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Review

Surgical management of acute appendicitis in adults: A review of current techniques

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ABSTRACT

Acute appendicitis is one of the most frequent disorders in abdominal surgery. Therefore, appendectomy is a matter of significant interest in that field. Yet, four different techniques are available: open appendectomy, (conventional) laparoscopic appendectomy, single port laparoscopic appendectomy and NOTES-appendectomy with its different variations. To evaluate the current state of the art in appendectomy a bibliographic search was conducted. All prospectively randomized trials and national register cohort studies published between 1/2010 and 5/2016 were included into the analysis. Overall, 25 respective studies were identified. All studies were screened for the following parameters: surgical site infection (SSI) (wound infection (WI) or intraabdominal abscess (IAA)), postoperative pain (PP), length of surgery (LoS), length of hospital stay (LHS), return to normal activities (RNA). Today the rate of laparoscopic appendectomy is reported to be up to 86% in the recent literature. Open appendectomy remains a safe and effective technique. Single port laparoscopic appendectomy presented almost equal in terms of safety and patient satisfaction. The method is still not as widespread as conventional three port laparoscopic appendectomy, presumably due to the necessity of special equipment and training. NOTES appendectomy is the newest development in appendectomy technique. First prospective cohort studies proved the safety and feasibility in experienced hands. However, the method is still experimental and further prospectively randomized trials are necessary. Concluding the current evidence, a laparoscopic approach, which is most commonly and increasingly frequently used, could be called “state of the art” in the treatment of appendicitis.

1. Introduction

Appendectomy was first described by Mc Burney in 1894. After being introduced, it rapidly developed to one of the most common operations in abdominal surgery [1]. The method was used without technical changes for almost one century. In 1983, Kurt Semm, a German gynaecologist, performed the first laparoscopic appendectomy [2]. Hardly accepted in the beginning, the method was used with growing frequency in the following three decades. Meanwhile, laparoscopic appendectomy is well established in the treatment of acute appendicitis. In Germany, LA rate increased from 47 to 86% between 2005 and 2009 [3]. This development could be supported by numerous international publications. Apart from open and standard laparoscopic approach, single incision laparoscopic surgery and NOTES procedures are concurrent techniques completing the technical variety of appendectomy.

The importance of the choice of the respective surgical technique is repeatedly discussed controversially concerning optimal patient treatment as well as for economic aspects [4, 5]. Advantages and disadvantages have been examined in an overwhelming number of studies. For best possible patient care and economically seen, it is of particular importance to define the optimal surgical treatment for appendectomy. This review analyzes the current evidence for different approaches within the last five years to identify a “state of the art” procedure for acute appendicitis.

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2. Material and method

2.1. Literature research

We carried out a bibliographic search in Medline/PubMed and Cochrane-Database. Search items were “appendectomy”, “laparoscopic appendectomy”, “open appendectomy”, “single port appendectomy”, “NOTES-appendectomy”. To provide the best scientific evidence, all randomized controlled trials (RCT) and population based national register studies published between 1/2010 and 5/2016 were included into the analysis. For NOTES-appendectomy, no RCT's were available. Therefore three prospective cohort studies and two register cohort studies were included. Retrospective studies and reviews were excluded. Overall, 25 studies were identified: 14 on open vs. laparoscopic appendectomy (8 RCTs, 6 national register cohort studies), 6 RCTs on single port laparoscopic appendectomy, five studies on NOTES-appendectomy (3 RCTs, 2 register cohort studies). All publications were analyzed for the following parameters: Surgical site infection (SSI) (wound infection (WI); intraabdominal abscess (IAA)), postoperative pain (PP), length of surgery (LoS), Length of hospital stay (LHS), Return to normal activities (RNA). Due to a lack of prospective and register data, retrospective studies were included for the cost analysis of OA and LA.

3. Laparoscopic appendectomy

3.1. Open vs. laparoscopic approach

In 2010, a Cochrane review compared open (OA) and laparoscopic appendectomy (LA). For diagnostic effects, laparoscopic appendectomy was identified to be superior to open approach. By usage of laparoscopy, the rate of negative appendectomy could be lowered. In comparison to unselected adults (RR 0.37; CI 0.13 to 1.01), this effect was stronger in fertile women (RR 0.20; CI 0.11 to 0.34). This benefit was most significant in fertile women. Wound infection, postoperative pain, time to regular bowel function, hospital stay and time to regular activities were significantly reduced in LA. The authors emphasized in that context, that differences are minor and by that only with slight clinical impact. Sauerland et al. concluded LA to be advantageous over OA. In their study, one of the disadvantages of LA was a higher rate of intraabdominal abscesses in the LA group (OR 1.87; CI 1.19 to 2.93). Duration of surgery was 10 min longer in LA than in OA (CI 6 to 15). LA leads to higher in-hospital but lower post hospital costs [5].

