Clinical Nutrition 40 (2021) 5000–5007

Contents lists available at ScienceDirect

Clinical Nutrition

journal homepage: http://www.elsevier.com/locate/clnu

Original article

Video-assisted placement of enteral feeding tubes using the Integrated Real-Time Imaging System (IRIS)-technology in critically ill patients

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ARTICLE INFO

Article history:
Received 11 February 2021
Accepted 21 July 2021

Keywords:
ICU
Feeding tube
Post-pyloric
Safety
Efficacy
Placement confirmation

SUMMARY

Introduction: In critically ill patients, nasogastric (NG) and nasojejunal (NJ) feeding tube placements are standard procedures. However, about 1.9% of blind tube insertions are malpositioned in the trache-opulmonary system, whereas guided procedures may result in a significant delay in nutritional delivery. Guided methods, such as Cortrak and fluoroscopy, have success rates of 82.6–85% and 93% respectively. The current study aims to investigate the performance of video-assisted feeding tube placement in the post-pyloric position using Integrated Real Time Imaging System (IRIS-) technology.

Methods: A prospective cohort study in patients requiring enteral feeding was conducted in a mixed medical-surgical intensive care unit (ICU). The primary outcome was the post-pyloric placement of IRIS feeding tubes, as confirmed by X-ray. Secondary study objectives included gastric placement, ease of use and adverse events.

Results: Thirty-one feeding tubes were placed using IRIS-technology; one patient was excluded for analysis due to protocol violation. One procedure was terminated due to significant bleeding (epistaxis) and desaturation. Only eighteen (58%) feeding tubes were placed in post-pyloric position (including two past the ligament of Treitz). In subjects who needed post-pyloric placement due gastroparesis, IRIS was mostly unsuccessful (success rate of 25%). However, when gastric placement was the primary objective, 96.8% of tubes were correctly placed. During insertion, tracheal visualization occurred in 27% of cases, and the IRIS feeding tube was repositioned early in the procedure without causing patient harm.

Conclusions: Real-time video-assisted post-pyloric feeding tube placement in critically ill ICU patients was only successful in 58% of cases and therefore currently cannot be recommended for this indication. However, a high success rate (96.8%) for gastric placement was achieved. IRIS tube placement detected tracheal misplacement immediately and had few adverse events.

1. Introduction

Most critically ill patients admitted to the intensive care unit (ICU) require enteral nutrition (EN), enteral administration of medication or gastric decompression [1,2]. It has been demonstrated that early enteral feeding (*i.e.,* within 24–48 h after ICU admission) is beneficial in critically ill patients concerning infectious complications (relative risk 0.76, confidence interval 0.59–0.97, $p < 0.03$; 1,3(^#), patient safety and outcomes [4]. Gastric access is recommended by the European, American, and Canadian clinical nutrition guidelines as the standard approach [1,4–8]. In patients with a high risk of aspiration (such as the absence of an intact gag reflex), proximal enteric fistulae or in cases of persistent gastric feeding intolerance despite the administration of prokinetics, post-pyloric feeding should be considered, with post ligament of Treitz as the optimal position [1,9–11].

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https://doi.org/10.1016/j.clnu.2021.07.026
0261-5614/

List of abbreviations

APACHE-II	Acute Physiology and Chronic Health Evaluation II
BMI	Body Mass Index
EN	Enteral Nutrition
Fr	French
ICU	Intensive Care Unit
IQR	Interquartile Range
IRIS	Integrated Real-Time Imaging System
ITT	Intention-to-treat
mGHAA-9	modified Group Health Association of America-9 survey
N	Number
NG	Nasogastric
NJ	Nasojejunal
NUTRIC	Nutrition Risk in Critically ill
PEG	Patient Experiences Questionnaire
PP	Per-protocol
QS-PEQ	Generic Short Patient Experiences Questionnaire
RASS	Richmond Agitation–Sedation Scale
SD	Standard Deviation
SOFA	Sequential Organ Failure Assessment
SUM	Single Usability Metric
ZGV	Ziekenhuis Gelderse Vallei (Gelderse Vallei Hospital)

