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Original Article

Abdominal wall-lifting versus CO_2 pneumoperitoneum in laparoscopy: a review and meta-analysis

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Abstract: The aim of this study is to compare the operative parameters and outcomes of conventional CO_2-pneumoperitoneum (PP) versus gasless abdominal wall-lifting (AWL) for laparoscopic surgery. The literature databases of PubMed, Google Scholar and Cochrane Library were searched for randomized controlled trials (RCTs) that had compared the CO_2-PP approach with that of gasless AWL for laparoscopic surgery and which had been published between 1995 and 2012. Data for the operative parameters (i.e. surgery duration, intraoperative heart rate (HR), perioperative complications, and postoperative duration of hospital stay and time to activity) and outcomes (postoperative shoulder pain, nausea/vomiting (PONV), partial pressure of CO_2 in the blood ($PaCO_2$), blood pH, and serum levels of the inflammatory cytokine interleukin (IL)-6) were extracted from the identified RCTs. RevMan software, version 5.2, was used for data synthesis and statistical analysis. Nineteen RCTs were selected for the meta-analysis, involving a total of 791 patients who had undergone laparoscopic operations with CO_2-PP (n = 399) or gasless AWL (n = 392). Sub-group analysis indicated that the patients who underwent gasless AWL had significantly shorter postoperative time to activity (weighted mean difference (WMD) = -0.23 d, 95% confidence interval (CI): -0.37 to -0.09; P = 0.001), lower incidence of PONV (odds ratio (OR) = 0.24, 95% CI: 0.10 to 0.57; P = 0.001) and lower postoperative $PaCO_2$ level (WMD = -3.09 mmHg, 95% CI: -4.66 to -1.53; P = 0.0001), compared to the patients who underwent CO_2-PP. However, the CO_2-PP method was associated with a significantly shorter surgery duration than the gasless AWL method (WMD = 8.61, 95% CI: 3.19 to 14.03; P = 0.002). There were no significant advantages detected for either approach with respect to the intraoperative HR, the perioperative complication rate, or the postoperative parameters of duration of hospital stay, shoulder pain, blood pH, or serum IL-6 level. We concluded form present study that the gasless AWL method has the features of shorter time, lower postoperative $PaCO_2$, and lower PONV incidence while the CO_2-PP method for laparoscopy requires shorter surgical time.

Keywords: Pneumoperitoneum, abdominal wall-lifting, laparoscopic surgery, randomized controlled trials, Meta-analysis

Introduction

A laparoscopic technique is preferred to open surgery by both doctors and patients, due to the less invasive nature that confers a lower risk of side effects (infection and/or hemorrhaging) and shorter healing times. The conventional approach to laparoscopic surgery involves generation of a pneumoperitoneum (PP) by CO_2 insufflation. However, reports of CO_2-PP-related cardiopulmonary compromise in some patients have prompted studies of this potentially life-threatening event [1, 5], and results have suggested that the risk factors may involve central venous pressure, various respiratory and endocrinologic parameters, hypothermia, and gas embolism [2-4, 6].

In the meantime, researchers and clinicians have sought to develop alternative approaches to CO_2-PP. Abdominal wall-lifting (AWL) by mechanical means (also known as gasless AWL), utilizing conventional laparoscopic devices coupled with constant suction, has emerged as one of the most promising alternative methods [7-9]. Compared with the CO_2-PP method, however, the gasless AWL method provides remarkably less exposure to the surgical area, hinder-

Table 1. Characteristics of included studies

Study	Journal	Type of surgery	Patients, *n*	Publication Year
Nanashima *et al*. [11]	*Surg Endosc*	Laparoscopic cholecystectomy	27	1998
Koivusalo *et al*. [12]	*Anesth Analg*	Laparoscopic cholecystectomy	30	1997
Goldberg *et al*. [13]	*Obstet Gynecol*	Laparoscopic surgery	57	1997
Kim *et al*. [14]	*JSLS*	Laparoscopic cholecystectomy	50	2002
Jiang *et al*. [10]	*Int J Colorectal Dis*	Laparoscopic colorectal surgery	39	2010
Uen *et al*. [15]	*J Laparoendosc Adv Surg Tech A*	Laparoscopic cholecystectomy	95	2002
Uen *et al*. [16]	*J Chin Med Assoc*	Laparoscopic cholecystectomy	80	2007
Ogihara *et al*. [17]	*J Clin Anesth*	Laparoscopic resection of ovarian tumors	12	1999
Vezakis *et al*. [24]	*Surg Endosc*	Laparoscopic cholecystectomy	36	1999
Larsen *et al*. [18]	*Br J Surg*	Laparoscopic cholecystectomy	50	2004
Koivusalo *et al*. [19]	*Br J Anaesth*	Laparoscopic cholecystectomy	26	1996
Cravello *et al*. [25]	*Eur J Obstet Gynecol Reprod Biol*	Laparoscopic surgery	103	1999
Andersson *et al*. [32]	*Acta Anaesthesiol Scand*	Laparoscopic cholecystectomy	20	2003
Hyodo *et al*. [20]	*Asian J Endosc Surg*	Laparoscopic splenectomy	54	2012
Ninomiya *et al*. [21]	*Surg Endosc*	Laparoscopic cholecystectomy	20	1998
Lindgren *et al*. [22]	*Br J Anaesth*	Laparoscopic cholecystectomy	25	1995
Talwar *et al*. [23]	*JK Science*	Laparoscopic cholecystectomy	40	2006
Galizia *et al*. [27]	*Surg Endosc*	Laparoscopic cholecystectomy	10	2001
Yoshida *et al*. [26]	*Surg Endosc*	Laparoscopic cholecystectomy	17	1997

ing manipulation of the instrumentation and making the procedure more technically challenging [10]. Comparative studies of the gasless AWL method versus the conventional CO_2-PP method have yet to provide a consensus on the benefit of these two approaches for a safe and effective laparoscopic procedure.