The frequency of laparoscopic approaches increased significantly in the last years. Data in Table 1 show the growing rate of LA over the last two decades. These data underline that LA is fully accepted for the treatment of appendicitis and the frequency of LA-use is not only equal but higher than OA in recent studies. In the German population in 2009, 86% of all appendectomies were performed laparoscopically [6].

Between 2011 and 2016, eight prospectively randomized controlled trials (RCT) and six national register studies were identified which directly compared open and laparoscopic appendectomy. All publications were analyzed for the above mentioned parameters (Tables 2 and 3).

Table 1
Trends to laparoscopic appendectomy.

Author	Year	Rate of LA (%)	Year	Rate of LA (%)
Bliss	2003	41.7	2011	80.1
Andersson	1992	3.8	2009	32.9
Buia	2002	15	2008	40
Masoomi	2006	58.2	2008	72.0
Sahm	1996/1997	33.1	2008/2009	85.8

LA = laparoscopic appendectomy.

Table 2
RCT's - laparoscopic vs. open appendectomy.

Author	n	Technique (%)			SSI (%)			IAA (%)			PP (VAS)			LoS (min)			LHS (d)			RNA (d)			NA (%)		
		OA	LA	CO	OA	LA	p	OA	LA	p	OA	LA	p	OA	LA	p	OA	LA	p	OA	LA	p	OA	LA	p
Mantoglu, 2015	63	50.8	49.2	n.a.	0	6,5	0.05	0	6,5	0.05	2.78	**1.61**	**0.0001**	46.25	41.42	0.386	1.5	1.4	0.256	8.06	**5.06**	**0.0001**	n.a.	n.a.	n.a.
Ciftci, 2015	243	49.8	50.2	n.a.	4.1	0.8	n.a.	2.5	3.3	n.a.	7.6	7.1	**0.001**	50.9	51.0	0.884	28.92*	25.61*	0.071	5	4	n.a.	14.8	**6.5**	**0.009**
Taguchi, 2015	81	48.1	51.9	2.38	7.7	19.0	0.197	17.9	19.0	1.000	n.a.	n.a.	n.a.	63.5	84.6	**0.001**	11.9	11.4	0.838	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Thomson, 2014	112	46.4	53,6	7.0	21.4	5.1	0.03	2.4	11.8	0.16	n.a.	n.a.	n.a.	58.4	75.8	0.08	4.5	5	0.26	n.a.	n.a.	n.a.	7.7	13.3	n.a.
Kocatas, 2013	96	47.9	52.1	n.a.	6	2.1	0.618	2	2.1	0.999	9	8.78	0.537	n.a.	n.a.	n.a.	21.1*	20.3	0.618	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Tzovaras, 2010	147	51.0	49.0	22.2	5.3	2.8	n.s.	0	2.8	n.s.	n.a.	n.a.	n.a.	45	60	**0.0027**	2	2	n.s.	7	6	n.s.	n.a.	n.a.	n.a.
Wei, 2010	220	49.1	59.9	0	13	0	**< 0.05**	8.3	1.8	**< 0.05**	n.a.	n.a.	n.a.	28.7	30	> 0.05	7.2	4.1	**< 0.05**	13.7	9.1	**< 0.05**	n.a.	n.a.	n.a.
Kouhia, 2010	99	52.5	47.5	6.4	11.5	2.1	**0.005**	1.9	4.25	0.999	n.a.	n.a.	n.a.	38	**65**	**0.001**	1.5	1.5	0.789	13	8	**0.013**	27.0	25.5	n.a.

na = not analyzed; n.s. = not significant different; ua = uncomplicated appendicitis, ca = complicated appendiciitis, OA = Open appendectomy, LA = laparoscopic appendectomy, CO = conversion, SSI = surgical site infection; IAA = intraabdominal abscess, PP = postoperative pain; LoS = length of surgery; LHS = length of hospital stay, RNA = return to normal activities, NA = negative appendectomy, ex = excluded.
Significant results are highlighted bold.
*hours.

Table 3
Lap. Vs. open Appendectomy - National registry studies.

