

# Magnetic resonance imaging study of the *in vivo* position of the extraglottic airway devices i-gel™ and LMA-Supreme™ in anaesthetized human volunteers

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## Editor's key points

- The anatomical *in situ* position of two extraglottic airway devices was investigated using magnetic resonance imaging.
- The LMA-S protrudes deeper into the upper oesophageal sphincter (UOS) than the i-gel™, despite fibreoptically identical positions.
- The i-gel™ causes a greater dilation of the upper UOS.
- The LMA-S compresses the laryngeal inlet more than the i-gel™.

**Background.** Exact information on the anatomical *in situ* position of extraglottic airway (EGA) devices is lacking. We used magnetic resonance imaging (MRI) to visualize the positions of the i-gel™ and the LMA-Supreme™ (LMA-S) relative to skeletal and soft-tissue structures.

**Methods.** Twelve volunteers participated in this randomized, prospective, cross-over study. Native MRI scans were performed before induction of anaesthesia. Anaesthesia was induced, and the two EGAs were inserted in a randomized sequence. Their positions were assessed functionally, optically by fibroscope, and with MRI scans of the head and neck.

**Results.** The LMA-S protruded deeper into the upper oesophageal sphincter than the i-gel™ ( $P < 0.001$ ). Both devices reduced the area of the glottic aperture ( $P < 0.001$ ), and the LMA-S had the largest effect ( $P = 0.049$ ). The i-gel™ significantly compressed the tongue ( $P < 0.001$ ). Both devices displaced the hyoid bone ventrally ( $P < 0.001$ ); the i-gel™ to a greater degree ( $P = 0.029$ ). The fibreoptically determined position of the bowl of the devices was identical.

**Conclusions.** The LMA-S and i-gel™ differ significantly with regard to *in situ* position and spatial relationship with adjacent structures assessed by MRI, despite similar clinical and fibreoptical findings. This could be relevant with regard to risk of aspiration, glottic narrowing, and airway resistance and soft-tissue morbidity.

**Keywords:** i-gel™; laryngeal mask airway; LMA-Supreme™; magnetic resonance imaging

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Extraglottic airway (EGA) devices are suitable for ventilation of the lungs because their cuffs form an airtight seal that isolates the distal airways. This pharyngeal–laryngeal seal, which is quantified by the leak pressure, is crucial for the ventilatory efficiency and for protecting the airways from material surrounding the cuff. For laryngeal mask airway type devices, it results from the close contact between the cuff surrounding a supraglottic bowl at the end of the ventilation tube and the adjacent soft tissues of the pharynx and the tongue.

In addition, the tips of the devices are designed to provide a certain degree of protection against the reflux of gastric contents by occluding the upper oesophageal sphincter (UOS; so-called oesophageal seal) and by venting off regurgitated fluids and gases through a drainage tube.

The original laryngeal mask airway design was based on studies of post-mortem laryngeal specimens<sup>1</sup> as were subsequent studies on the anatomical position.<sup>2</sup> No comparative

study had been performed to date to test whether their *in situ* positions in living humans actually corresponded to those extrapolated from the cadaver studies. Previous studies in living patients have been confined to assess the position of the exterior surface of the EGA and the position of its bowl relative to the glottis by fibreoptic observations.

In the present prospective, randomized, cross-over study in anaesthetized volunteers, we used magnetic resonance imaging (MRI) to visualize and compare the *in situ* positions of two popular EGA devices with drainage channels, the LMA-Supreme™ (LMA-S, The Laryngeal Mask Company Ltd, St Helier, Jersey, UK)<sup>3, 4</sup> and the i-gel™ (Intersurgical Ltd, Wokingham, UK).<sup>5</sup>

The LMA-S has an inflatable cuff with a strongly tapered tip, while the i-gel™ has a non-inflatable gel-cuff with a blunter and wider tip. The cuff of the LMA-S is longer than that of the i-gel™, and one might conclude that it would protrude further into the

UOS than the i-gel™. However, the distance from the intended position of the epiglottis in relation to the bowl until the tip of the cuff is similar for both devices. Nevertheless, because of its more strongly tapered tip, we hypothesized that the tip of the LMA-S might insert deeper into the UOS, whereas the blunter and wider tip of the i-gel™ might simply cause more soft-tissue displacement at the level of the UOS.

Thus, the aim of the present study was to provide the first comparative images of EGA devices *in situ* in living humans and to test our assumptions regarding the depth of insertion and the effects on the UOS. We also looked for differences regarding soft-tissue effects due to the EGA insertion focusing on the glottis as well as the tongue.

