR               |
|                         | RO                | 20/45 (44.4)           | Mean (SD): 6,085 (637) | Mean (SD): 4,215 (279) | NR                    | NR                      | NR                      | NR                  | Mean (range): 7.1 (2.2)   | P=NS                    | Mean (SD): 328.7 (121.8) | NR               |
| Waters, 2010[21]        | OP                | 22/57 (38.6)           | Mean: 11,372 | Mean: 2,572       | Mean: 8,800           | Y                        | NR                      | NR                  | Mean (range): 8 (3-25)    | NR                      | Mean (range): 234 (136-437) | NR               |
|                         | LA                | 18/57 (31.6)           | Mean: 9,451 | Mean: 2,251       | Mean: 7,201           | NR                      | NR                      | NR                  | Mean (range): 6 (3-34)    | 2/18 (11.1)             | Mean (range): 224 (100-346) | NR               |
|                         | RO                | 17/57 (29.8)           | Mean: 7,758 | Mean: 3,589       | Mean: 4,169           | NR                      | NR                      | NR                  | Mean (range): 4 (2-6)     | 2/17 (11.7)             | Mean (range): 298 (191-418) | NR               |
| Rectopexy Heemskerk, 2007[17] | LA                | 14/33 (42.4)           | Mean: 3,115.55 | NR              | NR                    | Y                        | Mean: 780               | NR                  | Mean (range): 4.3         | 0/19                    | Mean: 113               | NR               |
|                         | RO                | 19/33 (57.6)           | Mean: 3,672.84 | NR              | NR                    | NR                      | Mean: 780               | NR                  | Mean (range): 3.5         | 1/19 (5)                | Mean: 152               | NR               |
| Roux-en-Y gastric bypass Hagen, 2012[16] | OP                | 524/990 (52.9)         | Mean: 16,851 | NR              | NR                    | NR                      | Mean: 1,869             | NR                  | Mean (range): 10.9 (5-220) | -                       | NR                      | NR               |
|                         | LA                | 323/990 (32.6)         | Mean: 15,897 | NR              | NR                    | NR                      | Mean: 4,025             | NR                  | Mean (range): 16/323 (4.9) | NR                      | Mean (range): 11 (5-249)  | NR               |
|                         | RO                | 143/990 (14.5)         | Mean: 14,187 | NR              | NR                    | NR                      | Mean: 3,845             | NR                  | Mean (range): 2/143 (1.4) | P=0.038                 | Mean (range): 7.4 (4-24)  | P=NS             |
| Scozzari, 2011[33]      | LA                | 423/533 (79.4)         | Mean: 4,658.28 | Mean: 2,318.28   | Mean: 2,340           | Y                        | Mean: 765.78            | Mean: 1,402.5        | Mean (range): 8.3 (3-99)   | Mean (range): 0/423      | Mean (range): 187 (75-360) | NR               |
|                         | RO                | 110/533 (20.6)         | Mean: 5,777.76 | Mean: 3287.76    | Mean: 2,490           | P<0.001                  | Mean: 1,581.51          | Mean: 1,856.25        | Mean (range): 7.8 (3-65)   | Mean (range): 0/110      | Mean (range): 247.5 (90-405) | P<0.001          |

Contd...
Table 1: Contd...