Author	n	Technique (%)			SSI (%)			IAA (%)			PP (VAS)			LoS (min)			LHS (d)			RNA (d)			NA (%)		
		OA	LA	CO	OA	LA	p	OA	LA	p	OA	LA	p	OA	LA	p	OA	LA	p	OA	LA	p	OA	LA	p
Sahm 2015 (96–97)	17.732	66.9	33.1	7.2	6.7	2.8	**< 0.001**	n.a	n.a	n.a.	n.a.	n.a.	n.a.	42.6	48.5	**< 0.001**	7.8	6.9	**< 0.001**	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
(08–09)		14.2	85.8	6.1	11.9	1.5	**< 0.001**	0.6	0.8	0.428	n.a.	n.a.	n.a.	53.5	46.6	**< 0.001**	8.8	4.8	**< 0.001**	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Anderson, 2014	169.896	80.5	19.5	19.7	0.1	0.1	**0.004**	0.3	0.5	**0.001**	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	2.92	2.86	**0.001**	n.a.	n.a.	n.a.	8.5	5.5	**0.001**
Wang 2013	65.339	66.2	33.8	n.a.	n.a.	n.a.	n.a.	1.9	0.7	**< 0.001**	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	5.33	4.01	**< 0.001**	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Senekjian 2012	61.830	22.5	77.5	n.a.	ua: 4.0 ca: 8.0	ua: 1.3 ca: 2.0	**< 0.001** **< 0.001**	ua: 0.8 ca: 4.9	ua: 1.1 ca: 5.8	0.064 0.082	n.a.	n.a.	n.a.	59.5	51.4	**< 0.001**	ua: 2.6 ca: 5.53	ua: 1.5 ca: 2.79	**< 0.001** **< 0.001**	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Masoomi, 2011	573.244	34.8	65.2	n.a.	ua: 0.4 ca: 2.1	ua: 0.2 ca: 0.6	**< 0.01** **< 0.01**	ua: 0.8 ca: 3.6	ua: 0.3 ca: 1.7	**< 0.01** **< 0.01**	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	ua: 2.4 ca: 6.0	ua: 1.7 ca: 4.0	**< 0.01** **< 0.01**	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Ingraham, 2010	32.683	23.6	76.4	n.a.	3.89	1.26	**< 0.001**	1.7	1.8	0.68	n.a.	n.a.	n.a.	53.1	50.2	**< 0.0001**	2	1	**< 0.0001**	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

na = not analyzed; ua = uncomplicated appendicitis, ca = complicated appendicitis, OA=Open appendectomy, LA = laparoscopic appendectomy, CO = conversion, SSI = surgical site infection; IAA = intraabdominal abscess, PP = postoperative pain; LoS = length of surgery; LHS = length of hospital stay, RNA = return to normal activities, NA = negative appendectomy, ex = excluded.
Significant results are highlighted bold.

3.2. Surgical site infections

3.2.1. Wound infections and intraabdominal abscess

Interestingly, none of the RCTs showed an inferiority of LA in terms of wound infection or IAA. In fact, Wei found a significantly lower risk for both wound infection and IAA in LA and Kouhia found a significantly lower risk for wound infection [7, 8]. All other studies were without significant differences.

Five of six national database register studies showed a significant reduction of wound infection in LA [9–13]. Wang et al. did not analyze SSI [14]. Similarly, a significant reduction of IAA could be shown by two of six authors [12, 14]. Three studies were without significant difference for IAA [9, 11, 13]. A higher rate of IAA in LA was only demonstrated in the Swedish analysis by Andersson [10].

3.3. Postoperative pain

The visual analog scale-score (VAS-score) was elevated in three of eight RCTs. Data from Mantoglu and Ciftci demonstrated a significant pain reduction using a laparoscopic approach [15, 16]. No difference was shown in the analysis of Kocatas [17]. No data are available from the register studies.

3.4. Length of surgery

The studies of Taguchi, Tzovaras and Kouhia showed a significantly longer procedural duration in LA compared to OA. Mean length for laparoscopic approach was 60, respectively 65 min in the publications of Tzovaras and Kouhia. Taguchi and co-workers found a mean duration of 84 min, which seems noticeably long even in cases of complicated appendicitis [8, 18, 19]. The other five RCTs did not show significant differences concerning length of surgery.

In contrast, the review of three prospective multicenter quality assurance studies, conducted between 1988 and 2009, stated a significant increase of the duration of OA and a significant decrease for the length of LA (48.5 vs. 46.6, $p < 0.001$) [9]. These results are supported by North American National Surgical Quality Improvement Program database (NSQIP) analyses of Senekjian and Ingraham [11, 13]. Both found a significant reduction of procedural duration in LA. This could be caused by a negative selection bias, since LA became the standard treatment during the study period and OA was reserved for complicated cases. In the studies of Andersson, Wang and Masoomi, length of surgery was not analyzed [10, 12, 14].