## Methods

### Participants

This study was approved by our institutional review board (Clinical Trial Number, German Clinical Trial Registry: DRKS00003172). Twelve ASA I volunteers (six male, six female) were recruited and participated in the study after giving their written informed consent. General inclusion criteria were age >18 yr, body weight between 60 and 80 kg, no history of gastric reflux, no known or expected difficult airway, and a history of at least one uneventful general

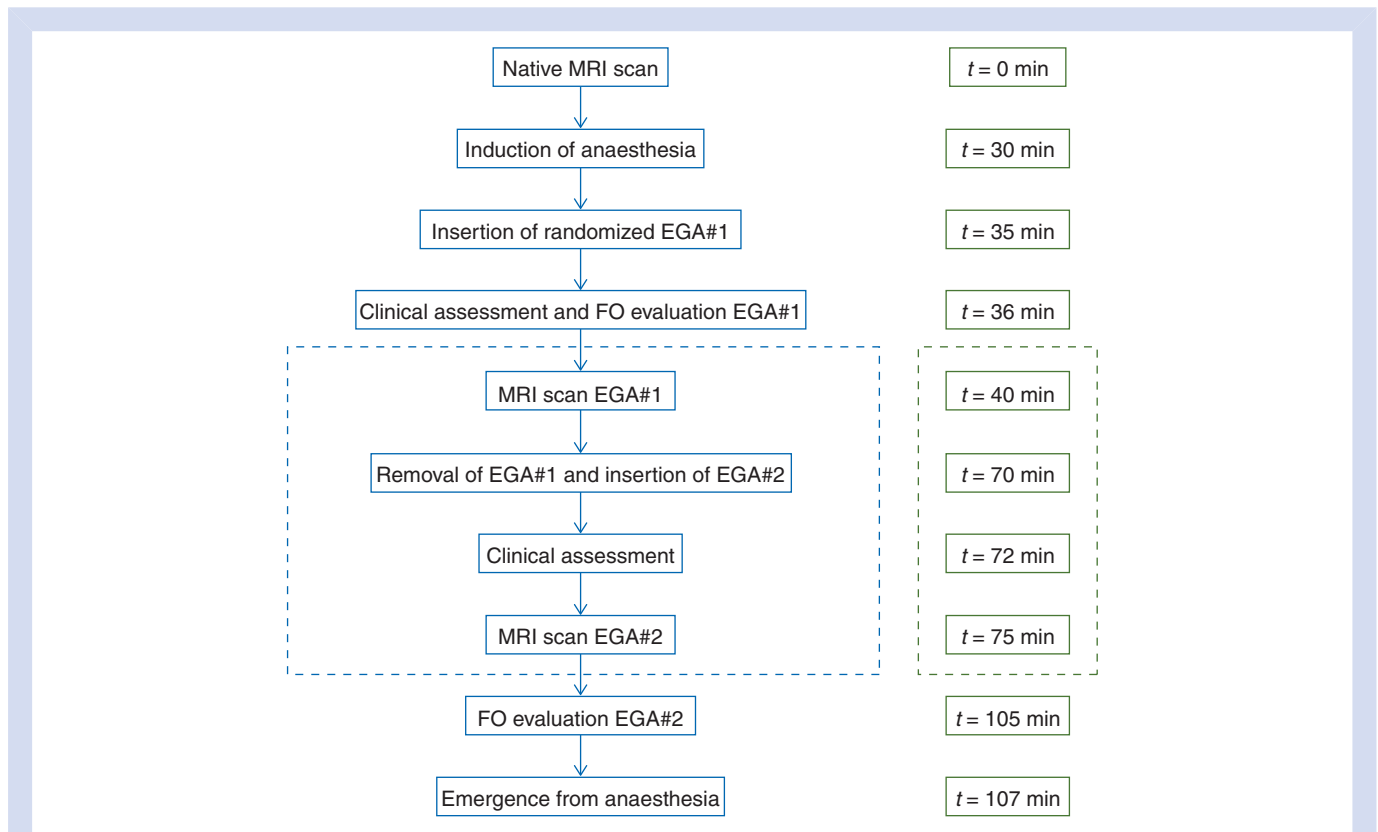
anaesthesia during the 5 yr period before the study. Potential participants were screened for undiagnosed medical conditions with an ECG and blood analysis for haemoglobin, electrolytes, creatinine, international normalized ratio, and activated partial thromboplastin time.

The participants were selected to represent the normal range of body heights in the German population. The normal ranges for males and females (German Institute for Economic Research, 2006) were stratified into three groups (males 170–174, 175–179, and 180–184 cm; females 160–164, 165–169, and 170–174 cm), and two participants were recruited for each of the six groups. We restricted body weight to between 60 and 80 kg, since this is the mid-range for a size 4 i-gel™ with its constant sized cuff. The LMA-S manufacturer recommends a size 4 as the first choice for all normal adults, since the sizes 4 and 5 differ only in the length of the airway tube but not in the size or shape of the cuff.