In ICUs, nasogastric (NG) and nasojejunal (NJ) feeding tube placements are standard procedures. Most NG feeding tubes are inserted blindly, whereas NJ feeding tubes are placed using a guided placement method, such as real-time electromagnetic signals (Cortrak), real-time X-ray (fluoroscopy) or endoscopically by gastroenterologists. Two systematic reviews by Gerritsen et al. [10] and Wei et al. [13] reported success rates of Cortrak and fluoroscopy to be about 82.6–85% and 93% respectively [12,13]. However, these guided procedures frequently result in significant delay in nutritional delivery due to the limited availability of qualified operators and equipment [10,14]. Since NG tube placements are conducted blindly, the final position should be confirmed before initiating nutritional therapy to avoid pulmonary misplacement, especially in mechanically ventilated patients who are at increased risk for tube misplacement due to unconsciousness and weakened cough reflex [15,16]. Chest or upper abdominal X-ray is currently considered the gold standard [16,17]. However, this technique results in radiation exposure and additional costs for each NG insertion [18,19]. Moreover, it is not foolproof: between September 2005 and March 2010, a total number of 21 deaths and 79 other cases of harm due to misplaced NG tubes were reported to the National Patient Safety Agency of the United Kingdom, of which 45% were due to X-ray misinterpretation [20]. Other studies have reported mortality rates of 0.27% [21]. Although a correct position may be confirmed on X-ray, migration of the feeding tube in the days after initial placement is not rare [22,23].

In this case series, video-assisted placement of NG and NJ enteral feeding tubes is examined. Enteral feeding tubes (either NG or NJ) are placed under direct visualization of anatomical landmarks using Integrated Real-Time Imaging System (IRIS-) technology (hereafter called “IRIS feeding tubes”; Cardinal Health, Mansfield, MA, USA). These IRIS feeding tubes are equipped with a mini video camera at the distal tip, allowing real-time visualization on an external portable monitor during tube insertion and thereby potentially eliminating the need for X-ray confirmation after the procedure [24,25]. Furthermore, IRIS feeding tubes allow daily position checks by re-visualizing the gastric/jejunal mucosa, thereby minimizing the risk of aspiration resulting from unrecognized tube migration [2]. To date, only three studies on the use of camera-equipped feeding tubes have been published [24–26]. In all studies, the intent was to place the tubes in the gastric position. Wischmeyer et al. and Mizzi et al. conclude that IRIS technology provides direct visualization of anatomical landmarks avoiding pulmonary misplacement in 20–35% of cases [24,25].

This study aimed to investigate IRIS feeding tube performance for post-pyloric placement, as confirmed by X-ray. The secondary focus of this study included gastric placement, testing the overall feasibility of enteral feeding tube insertion using IRIS-technology and to evaluate safety (adverse events). We hypothesized that NG/NJ tube placement under direct visualization using IRIS-technology is simple, safe and efficient in ICU-patients, providing identification of the esophagus and stomach (and small intestines if desired) greatly increasing the probability of accurate placement.

2. Materials and methods

This prospective cohort study was conducted from May 5, 2019 to December 12, 2019 in critically ill patients admitted to a mixed medical-surgical ICU of Gelderse Vallei Hospital (Ziekenhuis Gelderse Vallei (ZGV), in Ede, The Netherlands).

2.1. Study design and participants

Patients aged ≥18 years with an indication for enteral feeding and/or medication for at least 48 h were eligible for inclusion. After obtaining informed consent from the patient or legal representative, patients were enrolled in consecutive order. Patients with previous upper gastrointestinal tract ((oro)pharynx, esophagus, gastric or small bowel) surgery were not eligible, as well as patients with a suspicion of upper gastrointestinal bleeding or stenosis. Moreover, patients with altered anatomy, basal skull fracture or a life expectancy of fewer than 48 h were excluded. The number of patients to recruit was estimated at 30 subjects (15 per operator) to sufficiently analyze the primary study endpoints.

2.2. Insertion of the feeding tube

IRIS feeding tubes were inserted by strictly following a prescribed protocol developed by the study team in our hospital. All tubes were attempted to be placed in the post-pyloric position. Tubes were placed by two trained physicians (AvZ and HSB). Both performed a training phase with a total of five cases each. Feeding tubes were available in two lengths: 109 cm (10 French diameter) and 140 cm (10 and 12 French diameters). Feeding tubes were gradually advanced to the desired position. An insufflation device was used whenever necessary to aid in feeding tube placement. Prokinetics were not routinely administered. In case of tracheal malpositioning or other difficulties, which could not be solved without retraction of the feeding tube, a new attempt was started after withdrawal of the feeding tube into the nasal cavity.

Following the insertion procedure, all tubes were secured with tape to the patient's nose. The tube position was checked by chest or upper abdominal X-ray (for study reasons only; considered gold standard). X-rays were independently and blindly assessed by the operator and a radiologist (CvM). Enteral feeding and/or medication administration was only commenced after radiological confirmation of correct positioning. After X-ray evaluation by the operator, the tube was retracted to the gastric position (confirmed

by visualization of gastric mucosa) in patients without an indication for a post-pyloric feeding tube.