3.5. Length of hospital stay

Length of hospital stay did not differ in seven of eight included RCTs. Wei et al. found a significant reduction in the LA-group [7]. Days in hospital were 7.2 for OA and 4.1 for LA in this study. However, even for open appendectomy, a hospital stay of more than 7 days seems to be very long. No reason for that aspect was discussed. All national database register studies showed a significant association between LA and a reduced length of hospital stay.

3.6. Return to normal activities

Data of Mantoglu, Wei and Kouhia showed a faster onset of normal activities in patients after LA [7, 8, 16]. All other RCTs are without a significant difference. No data are available from the register studies.

3.7. Summary laparoscopic vs. open appendectomy

3.7.1. RCT

Four authors (Mantoglu, Ciftci, Wei, Kouhia) [7, 8, 15, 16], recommended LA as standard procedure, while the other four (Taguchi, Thomson, Kocatas, Tzovaras) [17–20] identified LA not to be superior

to OA.

Mantoglu et al. concluded that LA was significantly superior to OA in terms of postoperative pain, return to normal activities and cost. Moreover, they emphasized the diagnostic and therapeutic advantages of LA, which could be helpful in suspicious cases. Therefore, Mantoglu considers LA to become the standard procedure for the treatment of acute appendicitis [16]. However the authors called for cheaper laparoscopic equipment since OA leads to significantly reduced costs in the analysis.

Similarly, Ciftci et al. presumed LA as standard procedure in appendectomy. Negative appendectomy rate and postoperative need for pain medication was significantly lower in the LA group. Postoperative morbidity and recovery was equal in both groups [15]. Wei et al. found a significantly lower rate of wound infections, IAA as well as shorter hospital stay and faster return to normal activities as advantages of LA, concluding the minimally invasive technique to be a standard procedure in the surgical therapy of appendicitis [7]. Kouhia et al. showed slight advantages for LA, such as faster recovery and lower rate of wound infections. Yet, duration of operation was significant longer in their study [8].

Kocatas and coworkers showed no superiority of a laparoscopic approach concerning all analyzed parameters. However, the rate of intraabdominal abscesses was equal between LA and OA in their study [17]. The same issue was shown in the analysis of Taguchi et al. comparing LA and OA in complicated appendicitis. Wound infection and IAA were without significant difference comparing both techniques. Duration of LA was significantly longer than OA. Concluding all parameters, LA was presumed to be safe but not superior to OA in complicated appendicitis [19]. Thompson et al. stated LA to be safe in complicated appendicitis while no superiority to OA was found [20]. The study of Tzovaras and co-workers, focusing on appendectomy in men, found a longer operation time in LA as the only significant difference between both procedures. Since length of hospital stay and time to recovery was not shortened by LA, higher overall costs are expected in laparoscopic approach. No advantages could be identified for LA [18].

3.7.2. Population based studies

Six population based national register studies covering 920.724 patients overall were additionally included into the analysis. Four authors [9, 11, 12, 14], recommend LA as standard treatment while two [10, 13], found no relevant superiority of LA over OA.

Sahm et al. summarized three German multicenter quality assurance studies. Therein, application of LA was associated with a significant reduction of wound infections and length of hospital stay. The 2008/2009 study also stated a significantly shorter duration of surgery in LA. According to these results, LA is considered as procedure of choice in the treatment of acute appendicitis [9]. The analysis of the Swedish national patient register of Andersson et al. showed slight advantages and disadvantages for both, LA and OA. (LA: shorter hospital stay by 0.06 d OA 2.92 d; LA: 2.86 d $p < 0.001$), reduction of negative appendectomy (adjusted odds ratio (OR) 0·59; $P < 0·001$). Wound infection (adjusted OR 0·54; $P = 0·004$) and wound rupture (adjusted OR 0·44; $P = 0·010$), higher risk of intestinal damage (adjusted OR 1·32; $P = 0·042$), readmission (adjusted OR 1·10; $P < 0·001$), postoperative abdominal abscess (adjusted OR 1·58; $P < 0·001$), urinary infection (adjusted OR 1·39; $P = 0·020$). The study group therefore recommended an individualized decision process, taking into account patient characteristics as well as surgeon-specific preference and technical considerations. A clear recommendation for open or laparoscopic treatment was not given [10].