The workflow of the study is shown in Figure 1.

### Anaesthesia

The participants were not given any premedication. After obtaining the native MRI scans (see below), anaesthesia was induced on the MRI table immediately outside the MRI



**Fig 1** Study flow. Flow chart of the study progress. All steps indicated within the dashed box were performed in the MRI cabin. EGA, extraglottic airway device; FO, fiberoptic.

room with remifentanyl ( $1 \mu\text{g kg}^{-1}$ ) and propofol ( $2\text{--}3 \text{ mg kg}^{-1}$ ) and maintained with continuous infusions of propofol ( $6 \text{ mg kg}^{-1} \text{ h}^{-1}$ ) and remifentanyl ( $0.2 \mu\text{g kg}^{-1} \text{ min}^{-1}$ ). The participants were monitored continuously with a five-lead ECG, non-invasive arterial pressure, pulse oximetry, and capnometry. The EGA devices were inserted after a sufficient depth of anaesthesia had been ascertained by the response to a jaw thrust.<sup>6</sup> The lungs were ventilated with an  $F_{\text{IO}_2}$  of 0.5.

### Airway management

Both devices were evaluated in each volunteer in a random order. A computer-generated randomization list ([www.randomizer.org](http://www.randomizer.org)) determined which device was inserted first. Blinding was achieved using the closed envelope method. The first device was inserted immediately after induction of anaesthesia. After obtaining the MRI scans with this device, the participant was withdrawn from the MRI, the first EGA removed, and the second EGA device was inserted.

The EGA devices were inserted by one of the two investigators (S.G.R. and S.C.) following the manufacturer's recommendations.<sup>7, 8</sup> The i-gel<sup>TM</sup> was inserted with the head extended and the neck flexed, directed against the hard palate and pushed until a resistance was felt. The LMA-S was inserted from the inner aspect of the teeth along the hard palate and passed around the back of the tongue until a resistance was felt. The fixation tab had to be placed 1–2.5 cm above the volunteer's upper lip. The integrated bite block of both devices was to be located at the level of the incisors at this stage.

If the fixation tab was not positioned within the recommended limits, our protocol required that the device be replaced with an appropriately sized device, smaller or larger as deemed necessary.

Before insertion of the LMA-S, the cuff was deflated, filled with normal saline, and then evacuated to give a wedge-shaped, deflated cuff. After insertion, the LMA-S was filled with normal saline<sup>9</sup> containing  $0.25 \mu\text{g ml}^{-1}$  of gadolinium. The LMA-S devices were filled to an intra-cuff pressure of 60 cm H<sub>2</sub>O (44 mm Hg) measured with a pressure transducer

attached to the valve of the pilot balloon with a three-way stopcock.

If an air leak through the drainage channel was detected, the EGA device was inserted deeper until the leak stopped.<sup>10</sup> A gastric tube was passed through the drainage channel, and a successful insertion was taken as evidence that the tip of the device was neither bent nor impinged on pharyngeal tissues. The volunteer's lungs were ventilated to a targeted end-tidal CO<sub>2</sub> of 35–40 mm Hg in a pressure-control mode with a PEEP of 3 cm H<sub>2</sub>O, a respiratory rate between 14 and 16, and an inspiratory-to-expiratory ratio of 1:1.5 (Fabius MRI, Dräger Medical, Kiel, Germany). The chosen settings were kept for both EGA devices. Ventilation was rated as adequate, if there was no audible air leak at an expired tidal volume of 7 ml kg<sup>-1</sup>.

Leak pressure was determined by increasing the airway pressure to a maximum of 35 cm H<sub>2</sub>O by feeding oxygen into the closed circuit at a flow rate of 3 litre min<sup>-1</sup>. Leak pressure was defined as the airway pressure at which an audible air leak could be auscultated over the larynx with a stethoscope.<sup>11</sup> The minimum LMA-S cuff volume required to provide an airtight seal was determined in six of the 12 participants. After determining the leak pressure, the cuff volume was reduced in a step-wise manner until an audible air leak occurred during ventilation. The cuff was then refilled in 1 ml steps until the airtight seal was restored; the required volume was documented.

After successful insertion of the EGA, its position was assessed visually (Fig. 2) through the fibrescope using a previously used four-point score: 1, only vocal cords seen; 2, cords, arytenoids, or both seen; 3, only epiglottis seen; 4, other (e.g. cuff, pharynx, etc.).<sup>12</sup>

### MRI scans

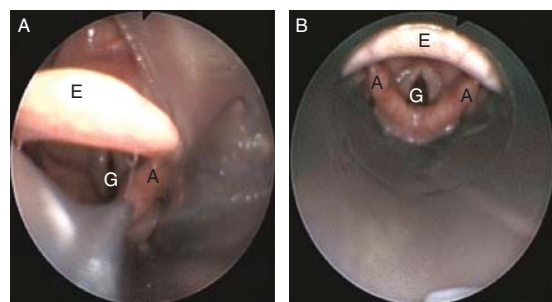
A native MRI reference scan of the neck was obtained before induction of anaesthesia. Further scans were made with each of the two EGA devices correctly positioned.

