Electromagnetic-guided placement of nasoduodenal feeding tubes versus endoscopic placement: a randomized, multicenter trial

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Background and Aims: Electromagnetic-guided placement (EMP) of a nasoduodenal feeding tube by trained nurses is an attractive alternative to EGD-guided placement (EGDP). We aimed to compare EMP and EGDP in outpatients, ward patients, and critically ill patients with normal upper GI anatomy.

Methods: In 3 centers with no prior experience in EMP, patients were randomized to placement of a single-lumen nasoduodenal feeding tube either with EGDP or EMP. The primary endpoint was post-pyloric position of the tube on abdominal radiography. Patients were followed for 10 days to assess patency and adverse events. The analyses were performed according to the intention-to-treat principle.

Results: In total, 160 patients were randomized to EGDP (N = 76) or EMP (N = 84). Three patients withdrew informed consent, and no abdominal radiography was performed in 2 patients. Thus, 155 patients (59 intensive care unit, 38%) were included in the analyses. Rates of post-pyloric tube position between EGDP and EMP were comparable (79% vs 82%, odds ratio 1.16; 90% confidence interval, 0.58-2.38; $P = .72$). Adverse events were observed in 4 patients after EMP (hypoxia, GI blood loss, atrial fibrillation, abdominal pain) and in 4 after EGDP (epistaxis N = 2, GI blood loss, hypoxia). Costs of tube placements were lower for EMP compared with EGDP: $519.09 versus $622.49, respectively ($P = .04$).

Conclusions: Success rates and safety of EMP and EGDP in patients with normal upper GI anatomy were comparable. Lower costs and potential logistic advantages may drive centers to adopt EMP as their new standard of care. (Clinical trial registration number: NTR4286.) (Gastrointest Endosc 2018;87:110-8.)

Malnutrition and inability to eat are frequently encountered conditions in hospitalized patients.[1] Early enteral feeding promotes wound healing, decreases infection risk, avoids central line placement, provides a route for enteral medication, and is associated with lower costs than parenteral feeding.[2,3] Although nasogastric feeding is generally preferred over duodenal or jejunal administration, post-pyloric feeding may be indicated in certain conditions, for example, gastric outlet obstruction, acute pancreatitis, or risk of aspiration.[4-8]

Post-pyloric feeding tubes usually are placed by using EGD. Alternatively, bedside electromagnetic-guided tube placement (EMP) can be performed.[9,10] This has several potential advantages compared with EGD placement (EGDP) because only 1 trained nurse and less equipment is needed. Several observational studies have demonstrated the feasibility and safety of EMP.[11-13] Two studies comparing EMP with EGDP in a controlled setting in patients with unaltered upper GI anatomy have been published.[14,15] These studies included low numbers of patients and highly selected patient groups and lacked a cost comparison. Recently, non-inferiority of EMP compared with EGDP with regard to the repeat intervention rate and costs was found in patients admitted to a surgical ward; however, several patients had a history of upper GI surgery.[16] It is unclear how EMP and EGDP compare in an outpatient and clinical hospital population with normal upper GI anatomy. Therefore, the aim of this randomized study was to compare effectiveness, safety, and costs of EMP and EGDP in patients with normal upper GI anatomy.

PATIENTS AND METHODS

Study design and patients

This investigator-initiated, multicenter, randomized, sequential, open-label, controlled trial was performed in 1 tertiary-care referral center and 2 teaching hospitals in The Netherlands between December 2013 and September 2015. Centers had no experience in EMP. Adult patients referred for endoscopic nasoduodenal feeding tube placement were eligible for inclusion. Exclusion criteria were the presence of an implantable pacing device, altered anatomy or high suspicion of stenosis of the upper GI tract, esophageal varices, signs of upper GI hemorrhage, and pregnancy. The study was approved by the Medical Ethics Committee of the University Medical Center Utrecht, The Netherlands and thereafter by the institutional review boards of the other centers. Written informed consent was obtained from all patients or their legal representatives before study inclusion. The study was conducted according to the principles of the Declaration of Helsinki. The study was registered at the Dutch Trial Registry (NTR4286). All authors had access to the data and reviewed and approved the final manuscript.