In this meta-analysis, the relevant randomized controlled trials (RCTs) published in the publicly available literature databases were collected and analyzed to gain stronger evidence for the advantageous operative and/or outcome parameters associated with the two approaches.

Methods

Electronic literature search strategy

The literature databases of PubMed, Google Scholar and the Cochrane Library were searched for publications between 1995 and 2012 that reported comparative analyses of gasless AWL with CO_2-PP in patients who underwent laparoscopic surgery. The electronic search was carried out using the following keywords, using the related articles function: 'laparoscopic surgery', 'pneumoperitoneum', 'laparoscopic and pneumoperitoneum', 'gasless abdominal wall lifting', and 'CO_2 insufflation'. The electronic search was performed by two investigators (Hao Ren and Yao Tong) working independently. The abstracts of all articles identified as potentially relevant were retrieved and considered in the study selection process.

Study selection and data extraction

The retrieved publications were screened using the following inclusion criteria: study design allowing for comparative analysis of gasless AWL with CO_2-PP; study carried out as a randomized controlled clinical trial; presence of concurrent controls; absence of a later publication based on the same dataset; and, clearly defined/described operational procedures for both the gasless AWL and CO_2-PP methods. The selection was further refined according to the following exclusion criteria: indeterminate and insignificant results, insufficient samples to support a result, non-comparative study design, and non-adult/pediatric patients (infants, children, adolescents up to age 18). All disagreements arising from the selection process were resolved upon consensus-based discussion.

Data extraction of the outcome measures was carried out by the same two investigators, working independently, and included intraoperative parameters (surgical time, heart rate (HR)), a perioperative parameter (complications), and postoperative parameters (hospital stay duration, time to activity, shoulder pain, nausea/

Table 2. Risk of bias assessment of included studies

Study	Sequence generation	Allocation concealment	Blinding	Incomplete data	Selective reporting
Nanashima *et al*. [11]	Unclear	Low	Unclear	Low	Low
Koivusalo *et al*. [12]	Low	Low	Low	Low	Low
Goldberg *et al*. [13]	Low	Low	Low	Low	Low
Kim *et al*. [14]	Low	Low	Low	Low	Low
Jiang *et al*. [10]	Unclear	Low	Unclear	Low	Low
Uen *et al*. [15]	Low	Low	Low	Low	Low
Uen *et al*. [16]	Low	Low	Low	Low	Low
Ogihara *et al*. [17]	Low	Low	Unclear	Low	Low
Vezakis *et al*. [24]	Low	Low	Unclear	Low	Low
Larsen *et al.* [18]	Low	Low	Low	Low	Low
Koivusalo *et al*. [19]	Low	Low	Low	Low	Low
Cravello et al. [25]	Low	Low	Unclear	Low	Low
Andersson *et al*. [32]	Low	Low	Low	Low	Low
Lindgren *et al*. [22]	Low	Low	Unclear	Low	Low
Talwar *et al*. [23]	Low	Low	Low	Low	Low
Galizia *et al*. [27]	Low	Low	Unclear	Low	Low
Yoshida *et al*. [26]	Low	Low	Unclear	Low	Low
Hyodo *et al*. [20]	Low	Low	Unclear	Low	Low
Ninomiya *et al*. [21]	Low	Low	Low	Low	Low

vomiting (PONV), partial pressure of CO_2 in the blood ($PaCO_2$), blood pH, and serum levels of the inflammatory cytokine interleukin (IL)-6). Among the studies that met the inclusion/exclusion criteria, those that provided data for at least one of the above-mentioned outcome parameters were included in the analysis. The included studies are summarized in **Table 1**.

Bias risk assessment

A "risk of bias" table was constructed with the Review Manager (RevMan) software (version 5.2; The Nordic Cochrane Centre, Copenhagen, Denmark) to perform quality assessment of the studies included in the meta-analysis. The parameters of bias included sequence generation (representing election bias), allocation concealment (representing selection bias), blinding (representing performance bias or detection bias), incomplete data (representing attrition bias), selective reporting (representing reporting bias). Each parameter was graded as 'low', 'high' or 'uncertain' to classify its risk of bias (**Table 2**). The same two investigators, working independently, carried out this assessment, with disagreements being resolved by consensus-based discussion involving a third investigator (Quan Li).

Meta-analysis and statistical methods

Data from the included studies were recorded in a computerized spreadsheet. The meta-analysis was performed using RevMan 5.2 software. Each study was weighted by sample size.

Statistical analysis of dichotomous variables (complications, shoulder pain, PONV) was performed using the odds ratio (OR) as the summary statistic; statistical analysis of continuous variables (surgery time, hospital stay, time to activity) was performed using the weighted mean difference (WMD). The OR was considered to represent the odds (estimated relative risk) of an adverse event occurring in the patient group treated with the gasless AWL method compared to that of the patient group treated with the CO_2-PP method. Moreover, the OR or WMD was considered statistically significant if the corresponding *P*-value was less than 0.05 and if the 95% confidence interval (CI) was not equal to 1 for the OR or 0 for the WMD.