2.3. Follow-up

Complications and adverse events were recorded from the start until the end of the study period. Study participation ended immediately after removal of the IRIS feeding tube, either on purpose or by accident.

To evaluate the feeding tube position and the IRIS-camera's ability to visualize the gastric/duodenal mucosa over time, daily screenshots were collected. This was performed until feeding tube removal or patient discharge from the ICU. When the IRIS feeding tube was still present on ICU discharge, patients were followed up in the general wards for complications and adverse events.

2.4. Questionnaires

After inserting the IRIS feeding tube, the operator completed a short questionnaire based on a standardized, summated and single usability metric (SUM, see Supplement 1) [27]. Conscious patients were also asked to complete a short survey to assess how they experienced the procedure. Since there were no validated scales available to measure patients' satisfaction after enteral feeding tube placement, we composed a new questionnaire based on existing questionnaires measuring patient experience and satisfaction (Supplement 1) [28–30].

2.5. Outcome measures

The primary outcome was the number (percentage) of post-pyloric feeding tubes using the IRIS-technology, assessed by X-ray. Secondary parameters included successful gastric placement, ease of use (number of attempts needed and operator & patient evaluation), and safety parameters (number of patients with visualization of the trachea and the ability to identify the correct position during daily enteral feeding).

The primary outcome analysis was based on an intention-to-treat (ITT) analysis. The ITT population consisted of all patients who met eligibility criteria and were enrolled in the study and not considered training cases. Additional per-protocol (PP) analyses were carried out. The PP population consisted of all patients in the ITT population who had an IRIS feeding tube placed in gastric or jejunal space and correct position confirmed by X-ray.

2.6. Data collection

Data collection included patient characteristics (age, gender, anthropometry, comorbidities), admission type (medical or surgical) and presence of mechanical ventilation, including information about the state of consciousness. Moreover, several scores (Acute Physiology and Chronic Health Evaluation-II (APACHE-II), Sequential Organ Failure Assessment (SOFA), Nutrition Risk in the Critically Ill (NUTRIC)) on ICU admission were determined. On the procedural day, gastric residual volume (24 h) and use of prokinetic agents were recorded. Data extraction was performed using queries searching the ICU patient data management system (MetaVision; iMDsoft, Tel Aviv, Israel) and electronic patient record system (Neozis; MI Consultancy, Katwijk, The Netherlands). These parameters of interest have been routinely collected during standard clinical care and therefore imposed no burden or risk to patients. Data verification was conducted manually.

2.7. Statistical analysis

All statistical analyses were conducted using IBM SPSS Statistics 24.0 (IBM Corporation, Armonk, NY, USA; 2016). Discrete variables were displayed as proportions. Continuous variables were reported in means including standard deviations (SD) or, in case of non-normal distribution, in medians with interquartile ranges (IQR). Normality was assessed graphically (visual inspection of histograms and Q–Q plots) and numerically, using the Shapiro Wilk test. Z-values were calculated to determine kurtosis and skewness. A p-value below 0.05 was considered statistically significant.

2.8. Ethical approval

The Institutional Review Board of ZGV approved the study (protocol number 1807-136).

3. Results

Between May 5th 2019 and December 12th 2019, a total of 182 unique patients needed an NG and/or NJ feeding tube for at least 48 h. Of these, 115 patients had an urgent indication for tube insertion during evening or night shifts (17:00–8:00), which could not wait until the next working day. Therefore, 67 patients required feeding tube insertion during daytime hours, when the study team was available. Of these, 32 patients were enrolled in the study (Fig. 1). However, one patient was excluded due to a protocol violation (previous history of gastric bypass surgery that was not identified on ICU admission). The majority of patients were male (61%), overweight (median body mass index (BMI) 28.4 kg/m^2), non-surgical (71%), and had sepsis on ICU admission (51.6%). In five patients (16%) a post-pyloric feeding tube was clinically indicated; all others needed a gastric feeding tube (Table 1). Four patients (12.9%) had gastric residual volumes of >500mL/24 h, and five patients (16.1%) were administered prokinetics on the day of feeding tube insertion.

Preprocedurally, about half of the study population (52%) already received intravenous sedation, analgesia and/or anxiety-reducing medication. Of these, nine patients (56%) were deeply sedated with propofol or midazolam (Richmond Agitation Sedation Scales (RASS) -4/-5). Others were prescribed dexmedetomidine or clonidine (n = 3), or intravenous opioids (n = 4). Due to unrest, a bolus of 5 mg midazolam was administered to three patients (10%) periprocedural. About 45% (n = 14) were invasively mechanically ventilated, and nine patients (29%) received non-invasive mechanical ventilation. The other study participants were stable without any supplemental oxygen therapy (n = 3) or were administered oxygen through an uncuffed tracheostomy (n = 1) or nasal cannula (n = 4) (Table 1).