Randomization

Patients were randomized in a 1:1 ratio to EMP or EGDP. Computer-generated, block-randomization sheets with a block size of 10 were stored in consecutively numbered, opaque, sealed envelopes. Randomization was stratified for participating centers and for severity of illness (intensive care unit [ICU] vs ward/outpatient). Obvious differences in placement techniques made blinding impossible. Assessment of the abdominal radiographs was performed by an independent radiologist formally blinded to the
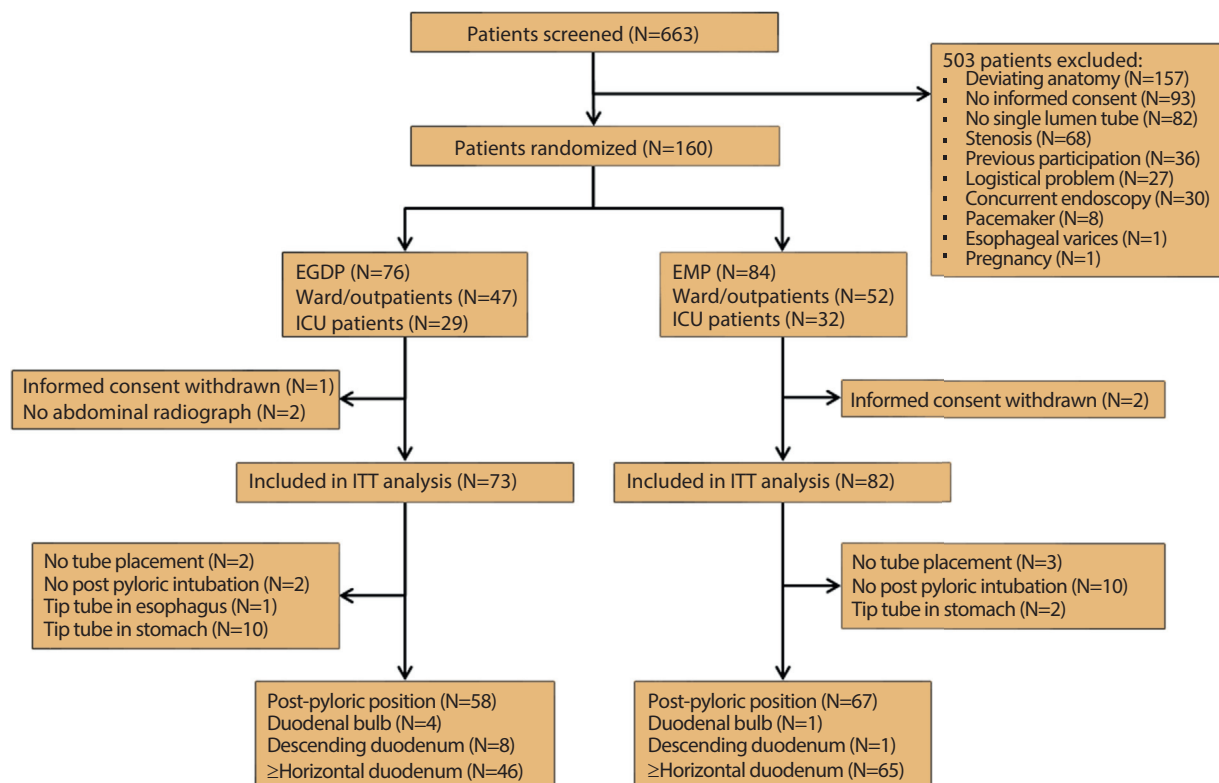

Figure 1. The electromagnetic-guided tube placement system consists of a system with an incorporated display, a guidewire with an electromagnetic transmitter in the tip, and a receiver unit.

randomization allocation. However, the 2 types of tubes have a different appearance on abdominal radiographs.

Procedures

Procedures were performed in patients who had been fasting for at least 6 hours. Conscious sedation with midazolam was allowed during EGDP but not during EMP on the clinical ward and in outpatients. In the ICU, conscious sedation or monitored anesthesia care with propofol was allowed in both groups.