In order to assess heterogeneity among the included studies, a fixed-effect model was initially prepared and the χ^2 and I^2 tests were performed. Higher χ^2 and I^2 values suggested higher levels of inconformity, and *P*-values less than 0.100 were considered indicative of heteroge-

Table 3. Meta-analysis of operative and outcome parameters

Parameter	No. of studies	Sample Size		Heterogeneity	Overall Effect Size			
		CO_2-PP	AWL	P, I^2	WMD	OR	95% CI	P
Surgical time, min	16	314	309	0.0002, 64%	8.61	N/A	3.19 to 14.03	0.002
Postoperative hospital stay, d	6	147	154	0.16, 38%	0.11	N/A	-0.08 to 0.30	0.26
Time to activity, d	4	105	94	0.17, 40%	-0.23	N/A	-0.37 to -0.09	0.001
Shoulder pain	5	101	100	0.002, 77%	N/A	0.82	0.14 to 4.78	0.82
PONV	3	78	77	0.35, 6%	N/A	0.24	0.10 to 0.57	0.001
Perioperative complications	8	179	170	1.00, 0%	N/A	1.15	0.58 to 2.29	0.69
Serum IL-6, pg/mL	4	98	94	0.16, 41%	-0.11	N/A	-2.45 to 2.23	0.93
$PaCO_2$, mmHg	5	95	90	0.001, 78%	-3.09	N/A	-4.66 to -1.53	0.0001
HR, bpm	4	65	57	0.25, 27%	1.39	N/A	-1.81 to 4.59	0.39
Blood pH	4	75	71	<0.0001, 86%	0.02	N/A	-0.02 to 0.05	0.29

Abbreviations: bpm: beats per minute; CI: confidence interval; HR: heart rate; IL-6: interleukin-6; N/A: not applicable; OR: odds ratio; $PaCO_2$: arterial partial pressure of CO_2; PONV: postoperative nausea and vomiting; WMD: weighted mean difference.

neity. To assess clinical heterogeneity, a random-effects model was used and the summary estimates and 95% CIs were calculated.

Results

Characteristics of included studies

The initial keyword search of the electronic libraries identified 219 potentially relevant studies (**Figure 1**). After retrieval and review of the articles' abstracts, 191 of the studies were excluded for irrelevant study design (i.e. not comparing the gasless AWL method with the CO_2-PP method), and a further 9 studies were excluded for incomplete/unavailable data (n = 7) or a study design based on non-human subjects (n = 2). Therefore, 19 studies in total were selected for inclusion in the meta-analysis [10-27, 32]. All studies were considered to be non-selective, and the overall results of the meta-analysis are summarized in **Table 3**.

Meta-analysis of intraoperative parameters

Surgery time: Sixteen of the studies [10-23, 26, 27] reported the surgery duration for the patients in the gasless AWL group and in the CO_2-PP group. As shown in **Figure 2A**, the laparoscopy surgery times (in min) were significantly shorter for the procedures performed with the CO_2-PP method than for those performed with the gasless AWL method.

HR: Four of the studies [13, 17, 23, 32] reported the HR of patients during their laparoscopy surgeries. As shown in **Figure 2B**, the intraoperative HR of patients (in beats per minute (BPM)) was similar between the groups who underwent surgery with CO_2-PP and gasless AWL.

Meta-analysis of a perioperative parameter

Complications: Eight of the studies [11, 15, 16, 19, 23-25, 27] reported on perioperative complications (including intraoperative bleeding and wound infection), with two of those [11, 20] citing a zero complication rate. Among the total 402 patients included in this analysis, the incidence of complications was 12.3% for the gasless AWL group and 10.6% for the CO_2-PP group, but the difference between the groups did not reach statistical significance (**Figure 2C**).

Meta-analysis of postoperative parameters

Duration of hospital stay: Six studies [10, 15, 16, 20, 22, 26] reported on the postoperative duration of hospital stay. No statistically significant difference was observed between the gasless AWL group and the CO_2-PP group for duration (in days) of hospitalization following the surgical procedure (**Figure 2D**).

Time to activity: Four studies [11, 13, 15, 19] reported on the amount of time it took for a patient to return to normal activity following the laparoscopy surgery. As shown in **Figure 2E**, the time to activity (in days) was significantly longer for the CO_2-PP group than for the gasless AWL group.