3.1. Primary outcome: success rates

A total of 30 IRIS feeding tubes were placed in the gastrointestinal tract. One procedure was terminated due to significant bleeding (epistaxis) and desaturation (SaO_2 85%). In total, 18 (58%) feeding tubes were confirmed in post-pyloric position on X-ray. Of these, two were in jejunal position (past the ligament of Treitz). Post-pyloric feeding tube insertion in patients with delayed gastric emptying (gastric residual volume (GRV) > 500mL/24 h) was only successful in one procedure (25%). In patients who were administered prokinetics, this was 75% (n = 3). In four patients (13%) there was discrepancy between camera image and radiographic confirmation. Based on camera images, it was believed that the feeding tubes were in post-pyloric position, but on X-ray visualization they were not. Reasons for terminating the insertion procedure before reaching the post-

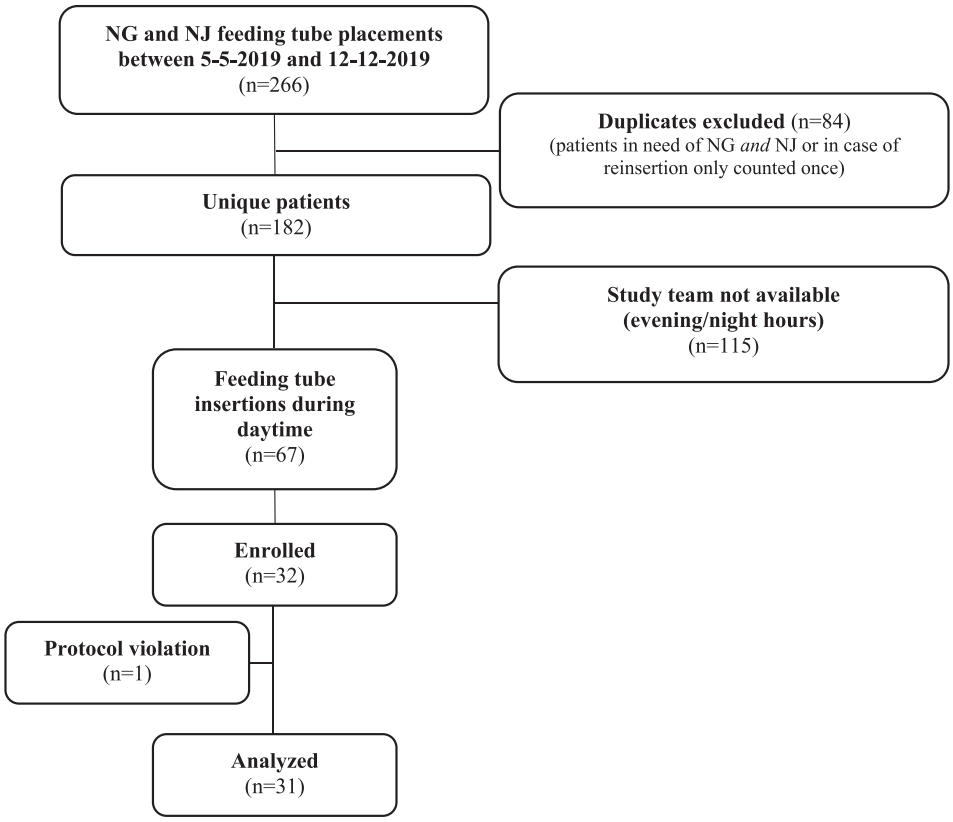

Fig. 1. Study flow chart. NG = nasogastric; NJ = nasojejunal.

Table 1
Patient characteristics.