EMPs were performed by nurses who underwent a structured training program, followed by 15 placements.[17] The EMP system consists of a system with an incorporated display (Cortrak Enteral Access System; Corpak Med Systems, Wheeling, Ill), a guidewire with an electromagnetic transmitter in the tip, and a receiver unit (Fig. 1). The receiver unit is positioned on the xiphoid process of the patient and triangulates the location of the guidewire tip. The guidewire comes preloaded in a feeding tube (CORFLO Ultra-Lite feeding tube, 10F, 140 cm; Corpak Med Systems, Buffalo Grove, Ill). The patient was placed in a supine position; a previously placed nasogastric tube was removed. The tube was advanced via the large curvature of the stomach to a post-pyloric position because the tip of the tube is not steerable, with the goal of reaching the duodenojejunal flexure. Hereafter, the guidewire was removed, and the tube was attached to the nostrils with tape. In the ICU, if the post-pyloric position was not reached within 30 minutes, erythromycin (200 mg) was administered intravenously.[17] A second attempt was made after 15 minutes. In patients not in

Figure 2. Patient inclusion. *EGDP,* EGD-guided placement; *EMP,* electromagnetic-guided placement; *ICU,* intensive care unit; *ITT,* intention to treat.

the ICU, a second attempt was made without administration of erythromycin. If the pylorus was not passed within 30 minutes, EGDP was performed.

EGDPs were performed by experienced gastroenterologists or supervised gastroenterology fellows, assisted by 1 or 2 nurses. Procedures were performed in the endoscopy unit, except for placements in the ICU. Preferably, patients were placed in the left lateral decubitus position. After transnasal duodenal intubation with a small-caliber (5.9 mm) endoscope (GIF-XP180 or GIF-XP190N; Olympus, Hamburg, Germany or EG-530NW; Fujifilm, Osaka, Japan), a straight-tip, stiff-shaft guidewire (Jagwire, Boston Scientific, Natick, Mass) was advanced as deep as possible. The endoscope was slowly retracted, after which a lubricated single-lumen feeding tube (Nutrisafe 2, 10F, 125 cm; Vygon, Ecouen, France) was advanced over the guidewire. Thereafter, the guidewire was removed, and the tube was attached to the nostrils with tape.

Subsequent placement of a nasogastric drain was permitted. Abdominal radiography was done within 3 hours after tube placement. An independent radiologist (F.W.), blinded to the treatment allocation of the patient, reviewed the radiographs to determine the position of the tip. The decision to initiate, adjust, and discontinue enteral nutrition was made by the treating physician based on clinical judgment and validated nutrition scores.[18,19] Patients were followed for 10 days to determine patency of

the tube, indication for reinsertion, repositioning (in case of EMP), and (severe) adverse events.

Outcomes

The primary endpoint was the success rate, defined as a post-pyloric position of the tube on abdominal radiography. Secondary endpoints were tube location, procedure time, sedation use, difficulty of placement, patient acceptance, electromagnetic tube location assessment, repeat intervention rate, safety, and costs. Procedure time was measured from insertion of the endoscope or electromagnetic tube until fixation of the tube to the nostrils. Difficulty of placement was scored on a 0- to 10-point numeric rating scale by the operator (0 = very easy, 10 = impossible). Patient acceptance was assessed directly after the procedure in unsedated patients and was scored on a similar 0- to 10-point numeric rating scale.

Costs were calculated by using actual unit costs rather than reimbursement rates submitted to a third party. For initial placement, a detailed calculation of required inventory was used; because the device itself is on loan, no costs were made for purchase of the device.[20,21] Procedure time was included in the cost calculation; 15 minutes were added to account for logistics (eg, patient preparation, report writing, room cleaning, walking to ICU). Where applicable, costs for sedation were included, including pre-sedation screening, presence of an additional nurse
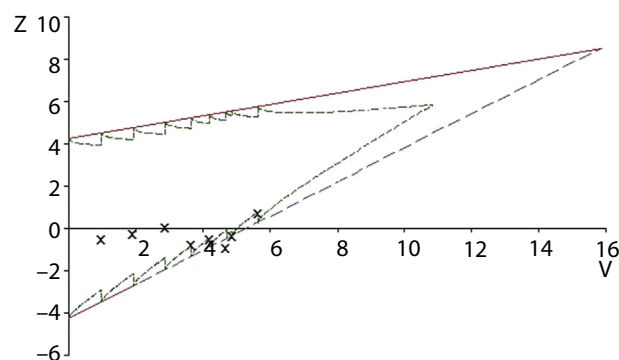
TABLE 1. Baseline characteristics