Wang analyzed data from the Taiwan National Health Insurance Research Database. Results showed LA to be associated with a lower 30-day readmission rate and a shorter length of stay. The only disadvantage were slightly higher costs per discharge. LA is recommended as standard treatment for both uncomplicated and complicated appendicitis. Higher costs per discharge were be balanced by a lower readmission rate [14].

An analysis of data from the North American National Surgical Quality Improvement Program (NSQIP) by Senekjian and co-workers identified LA to lead to a slight increase of intraabdominal abscesses which was statistically not significant. SSI were significantly and considerably reduced. According to the authors, this aspect should lead the surgeon to a minimally invasive approach. Moreover, length of surgery and length of hospital stay were significantly diminished in the LA group [11]. Masoomi used data of the US Nationwide Inpatient Sample (NIS) to demonstrate LA to be associated with lower morbidity, lower mortality and reduced hospital stay in both acute uncomplicated and complicated appendicitis. Moreover, costs were significantly lower in the LA group in acute perforated appendicitis. For these reasons, LA is recommended as standard procedure [12].

In another NSQIP database analysis by Ingraham, LA led to lower postoperative morbidity in selected patients. Therein patients with complicated appendicitis have a higher risk of IAA [13].

3.8. Patients and disease characteristics (uncomplicated/complicated, female/male)

Bliss et al. showed in a review of 1.663.238 patients from the U.S. Nationwide Inpatient Sample that not only disease specific factors but ethnic aspects and insurance status significantly influenced the choice of appendectomy technique. African-American patients and patients with public insurance were less frequently operated laparoscopically. Outcomes were inferior in this group [21]. Data of Andersson et al. showed a reduced rate of laparoscopy in patients with higher grades of co-morbidities. The severity of appendicitis did not influence the choice of technique [10]. In 2010, Ingraham also found a lower incidence of laparoscopy in patients with relevant co-morbidity. Patients undergoing LA were younger and had a lower ASA-Score [13]. The same was found in the study of Sahm et al. from 2015, where higher ASA-Score and older age correlated with OA and higher BMI predestined for LA [9]. Saia et al. analyzing 38.314 appendicitis cases, found that the laparoscopic approach was used more frequently in fertile women than in men and less often in the pediatric population than in adults. Moreover, the application of laparoscopy was significantly lower in urgent surgeries [22]. LA could be identified to be superior to OA even in perforated appendicitis in a review of 573.244 patients from the U.S. Nationwide Inpatient Sample by Masoomi and co-workers. Overall complications, in-hospital mortality, hospital charges and length of hospital stay could be reduced in comparison to OA [12]. Tiwari and co-workers demonstrated superiority of LA vs. OA in both uncomplicated and complicated appendicitis in their analysis of 40.337 appendicitis cases. Within this study, LA led to reduced mortality, morbidity, 30-day readmission rate, ICU admissions, length of hospital stay, and hospital costs. These results were obtained for uncomplicated and complicated stages [23].

3.9. Costs

Six studies (prospective studies, national register cohort studies, retrospective studies) reported procedural costs. Costa-Navarro and Di Saviero showed a significant cost reduction in LA [24, 25]. Interestingly, Masoomi et al. found a significant increase of costs for LA use in uncomplicated appendicitis but a significant decrease in complicated appendicitis [12]. While Minutulo et al. [26] identified no significant difference, Lee [27] and Mc Grath [28] found a significant cost increase in LA. (Table 4).

3.10. Conclusion: laparoscopic vs. open appendectomy

Concluding from current evidence, LA seems to be superior to OA. Main advantages are a reduced rate of negative appendectomies, wound infections, postoperative pain, length of hospital stay and return

Table 4
Costs LA vs. OA.

Author	Year	Study Type	LA	OA	p-Values
Masoomi et al.	2011	National Cohort	ua: $22,948 ca: $ 32,487	$ 20,944 $ 38,599	< 0.01 < 0.01
Costa-Navarro et al.	2013	Prospective	€ 1081	€ 1799	0.002
Di Saverio et al.	2014	Prospective matched pair	€ 424	€ 808	< 0.01
Lee et al.	2011	Retrospective	Won (Korea) 1,664,367	1,259,842	0.0057
Mc Grath et al.	2011	National Cohort	$19,978	$15,714	0.001
Minutolo et al.	2014	Retrospective	€2282	€ 2337	0.812

LA: laparoscopic appendectomy; OA: open appendectomy; ua: uncomplicated appendicitis; ca: complicated appendicitis.

to normal activities. It remains questionable if the duration of surgery and the rate of intraabdominal abcesses is diminished in LA. Current data on these parameters are inconsistent. Both parameters depend on the surgeon's experience and the evolution of the equipment. Due to the increasing rate of laparoscopic appendectomies (Table 1), operations are performed quicker and the rate of intraabdominal abscesses decreases.