Age (years)	Median (IQR)	71 (62–77)
Gender (male)	*N (%)*	19 (61)
Type of admission (medical)	*N (%)*	22 (71)
BMI on admission (kg/m^2)	*Median (IQR)*	28.4 (24.1–31.1)
APACHE II score on admission	*Median (IQR)*	20 (16–25)
SOFA score on admission	*Median (IQR)*	6 (5–8)
NUTRIC score on admission	*Median (IQR)*	5 (4–6)
Indication for post-pyloric feeding tube	*N (%)*	5 (16)
During procedure		
Intravenous sedation	*N (%)*	16 (52)
Propofol/midazolam (sedation level RASS -4/-5)		9 (56)
Dexmedetomidine/clonidine		3 (19)
Opioids		4 (25)
Oxygen therapy		
None	*N (%)*	3 (10)
Nasal cannula	*N (%)*	4 (13)
Non-invasive ventilation & High Flow Nasal Oxygen	*N (%)*	9 (29)
Uncuffed tracheostomy cannula	*N (%)*	1 (3)
Invasive mechanical ventilation	*N (%)*	14 (45)

IQR = interquartile range; N (%) = number (percentage); BMI = Body Mass Index; kg/m2 = kilograms per square meter; APACHE-II score = Acute Physiology And Chronic Health Evaluation II-score; SOFA score = Sequential Organ Failure Assessment score; NUTRIC score = Nutrition Risk in Critically ill score; RASS = Richmond Agitation–Sedation Scale.

pyloric position and leaving the tube in the gastric position included difficulties due to the absence of gastric peristalsis (n = 1), inability to pass the pylorus (n = 1), blurred image - impairing evaluation of the tube position (n = 2), an urgent need for non-invasive mask ventilation (desaturation SaO_2 <90% before start of procedure, n = 1), discomfort of the patient (n = 2), and suspected altered anatomy (n = 1) (see Supplement 3) (see Tables 2 and 3).

3.2. Secondary outcomes: safety parameters

The majority (n = 17) of IRIS feeding tubes were placed on the first attempt. However, some insertions needed a second (n = 8), third (n = 5) or fourth attempt (n = 1); mainly due to malposition in the trachea during the procedure (n = 8). In two patients, tracheal visualization occurred twice.

Ten patients (32%) experienced adverse events; eight patients experienced adverse events that were considered unlikely or unrelated to IRIS feeding tube insertion (see Supplement 2). Two major events were possibly related; in one mechanically ventilated patient, it was noticed on X-ray that the endotracheal tube had migrated into the right main bronchus after using a video laryngoscope to facilitate insertion of the IRIS feeding tube into the esophagus. Moreover, one procedure was terminated due to significant bleeding (epistaxis) and desaturation.

3.3. Follow-up

The median duration of study participation was four days (range 1–30). In total, 75 daily screenshots were taken to identify the correct position during enteral feeding. On the second and fourth day after insertion (study days three and five respectively), 2/18 and 2/4 screenshots were blurred due to a biofilm, impairing evaluation of proper positioning.

Nine patients (30%) were discharged to the general ward with the IRIS feeding tube in place. The most common reason for ending the study was the removal of the feeding tube by patients in a delirium (40%). One tube had to be removed due to cracked feeding ports resulting in enteral feeding leakage (see Fig. 2 and Table 4).

3.4. Secondary outcome: ease of use

In total, 29 operators' questionnaires were filled out. The median total score (range 3–14) for overall evaluation composed of task difficulty, device and task time, was 9 (IQR 7–13). Satisfaction with the device scored median four on a 5-point Likert scale (IQR 2–5). The degree of satisfaction was highly correlated with successful post-pyloric placement ($p = 0.005$).

3.5. Secondary outcome: procedural time

One operator at a time performed the procedure. The total procedure time (defined as the time from start of preparations until ready for use) for all feeding tubes was median 64.0 min (IQR 38.0–86.5). This period was composed of preparation time (median 2.0 min; IQR 1.6–3.0), the time needed for proper feeding tube insertion in post-pyloric position (median 8.7 min (IQR 4.7–28.1)) and waiting time until X-ray confirmation (median 43.5 min (IQR 28.4–58.7)).

3.6. Patients' evaluation

No patient questionnaires were completed; most patients were delirious (n = 20) or unconscious (n = 9) during tube insertion. Two patients who were conscious during placement were sedated and mechanically ventilated within 24 h after tube placement.

4. Discussion

Using Integrated Real-Time Imaging, only 58% of feeding tubes were successfully placed in the post-pyloric position, but 96.8% were properly placed when gastric placement should have been the

Table 2
Feeding tube placement procedure details.