	EGDP (N = 73)	EMP (N = 82)
Age, mean (± SD)	56.6 (14.3)	57.9 (16.8)
Sex, male, no. (%)	44 (60.3)	44 (53.7)
Setting, no. (%)		
Ward	43 (58.9)	47 (57.3)
Medium care	1 (1.4)	0 (0)
Intensive care unit	28 (38.4)	31 (37.8)
Outpatient clinic	1 (1.4)	4 (4.9)
Indication for tube placement, no. (%)		
Postoperative gastroparesis	17 (23.3)	21 (25.6)
Critical illness gastroparesis	27 (37.0)	31 (37.8)
Pancreatitis	7 (9.6)	6 (7.3)
Severe GERD	1 (1.4)	1 (1.2)
Severe vomiting	8 (10.9)	3 (3.6)
Low intake	7 (9.6)	11 (13.4)
Other	6 (8.2)	8 (9.8)
Previous intake, no. (%)		
Oral	32 (43.8)	33 (44.2)
Parenteral feeding	2 (2.7)	3 (3.7)
Nasoduodenal feeding tube	8 (11.0)	10 (12.2)
Nasogastric feeding tube	29 (39.7)	32 (39.0)
Nothing by mouth	2 (2.7)	4 (4.9)
Use of prokinetics, no. (%)	30 (41.1)	27 (32.9)
Use of anticoagulants, no. (%)	55 (75.3)	52 (63.4)
Use of opioids, no. (%)	30 (43.8)	46 (56.1)
Mechanically ventilated, no. (%)	25 (34.7)	27 (32.9)
Sedated, no. (%)	11 (15.3)	20 (24.4)

EGDP, EGD-guided placement; *EMP,* electromagnetic-guided placement; *SD,* standard deviation.

Figure 3. Sequential testing procedure. Each X depicts the result of an interim analysis. On the horizontal axis, V stands for the amount of information, that is, a function of the number of patients included at an interim analysis. On the vertical axis, Z is a function of the difference in success rates. The blue dashed line represents the lower futility boundary; if crossed, this indicates futility or similarity of the trial results. The red continuous line represents the upper efficacy boundary; if crossed, this indicates superiority of electromagnetic placement. The inner green dashed line represents a continuity correction. The lower margin was first crossed after 120 patients. In total, 155 patients were included and analyzed.

during the procedure, and recovery room time. An additional cost analysis was done to include placements after a failed initial placement; in this analysis, the mean costs of EGDP were used. For placements during follow-up, mean EGDP costs also were used. In this cost analysis, the costs of repeat procedures, tube-related interventions, additional hospital admission days because of tube-related adverse events, and abdominal radiographs during follow-up were included.

Statistical analysis

Analyses were performed according to the intention-to-treat principle. Categorical variables were expressed as proportions; continuous variables were expressed as medians (interquartile range [IQR]) or means (standard deviation [SD]), where appropriate. Comparisons between treatment groups were made by logistic and linear regression analyses, after stratification for center and admission ward. For the sample size calculation, we presumed a 90% success rate with

EMP, based on previous reports, and an 80% success rate with EGDP, based on our own experience.[17,22-24] A 1-sided P value of .05 and a power (1-β) of 80% were used for sample size calculations. This study was conducted by using a sequential trial design.[25-27] On average, 127 (90th percentile, 206) patients would be needed if there was no difference between groups, and 194 (90th percentile, 309) patients would be needed to detect a 10% difference in success rate. Sequential interim analysis was performed after every 20 patients by an independent statistician, to determine whether the success rates of the 2 techniques differed. After we crossed the predetermined boundaries of the sequential testing procedure, continuation of the study was no longer required. The point and confidence interval (CI) estimates for the success rate were adjusted for stratification and sequential testing.[27] For other statistical tests, a 2-sided P value of .05 was used. Analyses were performed by using R version 3.3.0 (R Development Core Team 2016) or SPSS version 23 (SPSS Inc, Chicago, Ill). Healthcare costs were expressed in American dollars. Because healthcare costs often are highly skewed, nonparametric bootstrapping with 100.000 samples was used to derive a P value for the difference in distribution of healthcare costs between the 2 groups.[28]