4. Single incision laparoscopic appendectomy

Overall, six prospectively randomized controlled studies could be identified focusing on single-incision laparoscopic appendectomy (sLA) in the study period (Table 5). All available studies compared the single incision approach with conventional three port laparoscopic appendectomy (cLA). One additional RCT compared OA with cLA and sLA. One study concluded sLA to be an alternate option to cLA in appendectomy [29]. Three studies (Lee et al. St Peter et al. Teho et al.) [30–32] stated safety and feasibility of sLA but no superiority to cLA. The authors did not give a clear recommendation which method to choose.

Of the six RCTs comparing cLA and sLA, two study groups (SCARLESS study group, Carter et al.) [33, 34], advised against sLA as treatment of choice for acute appendectomy.

The analysis of 184 appendicitis patients by Frutos et al. showed significant pain reduction in the sLA group, while length of surgery was lower using cLA. All other parameters were without significant difference. The authors evaluated the method to be safe and feasible and by that fitting as alternative approach to three port appendectomy [29]. Lee et al. stated safety and feasibility of sLA without demonstrating any advantages compared to cLA [30]. The largest respective analysis conducted by St Peter reported longer procedural length and higher costs in sLA approach, while other postoperative results were equal. Differences in length of surgery (5 min) and costs were only of slight clinical relevance [31]. Teoh et al. found increased postoperative pain and analgetics use in the sLA group, while wound cosmesis and satisfaction scores were better. The authors concluded that the use of sLA should comply with patient's preference and local surgical expertise [32]. Prospectively randomized data of the Scottish SCARLESS study group demonstrated a better patient reported body image and increased cosmetic results in sLA. sLA approach was significantly shorter and morphine use lower in this group. All other surgical outcomes were without significant difference. The method is not yet recommended for routine use in appendectomy due to its higher technical requirements [34]. A study of Carter et al. [33] was initially designed for 150 participants. The study was terminated after the inclusion of 75 patients due to significantly higher postoperative pain scores and longer operation time in sLA in the interim analysis. Postoperative complications, length of hospital stay and days off work were without statistical

Table 5
Single incision laparoscopic appendectomy.

Author	n	Technique (%)			SSI (%)			IAA (%)			PP (VAS)			LoS (min)			LHS (d)			RNA (d)		
		cLA	sLA	CO	cLA	sLA	p	cLA	sLA	p	cLA	sLA	p	cLA	sLA	p	cLA	sLA	p	cLA	sLA	p
SCARLESS-Study group, 2015	77	49.4	50.6	2.6	8	5	0.67	3	0	1.0	n.s.*	n.s.	**n.s.**	62	48	**0.048**	2.8	3	n.s.	20	15	0.49
Carter et al., 2014	75	50,7	49,3	1,3	0	0	> 0.99	0	1	0.49	3.5	4.4	**0.01**	38	54	**< 0.01**	1.6	1.4	0.65	6.9**	8.1	0.42
Frutos et al., 2013	184	50.5	49.5	0	0	0	0	0	0	0	3.78	2.76	**< 0.001**	32.12	38.13	**0.02**	21.32***	18.86	0.12	n.a.	n.a.	n.a.
Lee et al., 2013	230	50.4	49.6	0/10.3****	10.6	5.1	0.207	1.8	5.1	0.281	Nd	nd	0.651	35.8	43.8	0.845	3	3	1.0	n.a.	n.a.	n.a.
Teoh et al., 2012	195	49.7	50.3	8.1	5.1	8.2	n.s.	3.1	4.1	n.s.	nd*****	nd	0.109	60.2	63	0.520	3.2	3.53	0.155	6.38	6.17	0.754
St Peter et al., 2011	360	50	50	10****	1.7	3.3	0.50	0.6	0.0	0.99	n.a.	n.a.	n.a.	29.8	35.2	**< 0.001**	22.7***	22.2	0.44	8.5	7.5	0.33

na = not analyzed; n.s. = not significant different, nd = no data given; cLA = conventional three port laparoscopic appendectomy, sLA = single port laparoscopic appendectomy, CO = conversion, SSI = surgical site infection; IAA = intraabdominal abscess, PP = postoperative pain; LoS = length of surgery; LHS = length of hospital stay, RNA = return to normal activities, NA = negative appendectomy, ex = excluded.
Significant results are highlighted bold.
*severity of pain: numeric rating scale, analgetic use.
**days off work.
***hours.
****extraport insertion, not counted as conversion.
*****severity of pain: additional instruments: pain at rest score, activity score, use of tramadol hydrochloride.