Feeding tubes inserted by operator 1	*N (%)*	15 (48)
Feeding tube diameter 10 Fr[a]	*N (%)*	12 (39)
Feeding tube length 140 cm[b]	*N (%)*	9 (29)
Number of attempts	*N (%)*	
1		17 (55)
2		8 (26)
3		5 (16)
4		1 (3)
Total procedure time (start-ready for use) [min]	*Median (IQR)*	64.0 (38.0–86.5)
Preparation time [min]	*Median (IQR)*	2.0 (1.6–3.0)
Time needed to insert (all tubes) [min] *(n=30)*	*Median (IQR)*	9.8 (4.8–28.3)
Time until X-ray [min] (incl examination, *n*=30)	*Median (IQR)*	43.5 (28.4–58.7)
Time needed to insert gastric tubes [min] *(n=12)*	*Median (IQR)*	15.6 (6.1–29.0)
Time needed to insert *post-pyloric* tubes [min] *(n=18)*	*Median (IQR)*	8.7 (4.7–28.1)
Time needed to insert jejunal tubes [min] *(n=2)*	*Mean (min–max)*	28.9 (27.4–30.4)

N (%) = number (percentage); Fr = French; cm = centimeters; IQR = interquartile range; min = minutes.
NB: all tubes were attempted to be placed at the post-pyloric position.
[a] As compared to 12Fr feeding tubes.
[b] As compared to 109 cm feeding tubes.

Table 3
Outcomes and safety of the procedure.

Postpyloric position achieved	*N (%)*	18 (58)
Bulbus duodeni	*N (%)*	8 (44)
Pars descendens	*N (%)*	1 (6)
Transitional part of the pars descendens/inferior	*N (%)*	5 (28)
Pars inferior	*N (%)*	2 (11)
Jejunal position	*N (%)*	2 (11)
Visualization of trachea	*N (%)*	8 (26)
Desaturation (SaO_2 < 90%)	*N (%)*	2 (7)
Airway tube migration	*N (%)*	1 (3)
Epistaxis	*N (%)*	1 (3)
Operator's evaluation score, overall (min. 3, max.14) (n = 29)	*Median (IQR)*	9 (7–13)
Task difficulty (1 = Very Difficult; 5 = Very Easy)	*Median (IQR)*	3 (2–4)
Satisfaction with the device (1 = Very Unsatisfied; 5 = Very Satisfied)	*Median (IQR)*	4 (2–5)
Task time to achieve result (1 = Too Much Time; 4 = Very Little Time)	*Median (IQR)*	3 (2–4)

N (%) = number (percentage); IQR = interquartile range; SaO_2 = plethysmographic arterial oxygen saturation; min. = minimum; max. = maximum.

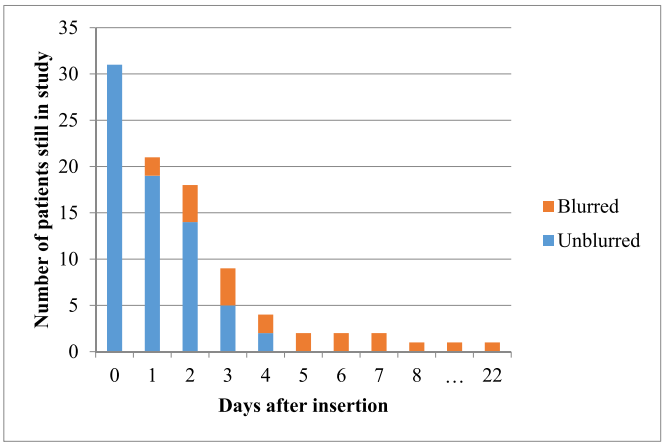

Fig. 2. Visualisation (daily screenshots) of gastric/duodenal mucosa with IRIS-technology. Daily screenshots were made to evaluate the feeding tube position and the ability of the IRIS-camera to visualize the gastric/duodenal mucosa over time. One tube had to be removed due to a cracked feeding port resulting in enteral feeding leakage.

goal. Tube placements were limited to two experienced physicians to guarantee a high exposure, and after a training session of 5 placements.

To date, this is the most extensive series of feeding tubes using IRIS-technology placed in the post-pyloric position. Taylor et al. [26] inserted 13 out of 15 feeding tubes successfully in gastric position [26]. Mizzi et al. [24] successfully positioned feeding tubes in the lower third of the stomach in 20 patients in a neurological ICU using IRIS-technology [24]. The correct position was confirmed by X-ray. Wischmeyer et al. (2019) demonstrated proper IRIS feeding tube placement in 44 of 45 ICU patients (97.8%), of which 6.8% were inserted post-pyloric [25]. Regarding tracheal visualization, an incidence of 27% was reported in our study. Notably, this was higher than Wischmeyer (20%) but lower than Mizzi (35%) [24,25]. This might be explained by the number of patients on mechanical ventilation: 42% and 95% respectively versus 45% in our study. In the three last mentioned studies, image quality of screenshots declined as the camera became obscured during the follow-up period, impairing proper evaluation of the feeding tube position. We have also reported problems with image quality during the feeding tube insertion. A blurred vision hampered two procedures; air insufflation did not improve the situation, making proper visual confirmation impossible.