RESULTS

During the study, 663 patients were screened for eligibility. Of these, 160 were included and randomized to EMP (N = 84) or EGDP (N = 76). Reasons for exclusion are shown in Figure 2. Three patients withdrew informed consent and were excluded from the analyses. Patients in whom no abdominal radiograph was obtained (N = 2) also were excluded because the primary endpoint could

TABLE 2. Feeding tube placement and position

	EGDP (N = 73)	EMP (N = 82)	OR crude (EGDP vs EMP) (95% CI)	OR adjusted (EGDP vs EMP) (95% CI)	P value†
Post-pyloric position, no. (%)	58 (79)	67 (82)	1.16 (0.59-2.26)	1.16 (0.58-2.38)*	.72
Tube placed by, no. (%)					NA
Staff	27 (37)	0 (0)			
Fellow	44 (60)	0 (0)			
Nurse	0 (0)	79 (96)			
Use of sedatives, no. (%)	43 (59)	11 (13)		0.09 (0.04-0.21)	< .001
Problems during placement, no. (%)	8	11		1.32 (0.49-3.56)	.58
Placement cancelled	2 (3)	3 (4)			
Anatomic difficulties	5 (7)	1 (1)			
Technical difficulties	1 (1)	7 (9)			
Erythromycin administered, no. (%)	NA	7 (9)			NA
Gastric drain placed, no. (%)	32 (44)	35 (43)		1.09 (0.49-2.41)	.84
Post-pyloric intubation, no. (%)	69 (95)	69 (84)	0.31 (0.10-0.99)	0.27 (0.08-0.91)†	.03
Procedure time, median (IQR)‡	10 (7-13)	20 (10-30)			< .001
Difficulty of placement, median (IQR)‡	3 (2-5)	4 (2.3-7)			< .01
Patient acceptance, median (IQR)‡	4 (0.8-7)	4 (2-6)			.50
Location on radiograph, no. (%)					.02§
Esophagus	1 (1)	0 (0)			
Stomach	10 (14)	2 (2)			
Duodenal bulb	4 (6)	1 (1)			
Descending duodenum	8 (11)	1 (1)			
Horizontal duodenum	12 (16)	6 (7)			
Ascending duodenum	23 (32)	35 (43)			
Jejunum	11 (15)	24 (29)			
NA	4 (6)	13 (16)			
Tube removed, no. (%)					
No	28 (38)	27 (33)			.74
Yes, no more indication	17 (23)	15 (18)			
Yes, tube adverse event	1 (1)	2 (2)			
Yes, unintentional removal	11 (15)	18 (22)			
Yes, inappropriate position	8 (11)	2 (2)			
Yes, intervention requiring removal	5 (7)	2 (2)			
Yes, migration	0 (0)	3 (4)			
NA	3 (4)	13 (16)			

Analyses performed according to intention to treat.
Data are expressed as proportions (%) or median (IQR).
EGDP, EGD-guided placement; *EMP*, electromagnetic-guided placement; *OR*, odds ratio; *CI*, confidence interval; *NA*, not applicable; *IQR*, interquartile range.
*Adjusted for center, patient ward, and sequential analyses. 90% confidence interval.
†Adjusted for center and patient ward.
‡Not including the 5 patients who did not undergo feeding tube placement.
§Pre-pyloric versus post-pyloric position.

not be determined. All remaining patients (Table 1) were included in the intention-to-treat analysis. In 3 patients randomized to EMP and in 2 patients randomized to EGDP, no feeding tube was placed. The majority of included patients (97%) were admitted to the clinical ward or ICU.

Figure 3 shows that the lower (futility) boundary of the sequential testing procedure was crossed after inclusion of 120 patients. This indicates that the efficacy of EMP and EGD was comparable and that continuation of the study for the purpose of determining the primary endpoint was not required. At the time of completion of reviewing the