| First author, year | Type of operation | Number of patients (% | Total costs | Operative charges | Non-operative charges | Robot cost included (Y/N) | Surgical equipment costs | Operating room costs | Length of hospital stay (days) | Conversion to laparotomy (%) | Duration of surgery (min) | Blood loss (mL) |
|--------------------|------------------|------------------------|-------------|-------------------|-----------------------|---------------------------|--------------------------|----------------------|-------------------------------|--------------------------|-------------------------|-------------------|
| Curet, 2009[13]    | LAH              | 36/135 (26.7)          | Mean: 50,408 | NR                | Mean: 42,055           | NR                        | NR                      | NR                   | Mean: 3.3                   | NR                      | Mean: 183.3              | NR                |
|                    | LAS              | 78/135 (57.8)          | Mean: 48,503 | NR                | Mean: 39,418           | NR                        | NR                      | NR                   | Mean: 3.6                   | NR                      | Mean: 185.6              | NR                |
|                    | RO               | 21/135 (15.5) P=0.047  | Mean: 57,002 | NR                | Mean: 48,796 P=0.015   | NR                        | NR                      | NR                   | Mean: 3                      | NR                      | Mean: 181.7              | NR                |
| Schraibman, 2014[32] | Sleeve Gastrectomy | LA              | 32/48 (66.7) Mean (range): 9,972 (23,518-54,645) | Mean (range): 7,138 (17,299-46,725) | NR | Y | NR | NR | Median (1<sup>st</sup>-3<sup>rd</sup> quartile): 3 (2-4) | NR | Median (1<sup>st</sup>-3<sup>rd</sup> quartile): 138 (115-170) | NR | Median (1<sup>st</sup>-3<sup>rd</sup> quartile): 148 (133-168) | P=0.211 |
|                    | RO               | 16/48 (33.3) P<0.001   | Mean (range): 15,521 (11,433-98,668) P=0.001 | Mean (range): 13,670 (8,532-20,144) P=0.001 | NR | NR | NR | Median (1<sup>st</sup>-3<sup>rd</sup> quartile): 3 (2-4) P=0.766 | NR | Median (1<sup>st</sup>-3<sup>rd</sup> quartile): 148 (133-168) | P=0.211 |
| Gelmis, 2011[15]   | Splenectomy      | LA              | 45/90 (50) Median: 1,898 | NR | NR | NR | NR | NR | Median: 5.3 | 5/45 (11.1) | Median: 125 | NR |
|                    | RO               | 45/90 (50) Median: 5,077 | NR | NR | NR | NR | NR | Median: 5.1 | 4/45 (8.9) | Median: 153 | P<0.05 |
| Bodner, 2005[9]    | LA               | 6/12 (50) NR       | Mean: 2,992 | NR | Y | NR | NR | Median: 6 (4-7) | 0/12 | Mean: 127 | Mean: <50 |
|                    | RO               | 6/12 (50) NR       | Mean: 5,075 | NR | Mean: 957 | P<0.05 | 7 (5-11) | P<0.05 | Mean: 154 (115-292) | P<0.05 | Mean: <50 | P<0.05 |

OP: Open, LA: Laparoscopic, RO: Robotic, NR: Not referred, NA: Not applicable, Y: Yes, N: No, hr: Hour, SD: Standard deviation, SEM: Standard error of mean, NS: Not statistically significant, LAH: Laparoscopic handsewn technique, LAS: Laparoscopic stapled technique. *All costs are estimated in Euros. †Expressed in hours. *Comparison between open and robotic. **Comparison between open and laparoscopy. ***Comparison between laparoscopy and robotics. ‡Adjusted median.
the health care systems as a consequence of the lack of data and of the high costs (acquisition and maintenance) of every novel equipment.\cite{37} In the current finance situation, where a great portion of the world is facing difficulties to sustain the already present health structures, it would be considered scandalous to introduce new and highly expensive technique such as robotics as the new standard of care without the presence of strong evidence of significant cost-effectiveness and the comparison of minimally invasive methods to standard surgical techniques. Although cost related studies are complicated to be organised, it is essential that all parts involved, society and doctors should comprehend the impact of the cost of robotics.

Robotic-assisted surgery specifically requires equipment of elevated cost as a result of the novelty and the high specialisation of the utilised devices.\cite{5,38} The high cost of acquisition (over 1 million Euros) as well the expensive maintenance costs (almost 150,000 Euros/year) are obstacles that should be overcome. van Dam et al. have suggested that the costs of robotic equipment could be amortised, if the health care systems permit the application of robotic equipment on elevated number of patients.\cite{4} Furthermore, the absence of competition in the market of robotic equipment, especially after 2003, is one of the most important factors that maintain high the costs of robotic instrumentation.\cite{39}

More specifically, in 2003, the merge of the only two existed companies in the market of robotic devices was achieved, creating monopoly conditions.

The operating time is another essential reason that may cause great variations on the total surgical costs. Even though for private health structures, the length of the operating time is not an issue, for public health systems, which are financed by the government’s budget, every penny must be carefully spent. The setup of the robotic equipment, which is significantly longer compared to either the laparoscopic or the open one can increase the cost. However, it was shown that this time can be substantially improved when the surgical team is well trained.\cite{37}

Furthermore, the operative time is related to the experience of the surgical team. The type of surgical operation, as well as the surgeon’s capability and experience, are factors that influence considerably the learning curve.\cite{4} In addition, the costs are in correlation with the learning curve and are considered an additional cost caused by the fact that surgeons already went through a training program for both laparoscopic and open technique.\cite{40}

Nevertheless, it should be mentioned that an effective way to decrease the costs related to learning curve is the presence of great volume of patients and the necessity of virtual reality simulators.\cite{41,42}

Minimal invasive techniques have revealed to have an edge over laparotomy for the management of patients in a wide spectrum of pathologies.\cite{43,44} Keyhole incisions offer various advantages over the open surgical method, such as decrease of both postoperative pain and recovery time, less postoperative complications, reduced blood loss, and better cosmetic result. In particular, robotic techniques have a positive impact on specific patients’ categories, such as the reduction of operative costs and of hospital stay in elderly or morbidly obese patients. According to some studies, the total cost between both open and laparoscopic technique do not present statistically significant difference.\cite{45,46}