Moreover, we reported discrepancy between the camera image and radiographic confirmation in four patients (12.5%). This may be due to insufficient user experience or camera image quality preventing optimal discrimination between antral and pyloric mucosa. A similar situation was reported by Wischmeyer et al. who attributed this to feeding tube migration after insertion [25]. In our study, in all four cases 109 cm tubes were used. These tubes precluded deeper placement compared to the 140 cm feeding tubes, which may have contributed to migration back into the gastric space. In addition, many critically ill ICU patients have reduced gastric motility and suffer from retroperistalsis, further hampering post-pyloric tube positioning [11]. In the current study, in patients with delayed gastric emptying, intestinal placement was successful in only 25% of insertions, increasing to 75% when prokinetics were administered. IRIS technology is therefore at present deemed to be unsuitable for post-pyloric tube positioning in this patient category.

Regarding nasojejunal placement, the IRIS technique performed poorly (only 7%) with a mean procedure time of 28.9 min. This is due to a lack of anatomical markers on the exact position in the duodenum and the flexibility of the tube hampering the passing of the tube to the proper post-pyloric position.

4.1. Comparison of the integrated real-time imaging technique with Cortrak, fluoroscopy and endoscopy

Two systematic reviews by Gerritsen et al. [10] and Wei et al. [13] reported success rates of Cortrak and fluoroscopy to be about 82.6–85% and 93% respectively, and 83.1–89% for endoscopy [12,13]. This is in contrast with 58% for IRIS technology. It should be noted however, that both reviews defined success as “tip of the tube in the post-pyloric position” during the procedure and without radiographic confirmation. By this definition, 22 (73%) of IRIS tubes in this study were successfully placed as we considered them in post-pyloric position; however, they were not confirmed by X-ray possibly due to migration.

Gerritsen et al. reported procedural times of 13.4 (SD 12.9, 16.2 (SD 23.6) and 14.9 (SD 8.7)) minutes, for Cortrak, fluoroscopy and endoscopy respectively [12]. The time needed for post-pyloric procedures using the IRIS technology (mean 14.2 (SD 13.1) minutes) was comparable to these methods [10]. Of note, we reported an additional median waiting time of 43.5 min for X-ray confirmation, which is not necessary after Cortrak, fluoroscopy or endoscopic placement. Other studies have reported waiting times up to 78.8 min for radiography [19].

Based on our results, at present IRIS technology cannot be recommended for post-pyloric placement. For gastric placement there are definite advantages over other methods.

In terms of clinical workflow, when using IRIS-technique there is no need to exclude patients with medical implants affected by

Table 4
Follow-up after IRIS technology feeding tube placement.

		N = 30
Number of screenshots per patient (total 75)	*Median (IQR)*	2 (0–3; range 0–22)
Number of study days (total 158 days)	*Median (IQR)*	4 (2–6; range 1–30)
Discharged with IRIS feeding tube to general ward	*N (%)*	9 (30)
Reason to terminate study	*N (%)*	
Insertion not successful		3 (10)
Removed by patient		12 (40)
Removed accidently by healthcare provider		3 (10)
No longer an indication for feeding tube		9 (30)
Other reasons[a]		3 (10)

IQR = interquartile range; N (%) = number (percentage).
-Removal of feeding tube requested by patient and approved by ICU doctors (n = 1).
-Transfer to another hospital (n = 1).
-Leakage of the feeding tube (cracked port).
[a] Other reasons to terminate the study.

electromagnetic fields (Cortrak) and procedures can be performed with less sedation compared to endoscopy [24]. Only a third of the study participants who were conscious during feeding tube insertion were administered midazolam periprocedurally. Moreover, IRIS guided insertion may avoid time-consuming scheduling with different departments and may reduce the risk associated with transporting critically ill patients through the hospital [3,12]. In our study, feeding tubes were inserted immediately, whenever the study team was available. As there is no need for an endoscopy team, procedure time is shorter and less demanding on personnel. Moreover, Cortrak and endoscopically placed feeding tubes are commonly not inserted during weekends and holidays. Consequently, these interventions are delayed until the next working day, causing considerable feeding delays. Furthermore, delays of up to 7.5 h until feeding initiation translated into an average energy deficit of 850 kilocalories [3,31,32]. After failed electromagnetically guided placement, this delay may increase to an average of 17 h before endoscopical or radiological placement is executed [3]. Although not investigated in this study, similar delays with IRIS-technology could be expected. However, the time until the first attempt was much shorter than 7 h in our study. Finally, if feeding tube migration is suspected, IRIS feeding tube position can be checked at the bedside if the camera is not blurred [24,25]. Similar to Cortrak feeding tubes, it is possible to rewire and reposition the tube, whereas endoscopically placed tubes that migrate would necessitate removal of the tube and replacement in a new procedure [33].