TABLE 3. ICU patients vs non-ICU patients

	No.	Clinical ward/outpatient	No.	ICU	Clinical ward/outpatient vs ICU (95% CI)†	P value*
Post-pyloric position, no. (%)						
EGDP	45	33 (73)	28	25 (89)	2.98 (0.62-14.36)	.17
EMP	51	38 (75)	31	29 (94)	2.44 (0.40-14.89)	.34
Use of sedatives, no. (%)						
EGDP	45	25 (56)	28	18 (64)	1.05 (0.31-3.53)	.94
EMP	51	0 (0)	31	11 (36)	NA	
Problems during placement, no. (%)						
EGDP	45	4 (9)	28	4 (13)	1.42 (0.23-8.64)	.71
EMP	51	9 (18)	31	2 (7)	1.64 (0.14-19.29)	.69
Erythromycin administered, no. (%)						
EGDP	45	0 (0)	28	0 (0)	NA	
EMP	51	0 (0)	31	7 (23)	NA	
Post-pyloric intubation, no. (%)						
EGDP	45	41 (91)	28	28 (100)	NA	
EMP	51	39 (77)	31	30 (97)	3.49 (0.33-37.43)	.30
Procedure time, median (IQR)†						
EGDP	40	10 (5.3-10.8)	27	10 (7-14)		.40
EMP	48	20 (12.3-30)	31	15 (10-32)		.27
Difficulty of placement, median (IQR)†						
EGDP	43	2 (1-4)	28	4 (2-5.8)		.53
EMP	42	4 (2.8-7)	30	4 (2-8)		.90
Patient acceptance, median (IQR)†						
EGDP	14	4 (0.8-7)	0	0 (0-0)		NA
EMP	39	4 (2-6)	1	0 (0-0)		.02

Data expressed as proportions (%) or median (IQR).
ICU, Intensive care unit; *OR,* odds ratio; *CI,* confidence interval; *EGDP,* EGD-guided placement; *EMP,* electromagnetic-guided placement; *NA,* not applicable; *IQR,* interquartile range.
*Adjusted for center.
†Not including the 5 patients who did not undergo feeding tube placement.

abdominal radiographs, approximately 150 patients were already included in the study. When the final results of the sequential analysis were available, the decision was made to stop further inclusion after inclusion of 160 patients.

Feeding tube placements

According to the intention-to-treat analysis, the tip of the feeding tube was located past the pylorus in 67 of 82 patients (82%) after EMP and in 58 of 73 (79%) after EGDP (odds ratio [OR] adjusted for center and ICU/non-ICU, 1.16; 90% CI, 0.58-2.38; P = .72) (Table 2). A tip position beyond the descending duodenum was observed more frequently after EMP compared with EGDP (OR 2.32; 95% CI, 1.11-4.82). Repeat intervention rates were not different between EMP and EGDP: 21 (26%) versus 23 (32%), respectively (OR 0.76; 95% CI, 0.37-1.55).

Post-pyloric intubation was considered to be achieved in 69 of 73 patients (95%) during EGDP and in 69 of 82 (84%) during EMP (OR 3.72; 95% CI, 1.10-12.56). However, 11 of 69 tubes (16%) actually were located proximal to the pylorus after EGDP, compared with only 2 of 69 (3%) after EMP (OR 6.35; 95% CI, 1.34-30.15).

Median procedure time was longer for EMP compared with EGDP: 20 (IQR 10-30) versus 10 (IQR 7-13) minutes, respectively (P < .001). Patient acceptance of EMP and EGDP was comparable; 4 (IQR 2-6) versus 4 (IQR 0.8-7), respectively (P = .50). However, 25 of 45 EGDPs (56%) were performed with sedation in non-ICU patients, versus none of the 51 EMPs. In the ICU, 18 of 28 EGDPs (64%) and 11 of 31 EMPs (35%) were performed after administration of sedation.

ICU versus clinical ward and outpatients

No differences were observed between non-ICU patients and ICU patients in EMPs with regard to success rate (OR 2.44; 95% CI, 0.40-14.89), procedure time (P = .27), or difficulty of placement (P = .90) (Table 3). For EGDP, the success rate (OR 2.98; 95% CI, 0.62-14.36), procedure time (P = .40), and difficulty of placement (P = .53) were comparable as well.

Safety

Eight patients developed an adverse event related to tube placement (Table 4). In the EMP group, 1 patient with a history of unexplained abdominal pain reported an increase in abdominal pain after EMP. A decrease in hemoglobin level from 6.6 to 4.1 mmol/L was observed after repeat EGDP in a patient with mucositis. One patient allocated to EMP underwent EGDP because sedation was considered mandatory by the treating physician after inclusion; de novo atrial fibrillation was observed thereafter. One patient developed hypoxia after a repeat EGDP with sedation.