differences. Interestingly, cLA patients perceived a higher physical attractiveness while sLA patients had higher satisfaction concerning their scars. Causing more pain and longer operation time, the method was without advantages to cLA. A single RCT by Sozutek et al. compared open, three port laparoscopic and single port laparoscopic appendectomy. Recovery was faster in laparoscopic approaches. The longest operation time was observed in sLA. Postoperative pain was significantly higher in OA than in laparoscopic operations. Overall, laparoscopic surgery was described as option of first choice even if all techniques are safe and feasible [35].

4.1. Conclusion: single incision laparoscopic appendectomy vs. laparoscopic appendectomy

Single incision laparoscopic appendectomy is an interesting variation of the conventional laparoscopic technique. Data from current RCTs underline the method's safety and feasibility. However, all studies failed to show clear advantages concerning perioperative parameters. The only significant differences were found for length of surgery in four studies and for postoperative pain in two studies. Results were not consistent. Three of four studies which demonstrated differences in length of surgery stated an increased duration for sLA (Carter et al. Frutos et al., St Peter et al.) [29, 31, 33], while the sLA procedures were shorter in the SCARLESS results [34]. Concerning post-op pain, Carter et al. [33] showed higher and Frutos et al. [29] showed lower pain scores in sLA. Partly, a slight advantage concerning postoperative satisfaction and cosmesis was found, but only with little difference to cLA outcomes. A general issue of sLA is the availability of the equipment and the technical skills of the surgeon. Overall, cLA remains standard procedure for acute appendicitis. sLA can be safely applied depending on the patient's preference and presence of technical expertise and equipment.

5. NOTES

Natural orifice transluminal endoscopic surgery (NOTES) is the newest evolution of minimally invasive surgery. A transgastric and a transvaginal abdominal access has been used in NOTES appendectomy so far [36, 37]. Two different approaches could be identified, namely the pure or totally NOTES appendectomy (pNOTES) and the hybrid NOTES appendectomy (hNOTES). In hybrid NOTES, an additional abdominal port is used for video assisted visualization as well as for instrumental insertion [38, 39]. Pure NOTES is performed only through natural orifices, usually with flexible endoscopic instruments. In 2008, Rao et al. published a first case series of 10 consecutive patients who underwent totally transgastric NOTES appendectomy. Eight operations could be finished purely transgastric with a flexible double channel endoscope, while two cases were converted to the laparoscopic technique [40]. In the same year, Palanivelu published results of a first successful totally transvaginal appendectomy and two laparoscopically assisted transvaginal hybrid NOTES appendectomies out of a series of six patients [41].

Overall, three prospective trials and two register cohort studies could be identified in the study period and were included into the analysis. No RCTs were found by now.

Results of a first prospective comparative study were published by Bernhard et al., in 2015. Therein, a comparison between 10 flexible transvaginal hybrid NOTES- appendectomies and 10 conventional laparoscopic appendectomies was performed. All NOTES procedures were complemented with an additional umbilical 5 mm port. In this series Bernhard et al. stated flexible hybrid notes to be safely applicable. Recovery and quality of life were improved in the NOTES group [42]. Similarly, Knuth et al. found hNOTES to be safe and feasible in an analysis of 13 consecutive patients. Intraoperative and postoperative complications were comparable to conventional laparoscopic appendectomy. Mean procedural duration was 52 min [39]. Bulian et al. published data of the first 217 patients of the largest NOTES registry worldwide – the German NOTES registry – in 2016. The feasibility and safety of the method were evaluated and a comparison between the transgastric and the transvaginal approach was drawn. The majority of all procedures was performed as hNOTES approach. A transvaginal access was used in 181 cases, a transgastric approach in 36 cases. Conversion rate in the transvaginal group was 0.5% (n = 1) and 19.4% (n = 7) in the transgastric group. Mean procedural duration was 35 min versus 96 min in transvaginal and transgastric access, respectively. Perioperative complications were similar to rates in conventional laparoscopic appendectomy. The authors concluded that hNOTES is a safe procedure. The data showed a superiority of the transvaginal access to the transgastric approach in terms of conversion rate and operation time [38]. The EURO-NOTES clinical registry reported on 33 cases of NOTES appendectomies. The access was transgastric in 28 cases and transvaginal in five cases (3x use of a flexible endoscope, 2x use of a rigid endoscope). All procedures were hybrid with one or more percutaneous trocars. Overall duration was 93.5 min (transgastric: 99.8 min; transvaginal: 59 min, p = 0.002). Two IAA occurred in the transgastric group. The transvaginal group was without relevant complications. Length of stay was significantly longer in the transgastric approach (3.9 vs. 1.4 days, p = 0.003). According to the study group, the introduction of NOTES techniques into clinical routine is ongoing. Results are favorable, but the technique is reserved for a highly selected group of patients in specialized centers so far [43]. In 2012 Roberts et al. published data on a prospective cohort study on pure transvaginal NOTES appendectomy vs. conventional laparoscopic appendectomy. Therein, 18 patients underwent pNOTES appendectomy. In the pNOTES group, one IAA occurred. Mean operative time and mean length of stay were without significant differences. Mean postoperative morphine use, mean return to normal activity and mean time to normal work were significantly lower with the pNOTES-approach. The authors concluded that the method is safe and feasible with advantages in postoperative pain and recovery in the NOTES procedure [44].