$PaCO_2$: Five studies [11, 12, 16, 17, 23] reported on the $PaCO_2$ level in patients following the

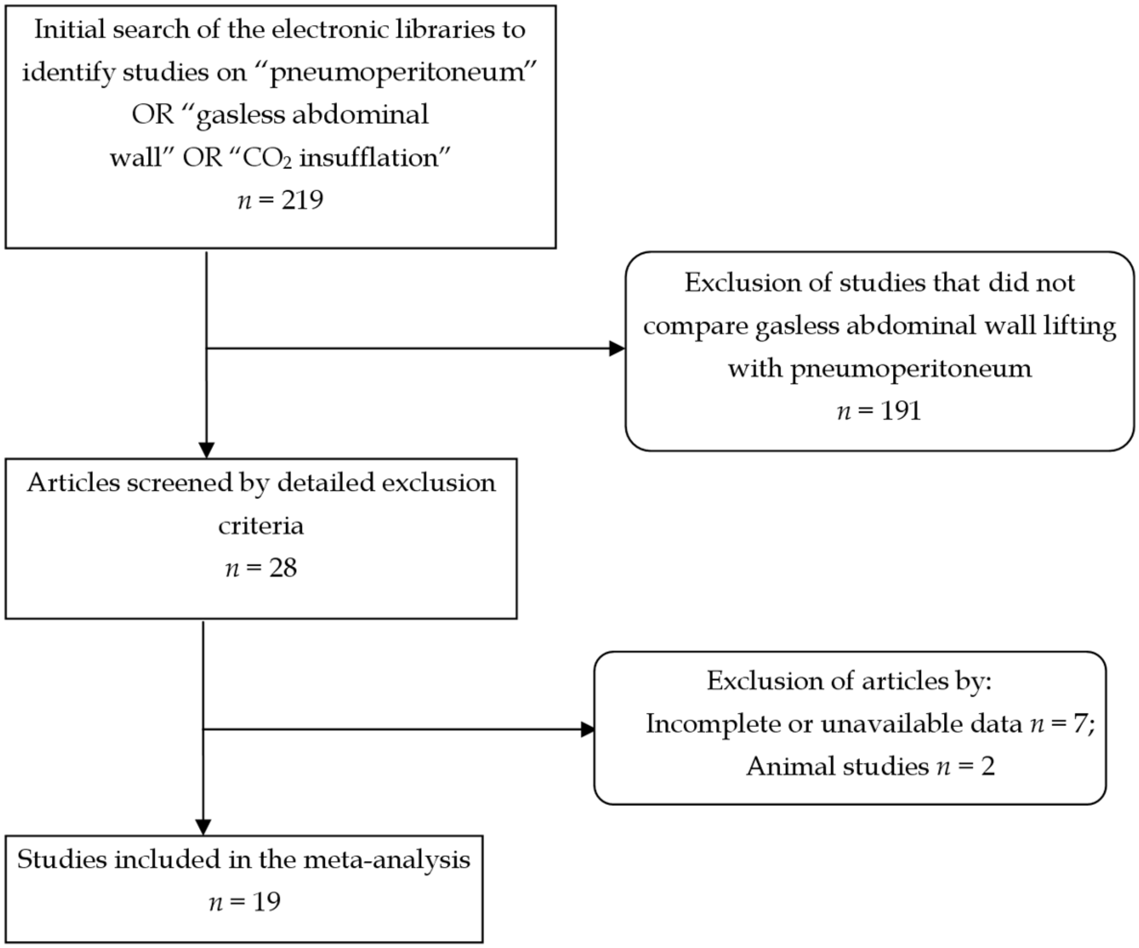


Figure 1. Flow diagram of the study selection process.

laparoscopy surgeries. As shown in **Figure 2F**, the gasless AWL group had a significantly better level of $PaCO_2$ (in mmHg) than the CO_2-PP group.

Blood pH: Four studies [11, 12, 16, 17] reported the blood pH in patients following the laparoscopy surgeries. No statistically significant difference was observed between the gasless AWL group and the CO_2-PP group for postoperative blood pH (**Figure 2G**).