The extent of hospital stay has an important influence on the total charges of hospitalisation. The limited hospital stay is a principal characteristic of both robotic and laparoscopic approach as it is expected in comparison to the open method.\cite{5} Therefore, the decreased number of hospital days can amortise part of the increased operative costs of the minimally invasive techniques. Besides, the expenses of hospitalisation are also in strait correlation with the category of health care system and the type of health care structure.\cite{4,47} Differences between countries, private or public sectors render complex any approach to evaluate those cost data. Regarding the comparison of robotic procedures to laparoscopy, several studies claim that over hospital stay the robotic surgery seems to have a slight financial advantage over the standard laparoscopy.\cite{48} Nevertheless, currently, it appears that laparoscopy is a most economic approach among the other minimally invasive methods.

As presented in Table 1, the greater part of the studies referred to gastric fundoplication and showed that robotic is more expensive in comparison to laparoscopic technique. Despite the cost of acquisition the robotic devices, professional charges, operating theatre costs, surgical equipment costs present great variation in the included studies. Such a cost could be minimised if we also take into consideration the decrease of the hospital stay, the sooner return to normal patient’s activities, the reduction of blood loss and the decrease on conversion rates to laparotomy. Furthermore, by improving the robotic training of all personnel, the surgical time could be further reduced and as consequence favour the use of minimally invasive techniques.

The utilisation of robotics in almost every surgical field could be thought, in the future, as a valuable tool in common surgical practice. To realise this fact, both operative costs and unnecessary charges should be eliminated. The formation of specialised robotic units operating on great number of cases per year, the reduction of operating time per procedure by
specialised training on robotic approach, the decision for early discharge of the patients when that is possible and the minimisation of the number of instruments used per operation are some of the first steps that could be done in this direction. An additional proposal to minimise the cost is the multiple-use of the robotic equipment by multiple surgical specialties, good training of all the team members implicated while the acquisition of the robotic devices could be made through research funding or even charities.

Numerous limitations should be taken into consideration in the interpretation of the results of this review. The restricted number of the included studies and of the number of the included patients in these studies is in relation with the innovation of the technique. The study design, the volume of the surgical cases, the surgeon’s experience as well as the different hospital suppliers among the various institutions and the different countries are factors that render difficult any comparison between the robotic-assisted and the other techniques. Due to the lack of available data, we limited to evaluate the weighted median average cost of only the types of operations. The “cost” calculation is also difficult to be evaluated due to the existence of multiple variables, such as presence of diverse health systems and the differences between private and public sector. Cost is a difficult parameter to obtain from hospitals. We refer to cost, even when discussing professional fees, however the majority of the literature typically reports hospital charges rather than cost. Thus, somebody could highlight that the stated purpose for the review might be better stated to compare hospital charges for performing robotic surgery to more traditional approaches (open and/or laparoscopically). Based on our literature search, robotic-assisted technique cost more in comparison with laparoscopic or open procedures, although it appears that when the initial acquisition costs for robotic equipment is left apart then robotic techniques are the most effective method regarding costs. Nevertheless, because of great heterogeneity of the included studies and the absence of all the above mentioned information (indirect, direct, total, fixed or variable cost of each included study), in our opinion, safe conclusions could not be extracted on cost-effectiveness of robotic use in general surgery, due to more recent studies including operations performed by more well trained surgical teams. In addition, the lack of studies that refer on long-term clinical outcomes, such as quality adjusted life-year gained, is an obstacle on the realisation of a real cost-effective analysis. The costs related to readmission are difficult to be retrieved and included in the data analysis. Last but not least, the diverse types of operations included have different costs as well as different cost of total surgical time. Regarding, the adopted search strategy which was previously mentioned, it could be defined as restricted as a result of the exclusion of various publication types (such as abstracts, short surveys, reviews, etc.) and the limitation on the written language of the included studies.

CONCLUSION

The implement of robotic technology in operations of general surgery represent a novelty that may influence both the surgical treatment of numerous pathologies and the postoperative outcomes. The robotic assisted surgery has serious possibilities to evolve in a cost-effective technique, especially in centres with large number of cases, in spite of the undeniable elevated costs of acquisition and maintenance. Having as intention to increase the use of this surgical technique, it should be utilised not only on clinical treatment of patients but as well for the surgical training of all residents. The possible future industry competition in correlation with the technological development may steadily reduce the cost of the robotic equipment, making robotics a more cost-effective and affordable technique.

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Financial support and sponsorship
Nil.

Conflicts of interest
There are no conflicts of interest.
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