In the EGDP group, 2 patients developed self-limiting epistaxis. In 1 patient, a small amount of blood was seen in the gastric drain after EGDP; EGD showed a small laceration in the stomach. Finally, 1 patient developed hypoxia during a repeat EGDP with sedation.

Costs

Costs of placements are shown in Table 5. For initial EGDP, the mean sum of costs was considerably higher than the costs of EMP ($P < .001$). When we included the costs of repeat EGDP after a failed initial placement or an inadequate position of the tube on the radiograph, costs for EGDP were higher compared with those of EMP ($P = .002$). Costs of all placements combined during the study period were higher for EGDP compared with EMP ($P = .04$). When we included costs of diagnostic and therapeutic interventions because of adverse events, the costs of EGDP and EMP were similar ($P = .10$). If the initial abdominal radiograph was not included in the cost calculation for EMP (this often is considered unnecessary), the price for EMP was reduced to $319.11 (SD 28.82) for initial placement, $377.63 (SD 157.85) when we included the repeat endoscopies, $498.19 (SD 291.28) for all placements during the study, and $522.28 (SD 340.45) for total healthcare costs. In this scenario, total healthcare costs were significantly lower for EMP compared with EGDP ($P = .04$).[28]

DISCUSSION

This large, randomized comparison between EMP and EGDP for post-pyloric feeding tube placement showed comparable success rates in outpatients, ICU patients, and clinical ward patients with normal upper GI anatomy, even though participating centers had no prior experience with EMP. Furthermore, no difference in patency or adverse event rates was observed. Finally, although EMP was more time consuming, the fact that EMP requires fewer personnel and equipment resulted in considerably lower costs compared with EGDP.

Success rates for EMP and EGDP are in line with those of a recently published trial.[16] The primary endpoint of that study was repeat intervention rate, which is

TABLE 4. Adverse events, possibly related to tube placement

	EGDP (N = 73)	EMP (N = 82)
Severe adverse events		
After initial procedure	0	0
After repeat procedure (EGDP)		
GI blood loss	0	1
Hypoxia	1	1
Atrial fibrillation	0	1
Adverse events		
After initial procedure		
Epistaxis	2	0
Abdominal pain	0	1
GI blood loss	1	0
After repeat procedure (EGDP)	0	0

Grouping according to intention to treat.
EGDP, EGD-guided placement; EMP, electromagnetic-guided placement.

influenced by more factors than an unsuccessful placement. The primary endpoint of the current study, a post-pyloric position on abdominal radiography performed directly after placement, is directly related to the method used and less influenced by other factors. In the study by Gerritsen et al,[16] inclusion of patients with a history of upper GI surgery was allowed. Because EMP relies on natural structures for advancement of the tube, a history of upper GI surgery could have negatively affected the success rate and costs of EMP more than that of EGDP. Although no such differences were observed, the number of patients with altered anatomy was too low for a valid comparison. In the current study, only patients with normal upper GI anatomy were included. Furthermore, a detailed cost comparison was added, and only centers with no prior experience in EMP were included. These factors improve generalizability of the results considerably.

The success rate of EGDP was as expected.[24] However, the success rate of EMP was somewhat lower than anticipated. Reported success rates vary from 43% to 97%. Early studies report success rates of EMP of 74% to 78%, comparable to our findings.[12,29] However, in 2 prospective studies, success rates of 92.7% and 95.1% were reported when an experienced team performed the placements.[22,30] A success rate of just 43% was reported in another study, in which a team without extensive experience performed EMPs in ICU patients.[31] The importance of experience was shown in another study in which a clear learning curve was observed; in the first 25 EMPs, the success rate was 60% versus 84% in the second 25 cases.[17] No such improvement can be expected with EGDP over time. The limited experience of the nurses who performed the EMPs in the current study could be considered a shortcoming because it could have resulted