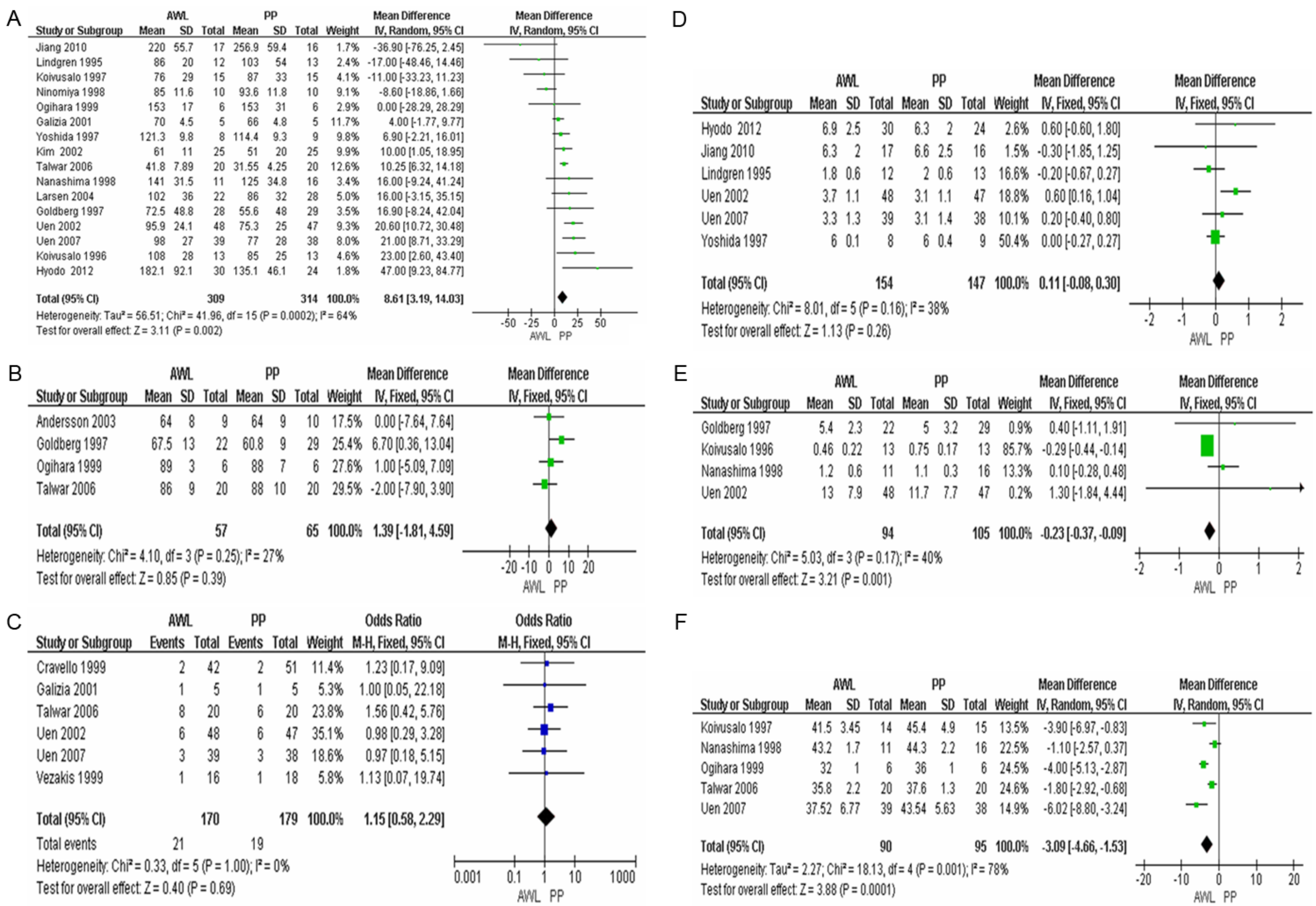
Serum IL-6: Four studies [11, 14, 15, 21] reported the serum level of IL-6 in patients following the laparoscopy surgeries. No statistically significant difference was observed between the gasless AWL group and the CO_2-PP group for this postoperative marker of immune preservation (in pg/mL) (**Figure 2H**).

PONV: Three studies [15, 19, 24] reported on the incidence of PONV in patients following the laparoscopy surgeries. As shown in **Figure 2I**, the gasless AWL group had a significantly lower rate of PONV than the CO_2-PP group.

Shoulder pain: Five studies [16, 19, 22-24] reported on the incidence of shoulder pain in patients following the laparoscopy surgeries. No statistically significant difference was observed between the gasless AWL group and the CO_2-PP group for this postoperative complication (**Figure 2J**).

Discussion

Laparoscopic techniques continue to be improved, both from the standpoint of design of the surgical devices and of laparoscopists' experience. This evolution has further promoted the use of laparoscopy for both minor and complex abdominal surgeries. The conventional method of separating the abdominal wall from the organs and tissues targeted for surgery involves