4.2. X-ray confirmation

When camera image quality can be improved to make better distinction of the antrum-pylorus-duodenum, IRIS technology should make X-rays redundant to conform proper post-pyloric placement. Artificial intelligence techniques for processing and analysis of images may further optimize the technique. X-ray confirmation is not necessary when gastric placement is the goal. There was 100% agreement between X-ray and real-time imaging regarding placement in the gastrointestinal tract; none of the feeding tubes positioned by IRIS guidance was found to be in the respiratory tract on X-ray. This is relevant as a chest or abdominal film dose is similar to 10 days or 2–3 years of background radiation, respectively [31]. Using IRIS technology, enteral nutrition can be safely started immediately after gastric tube insertion.

4.3. Safety

An important finding in this study was the avoidance of airway placement in 27% of all patients. Due to real-time visualization of anatomic landmarks, entering the trachea was immediately recognized and corrected early in the procedure. As mentioned above, in one patient the insertion procedure was discontinued due to epistaxis with oxygen desaturation (3.2%), and in another patient airway tube migration was encountered after using a video laryngoscope to introduce the feeding tube. In both cases, the slightly larger diameter of the IRIS feeding tube tip (containing the camera) might have contributed to these occurrences. In current literature, placement-related epistaxis was reported 3.5% and 4.8% in the Cortrak and endosopic insertions respectively. Procedure-associated hypoxia, was encountered in 0.3% and 1.6% of procedures respectively [13]. Periprocedural sedative medication and the larger diameter of the endoscope may account for this difference in reported insertion-related desaturations.

4.4. Strengths

Strengths of this study include the number of post-pyloric and nasojejunal feeding tubes compared to previous studies, and daily follow-up until 30 days after the procedure. Moreover, blind evaluation of chest and upper abdominal X-rays was used to independently confirm IRIS tube positioning.

4.5. Limitations

Although this is the most extensive study with IRIS feeding tubes in post-pyloric position until now, the study is limited by its single-centre design and the lack of a control arm with another blinded approach technique. Moreover, patients with an urgent indication for tube insertion during evening or night hours were excluded from the study, influencing the amount of time needed until initiation of feeding. Furthermore, only two trained physicians performed the procedures. Suggestions for further research include further study into the success rates of IRIS feeding tube insertion in patients with an indication for nasojejunal feeding tubes. When studying patients with gastroparesis, routine administration of prokinetics should be considered. Moreover, the technique could be adapted to enhance post-pyloric placement performance, such as the addition of controls to move the tip of the feeding tube to guide placement (like a mini-endoscope) or simulated peristalsis in the distal esophagus as used in peristaltic feeding tubes [34]. Moreover, image quality can be improved.

5. Conclusion

Real-time video-assisted placement of post-pyloric feeding tubes in critically ill ICU patients using IRIS-technology was successful in only 58% of the procedures and is therefore not recommended for this indication. Deep jejunal placement was achieved in only a low number of attempts (6.5%). In patients with delayed gastric emptying (GRV >500mL/24 h) only one procedure was successful (25%). However, a high success rate (96.8%) for gastric placement was achieved. The technique is safe in avoiding tracheal malpositioning. Furthermore, it allows for daily checks for correct positioning, thereby minimizing the risk of tube migration and aspiration, although image quality may decline after two days.

Financial disclosure

An unrestricted grant from Cardinal Health Mansfield, MA, USA and the provision of a monitor device and IRIS feeding tubes supported this investigator-driven study.

Author contributions

HSB contributed to the study's conceptualization, feeding tube insertions, data collection, data analysis, writing, and revision of the manuscript. MBR contributed in procedure preparations and data collection. CvM evaluated feeding tube positions on X-rays. SA contributed in revision of the manuscript. AvZ contributed in conceptualization of the study, feeding tube insertions, data analysis and revision of the manuscript.

Conflict of interest

Prof. Dr A.R.H. van Zanten has reported having received honoraria for advisory board meetings, lectures, research, and travel expenses from Baxter, Braun, Cardinal Health, Danone-Nutricia,

Dim-3, Fresenius Kabi, Mermaid, Lyric, and Nestle-Novartis. The other authors have nothing to declare.

Acknowledgements

Not applicable.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.clnu.2021.07.026.

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