5.1. Conclusion: NOTES

NOTES procedures are propagated to be associated with a reduction of SSI, hernias, postoperative pain and intra-abdominal adhesions. However, the technique still has numerous limitations. First, a standardized approach for different operations is lacking. Flexible and rigid instruments as well as pure and hybrid NOTES approaches with different access routes are competing. The learning curve is much longer due to the difficult handling of a flexible endoscope in the abdominal cavity, less familiar working angles and uncommon intraoperative views. Moreover, increased procedural time and special technical equipment lead to higher costs. Nevertheless, NOTES is worth being evaluated thoroughly since current study results show a safe applicability in certain indications and carefully selected patients. In 2014, a panel of experts congregated at the American College of Surgeons meeting to evaluate new techniques in minimally invasive surgery. In that context, transgastric and transvaginal accesses were found to be potentially safe and feasible in very experienced hands. Contrarily, cost, training, operative time and requirements on instruments limit the adaptability for routine procedures such as appendectomy. Due to a lack of prospectively randomized trials, the application was recommended to be considered carefully. Superiority of a NOTES appendectomy could not be proven yet. Moreover, the technique is usually performed in very specialized centers, which is why a generalization of the study results is currently not universally applicable [45].

6. Conclusion: current techniques

Currently, four different approaches with several technical variations are described for appendectomy: open appendectomy,

conventional three port laparoscopic appendectomy, single port appendectomy, NOTES appendectomy. Laparoscopic appendectomy is the current state of the art in the treatment of appendicitis concerning the frequency of use, safety in comparison to other techniques, costs, invasiveness, availability and learning curve. Procedural length, the rate of intraabdominal abscesses and costs decreased with increasing operation frequency. Certainly, laparoscopic appendectomy requires more equipment and consecutively is more cost intensive. Moreover, respective technical expertise is necessary for successful application of the method. Therefore, its raising development and popularity is focused on hospitals/countries where these preconditions are given. In case of lacking availability of equipment and expertise, open operation remains a safe and fast and thereby well fitted approach. In case of generalized peritonitis, both, open and laparoscopic surgery could be appropriate. Laparoscopic lavage for the control of abdominal sepsis is an effective and sufficient option, regarding the results of laparoscopic lavage for perforated diverticulitis of the sigmoid colon. Nevertheless, open surgery could be better for peritonitis treatment. However, laparoscopic exploration is a good technique for a “staging” of the inflammation and for decision making, if conversion by (median) laparotomy is warranted. Current data underline the significance of single port appendectomy in experienced centers. The technique is not inferior to conventional laparoscopic appendectomy concerning the aforementioned parameters. However, a clear advantage of the technique could not be shown yet. NOTES appendectomy in its different variations is a very interesting evolution in the field of appendectomy. Safety and feasibility could be proven in several prospective cohort studies. Due to technical requirements and specific equipment, the method should currently be reserved to specialized centers and to thoroughly selected patients. By now, evidence based assessment of the method is not available, wherefore its highly experimental character must be pointed out. Prospectively randomized trials are urgently necessary for a potential inclusion in the clinical routine.

Conflicts of interest

All the authors declare that they have no conflict of interests.

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Ethical approval

No ethical approval available. The current review is based on a bibliographic search.

Author contribution

Sohn M designed the study and wrote the paper; Agha A supervised the work, Iesalnieks I supervised the work and did literature review; Lehman K revised the work before submitting, Bormann M constructed tables and did literature review; Hochrein A translated the work and did literature review. Bormann M and Hochrein A equally contributed to the manuscript.

Guarantor

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