A
AWL PP Mean Difference Mean Difference
Study or Subgroup Mean SD Total Mean SD Total Weight IV, Random, 95% CI IV, Random, 95% CI
Jiang 2010 220 55.7 17 256.9 59.4 16 1.7% -36.90 [-76.25, 2.45]
Lindgren 1995 86 20 12 103 54 13 2.4% -17.00 [-48.46, 14.46]
Koivusalo 1997 76 29 15 87 33 15 4.1% -11.00 [-33.23, 11.23]
Ninomiya 1998 85 11.6 10 93.6 11.8 10 9.1% -8.60 [-18.86, 1.66]
Ogihara 1999 153 17 6 153 31 6 2.9% 0.00 [-28.29, 28.29]
Galizia 2001 70 4.5 5 66 4.8 5 11.7% 4.00 [-1.77, 9.77]
Yoshida 1997 121.3 9.8 8 114.4 9.3 9 9.8% 6.90 [-2.21, 16.01]
Kim 2002 61 11 25 51 20 25 9.9% 10.00 [1.05, 18.95]
Talwar 2006 41.8 7.89 20 31.55 4.25 20 12.6% 10.25 [6.32, 14.18]
Nanashima 1998 141 31.5 11 125 34.8 16 3.4% 16.00 [-9.24, 41.24]
Larsen 2004 102 36 22 86 32 28 5.0% 16.00 [-3.15, 35.15]
Goldberg 1997 72.5 48.8 28 55.6 48 29 3.5% 16.90 [-8.24, 42.04]
Uen 2002 95.9 24.1 48 75.3 25 47 9.3% 20.60 [10.72, 30.48]
Uen 2007 98 27 39 77 28 38 8.0% 21.00 [8.71, 33.29]
Koivusalo 1996 108 28 13 85 25 13 4.6% 23.00 [2.60, 43.40]
Hyodo 2012 182.1 92.1 30 135.1 46.1 24 1.8% 47.00 [9.23, 84.77]
Total (95% CI) 309 314 100.0% 8.61 [3.19, 14.03]
Heterogeneity: Tau² = 56.51; Chi² = 41.96, df = 15 (P = 0.0002); I² = 64%
Test for overall effect: Z = 3.11 (P = 0.002)
-50 -25 0 25 50
AWL PP
B
AWL PP Mean Difference Mean Difference
Study or Subgroup Mean SD Total Mean SD Total Weight IV, Fixed, 95% CI IV, Fixed, 95% CI
Andersson 2003 64 8 9 64 9 10 17.5% 0.00 [-7.64, 7.64]
Goldberg 1997 67.5 13 22 60.8 9 29 25.4% 6.70 [0.36, 13.04]
Ogihara 1999 89 3 6 88 7 6 27.6% 1.00 [-5.09, 7.09]
Talwar 2006 86 9 20 88 10 20 29.5% -2.00 [-7.90, 3.90]
Total (95% CI) 57 65 100.0% 1.39 [-1.81, 4.59]
Heterogeneity: Chi² = 4.10, df = 3 (P = 0.25); I² = 27%
Test for overall effect: Z = 0.85 (P = 0.39)
-20 -10 0 10 20
AWL PP
C
AWL PP Odds Ratio Odds Ratio
Study or Subgroup Events Total Events Total Weight M-H, Fixed, 95% CI M-H, Fixed, 95% CI
Cravello 1999 2 42 2 51 11.4% 1.23 [0.17, 9.09]
Galizia 2001 1 5 1 5 5.3% 1.00 [0.05, 22.18]
Talwar 2006 8 20 6 20 23.8% 1.56 [0.42, 5.76]
Uen 2002 6 48 6 47 35.1% 0.98 [0.29, 3.28]
Uen 2007 3 39 3 38 18.6% 0.97 [0.18, 5.15]
Vezakis 1999 1 16 1 18 5.8% 1.13 [0.07, 19.74]
Total (95% CI) 170 179 100.0% 1.15 [0.58, 2.29]
Total events 21 19
Heterogeneity: Chi² = 0.33, df = 5 (P = 1.00); I² = 0%
Test for overall effect: Z = 0.40 (P = 0.69)
0.001 0.1 1 10 1000
AWL PP
D
AWL PP Mean Difference Mean Difference
Study or Subgroup Mean SD Total Mean SD Total Weight IV, Fixed, 95% CI IV, Fixed, 95% CI
Hyodo 2012 6.9 2.5 30 6.3 2 24 2.6% 0.60 [-0.60, 1.80]
Jiang 2010 6.3 2 17 6.6 2.5 16 1.5% -0.30 [-1.85, 1.25]
Lindgren 1995 1.8 0.6 12 2 0.6 13 16.6% -0.20 [-0.67, 0.27]
Uen 2002 3.7 1.1 48 3.1 1.1 47 18.8% 0.60 [0.16, 1.04]
Uen 2007 3.3 1.3 39 3.1 1.4 38 10.1% 0.20 [-0.40, 0.80]
Yoshida 1997 6 0.1 8 6 0.4 9 50.4% 0.00 [-0.27, 0.27]
Total (95% CI) 154 147 100.0% 0.11 [-0.08, 0.30]
Heterogeneity: Chi² = 8.01, df = 5 (P = 0.16); I² = 38%
Test for overall effect: Z = 1.13 (P = 0.26)
-2 -1 0 1 2
AWL PP
E
AWL PP Mean Difference Mean Difference
Study or Subgroup Mean SD Total Mean SD Total Weight IV, Fixed, 95% CI IV, Fixed, 95% CI
Goldberg 1997 5.4 2.3 22 5 3.2 29 0.9% 0.40 [-1.11, 1.91]
Koivusalo 1996 0.46 0.22 13 0.75 0.17 13 85.7% -0.29 [-0.44, -0.14]
Nanashima 1998 1.2 0.6 11 1.1 0.3 16 13.3% 0.10 [-0.28, 0.48]
Uen 2002 13 7.9 48 11.7 7.7 47 0.2% 1.30 [-1.84, 4.44]
Total (95% CI) 94 105 100.0% -0.23 [-0.37, -0.09]
Heterogeneity: Chi² = 5.03, df = 3 (P = 0.17); I² = 40%
Test for overall effect: Z = 3.21 (P = 0.001)
-2 -1 0 1 2
AWL PP
F
AWL PP Mean Difference Mean Difference
Study or Subgroup Mean SD Total Mean SD Total Weight IV, Random, 95% CI IV, Random, 95% CI
Koivusalo 1997 41.5 3.45 14 45.4 4.9 15 13.5% -3.90 [-6.97, -0.83]
Nanashima 1998 43.2 1.7 11 44.3 2.2 16 22.5% -1.10 [-2.57, 0.37]
Ogihara 1999 32 1 6 36 1 6 24.5% -4.00 [-5.13, -2.87]
Talwar 2006 35.8 2.2 20 37.6 1.3 20 24.6% -1.80 [-2.92, -0.68]
Uen 2007 37.52 6.77 39 43.54 5.63 38 14.9% -6.02 [-8.80, -3.24]
Total (95% CI) 90 95 100.0% -3.09 [-4.66, -1.53]
Heterogeneity: Tau² = 2.27; Chi² = 18.13, df = 4 (P = 0.001); I² = 78%
Test for overall effect: Z = 3.88 (P = 0.0001)
-20 -10 0 10 20
AWL PP