TABLE 5. Direct medical unit costs

		Amount		Costs ($) per patient, mean (± SD)		
	Unit/h price	EGDP	EMP	EGDP (N = 73)	EMP (N = 82)	P value
EMP		0	79	0	304.04 (63.25)	
Equipment	167.33					
Personnel (1 nurse), $	32.63					
Overhead + other personnel, $	126.50					
Abdominal radiographs	24.20					
EGDP		72	3	381.48 (47.41)	14.08 (72.93)	
Equipment/facilities, $	201.83					
Personnel (1 staff/fellow + 1 nurse), $/h	134.49					
Overhead +other personnel, $	126.50					
Abdominal radiographs, $	24.20					
Sedation + nurse	64.90 + 32.63/h	25	1	27.06 (37.84)	0.99 (8.69)	
Abdominal radiographs	24.20	65	71	21.56 (7.59)	21.01 (8.25)	
Initial placement		73	82	430.10 (65.12)	340.12 (28.27)	< .001
Repeat endoscopy for failed placement	411.84	7	11	39.49 (122.10)	55.22 (141.24)	
Abdominal radiographs after repeat endoscopy	24.20	7	11	2.31 (7.15)	3.30 (8.25)	
Initial placement including repeat endoscopy		73	82	471.90 (143.77)	398.64 (147.71)	.002
Repeat endoscopy during follow-up	411.84	26	24	146.63 (241.45)	120.56 (237.71)	
Fluoroscopy during placement	95.70	3	0	3.96 (24.86)	0	
All placements during study period		73	82	622.49 (324.50)	519.09 (286.99)	.04
Chest radiograph	24.20	0	1	0	0.30 (2.64)	
Blood products	303.49-614.02	0	4	0	19.69 (147.95)	
Medication	2	0	1	0	0.02 (0.22)	
Additional abdominal radiographs	22	28	14	9.24 (17.82)	4.18 (9.90)	
Total costs including all placements and interventions		73	82	631.84 (332.53)	543.29 (335.83)	.10
Total costs excluding initial radiographs in EMP group		73	82	631.84 (332.53)	522.28 (340.45)	.04

Analyses performed according to intention to treat.
Data expressed as mean (± SD).
EGDP, EGD-guided placement; *EMP*, electromagnetic-guided placement; *SD*, standard deviation; *$*, U.S. dollars.

in a lower success rate than might have been achieved by a more-experienced team. On the other hand, EGDPs were performed by both gastroenterology fellows and gastroenterologists with various experience.

In addition to a comparable success rate, EMP offers various potential advantages compared with EGD. Agreement with regard to a post-pyloric position between the electromagnetic device and abdominal radiograph was very good; as opposed to EGDPs, almost all EMPs considered to be successful by the operator resulted in a post-pyloric tube position. Consequently, very few patients required repeat EGDP after assessment of the radiograph before initiation of tube feeding, thereby reducing the delay in restoring appropriate caloric intake. This could positively affect mortality and morbidity.[32,33] Moreover, these findings suggest that performing abdominal radiography may well be unnecessary after EMP, confirming findings of previous reports.[22] In case of (suspected) partial migration, repositioning of the electromagnetic tube can be done at the bedside, whereas repositioning of an EGDP tube would require removal of the previously placed tube and repetition of the entire placement procedure (including sedation). Furthermore, abdominal radiographs showed that EMP resulted in a deeper position of the feeding tube, compared with EGDP. It is plausible that a deeper tube position positively affects tube function and spontaneous migration rates, even though this was not found in the current study.[17] Another advantage is that the EMP tube is thinner and more flexible than an endoscope. Therefore, EGDP may well be more uncomfortable in unsedated patients, although the current study was not designed to test this hypothesis. Consequently, sedation during EGDP often is requested by the patient or suggested by the physician. However, conscious sedation is associated with a small risk of cardiopulmonary adverse events, for example, hypoxia.[34,35] Finally, direct costs associated with EMP were considerably lower compared with those of EGD.

Because only 1 nurse is required and the placement can be done at the bedside, personnel and facilities can be allocated to other endoscopic procedures. The fact that no sedation is required during EMP and that no abdominal radiography is required after EMP results in another cost reduction. Therefore, the cost difference between EMP and EGDP found may be an underestimation of the true cost difference.

In conclusion, this large, randomized trial in a hospital population and critically ill patients with unaltered upper GI anatomy showed that success rates of EMP and EGDP are comparable. Cost savings and, in the long term, logistic advantages may drive centers to consider EMP as their new standard of care.

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