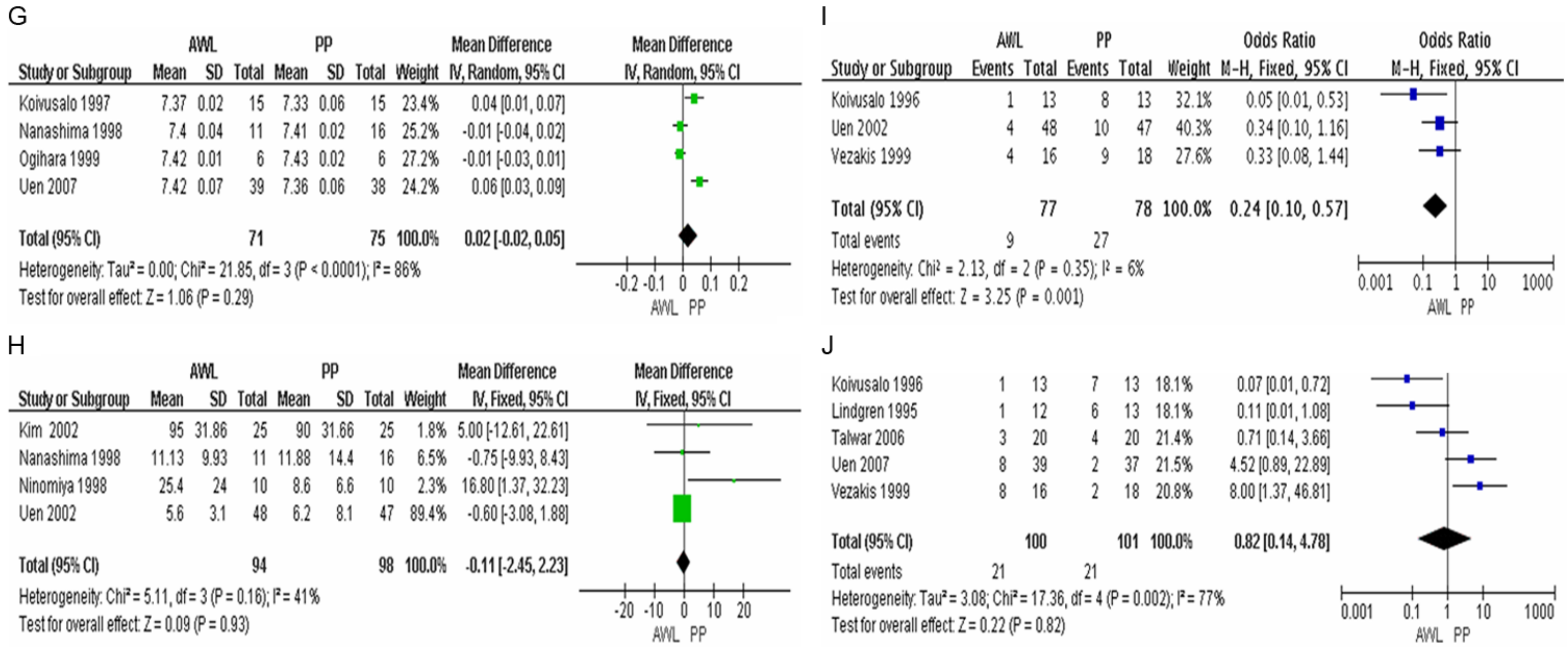


Figure 2. Forest plots of the operative and outcome parameters for abdominal wall-lifting (AWL) versus CO_2 pneumoperitoneum (CO_2-PP) in laparoscopic surgery. A: Surgery time; B: Intraoperative heart rate, in beats per minute; C: Perioperative complications; D: Postoperative hospital stay duration, in days; E: Postoperative time to activity, in days; F: Postoperative $PaCO_2$ level, in mmHg; G: Postoperative blood pH; H: Postoperative serum level of interleukin-6, in pg/mL; I: Postoperative incidence of nausea and vomiting; J: Postoperative shoulder pain.

gas insufflation (most commonly via high-pressure CO_2), which expands the abdominal wall to create an adequate working space. However, the CO_2-PP itself has been shown to disrupt the internal milieu of the abdominal cavity, to induce changes in hemodynamics, and to elevate central venous pressure and mean arterial pressure (MAP) [28, 34, 35]. In addition, some cases of life-threatening CO_2-PP-related conditions have been reported, including renal dysfunction [17], pulmonary edema, and gas embolism [36, 37].

A frequent and troubling complication of laparoscopic surgical operations, occurring regardless of the method used to separate the abdominal wall for access, is elevation of intra-abdominal pressure (IAP). However, it has been reported that the newer approach of gasless AWL may be superior to the conventional CO_2-PP method in its impact on IAP, as evidenced by less effects on urine output following the procedure [38, 39]. Elevated IAP is not as serious a complication for younger or generally healthy patients compared to patients of older age or with underlying cardiovascular or pulmonary diseases, for whom serious hemodynamic changes and peritoneal morphological changes may be detrimental [30]; therefore, a patient's condition should influence the treating physician's selection of an appropriate laparoscopic access procedure. The elevated IAP itself may also put a patient at risk of mechanically-restricted lung function by increasing the intrapleural pressure, through its subsequent elevation of the diaphragm and the abdominal part of the chest wall. Ultimately, the increased airway pressure and decreased pulmonary dynamic compliance may cause hemodynamic instability, even in the absence of severe cardiovascular disturbances [33]. Obese patients are at especially high risk of this complication, and represent another group that should be given special consideration in selecting an appropriate laparoscopic access procedure [34].

To create an intraperitoneal working space of adequate volume for instrument manipulation during laparoscopic surgery, the necessary amount of CO_2 pressure ranges between 10 to 15 mmHg; however, it has been demonstrated that a 12 mmHg CO_2-PP is associated with significant increases in both systemic vascular resistance and MAP [27]. Investigations of these potential complications using animal models have shown that IAP induced at higher pressures (15 mmHg in cats) is associated with significantly higher $PaCO_2$ levels and acidosis [40]. Yet not all results from human studies have yielded consistent results. A clinical trial IAP-induced oxidative stress responses found no difference between the lower (10 mmHg) and higher (15 mmHg) pressures [41]. Certainly, further studies are needed to gain a more detailed understanding of the effectiveness and risks of various IAPs in patients undergoing laparoscopy.

A major advantage of the gasless AWL method is its lower risk of inducing many of the adverse effects of the CO_2-PP method. For example, the gasless AWL induces significantly lower postoperative levels of peak airway pressure (PAP) and minute ventilation (MV) than the CO_2-PP method [23]. The gasless AWL method is also preferred by laparoscopists, since it allows for unlimited suction to be applied by the surgeon, which helps to ease the technical difficulty of more complex laparoscopic procedures. Moreover, clinical feasibility studies have shown that the gasless AWL method provides cost savings to both the healthcare facility and patient's financially responsible party [42].

The gasless AWL method for laparoscopic surgery, however, did not achieve immediate acceptance in the clinical field. The laparoscopists' reservations were based mainly on two unknown procedure- and outcome-related parameters; the first concern was whether the procedure would create a greater extent of pain and surgical stress at the targeted site, while the second involved a concern about whether the operating space achieved would be sufficient for the laparoscope to be manipulated effectively and safely in the peritoneal cavity. Over time, these concerns have been alleviated. Increased application of the gasless AWL method in clinics worldwide and increased experience of the laparoscopists have led to technical advances that have further promoted the efficacy and safety of this method. Hashimoto *et al.* [29] developed an improved AWL device that allowed for creation of a more efficient operating space with greater ease. In addition, the novel Laparo-V lifting method provided efficacious operating spaces in various colorectal laparoscopic procedures and was shown to be associated with a better outcome for patients with high cardiopulmonary risk [10]. Most recently, however, a newly developed umbrella-like abdominal wall-lifting device was shown to safely provide sufficient exposure of the laparoscopic surgery target areas [31]. It is certain that even more convenient, safe, and efficacious AWL instruments will be developed, further decreasing the risk to patients undergoing laparoscopy.

Results from the current meta-analysis, however, indicate that the gasless AWL method dose not offer an outstanding benefit over the conventional CO_2-PP method in regards to the major outcome measures of physiologic stress response, immune preservation, and hemodynamic balance. The patients who underwent laparoscopy with the AWL method showed significantly advantageous outcomes for only three parameters; namely, these patients had lower postoperative $PaCO_2$ level, lower incidence of PONV, and lower time to activity, but the method itself was associated with a significantly longer surgery time. Currently, AWL remains to be adopted in clinics worldwide as a routinely applied technique for laparoscopy surgeries, and its use is more common in specialized medical centers that serve selected patient groups by more experienced laparoscopists. Yet, its widespread acceptance and application is promising, as studies have indicated that it may be comparably feasible to the conventional CO_2-PP method (as demonstrated for conventional laparoscopic cholecystectomy [16, 43]).

Shoulder pain is a common postoperative complication of the laparoscopic operation. Positive IAP induced by CO_2 insufflation may cause diaphragmatic expansion, which stimulates a nerve signal that manifests as shoulder pain [19, 22]. Two previous clinical studies of laparoscopy-related shoulder pain showed that the gasless AWL method was associated with a higher incidence of shoulder pain than the CO_2-PP method [16, 24]. However, the current meta-analysis showed no statistically significant difference for this parameter when compared between the gasless AWL group and the CO_2-PP group. This finding reflected the insignificant differences found in several other studies [13, 15]. Indeed, since the laparoscopy-related shoulder pain may be due to diaphragmatic stretching, the individual patient's experience of this postoperative complication may be due to the particular extent of upward retraction of the abdominal wall during their procedure; future studies should investigate this possibility and whether a target level of upward retraction should be recommended.

The results of the current meta-analysis should be interpreted with careful consideration given to the limitations inherent to the study's design. First, some of the major outcomes had small sample sizes (e.g. hemodynamic parameters, internal environment-related indicators, and shoulder pain), which may result in a small-study effect. Second, some of the studies included in the analysis had included data for different kinds of AWL devices. Third, the most common type of laparoscopic surgery was cholecystectomy, and other types of laparoscopic surgeries were infrequently represented in the dataset used for this meta-analysis. Thus, some results of this research may be influenced by bias. Finally, some of the other major procedure-related parameters (i.e. conversion rates, costs, and learning curve) were not included in this meta-analysis, due to insufficient data; no conclusions may be drawn for these features.

Conclusions

The AWL method was shown to be associated with generally similar outcomes to the conventional CO_2-PP method, with regard to hemodynamic stability, major complications, and stress responses; however, the gasless AWL method may be superior for the outcomes of postoperative $PaCO_2$ level, incidence of PONV, and time to activity, with the disadvantage being longer surgical time than the CO_2-PP method. Further studies are needed to determine which of these two methods is more effective and safe for particular sets of patients according to the patient's condition.

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Disclosure of conflict of interest

None.

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