MRI scans were performed in the supine participants in a 3 T whole-body scanner (TIM Trio; Siemens, Erlangen, Germany) with a head and neck coil. The participant's head was fixed in the MRI cage. The standard scanning protocol consisted of T1 coronal (TE11/TR611, slice thickness 5 mm, FOV 240, matrix 500×600), T2 sagittal (84/3320, 2 mm, FOV 200×220, matrix 570×760), T1 sagittal (12/753, 2 mm, FOV 200, matrix 380×450), and T1 3D vibe axial (7/2,45, flip 12°, FOV 200, matrix 512×512) slices.

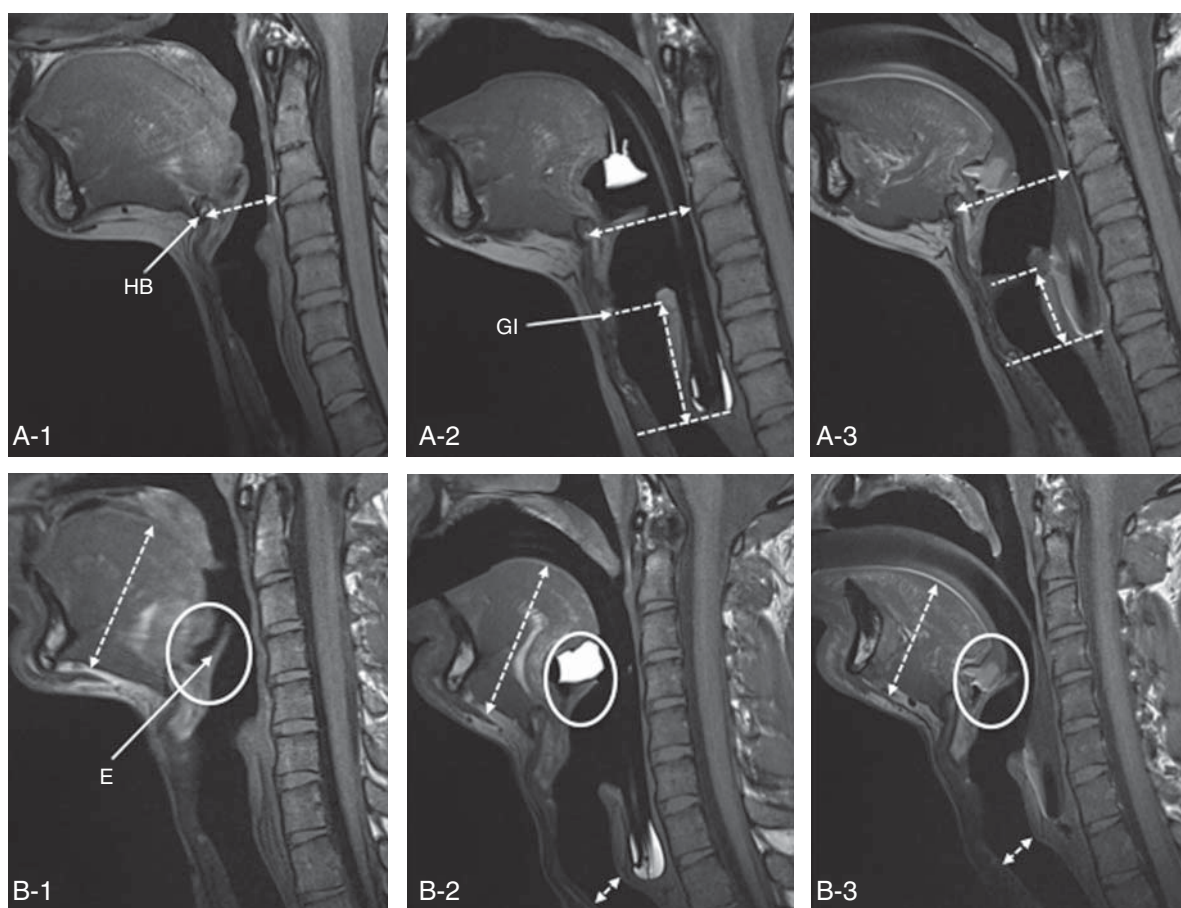
### Depth of insertion and impact on the UOS

#### Relative to the glottis

The depth of insertion relative to the glottis was defined as the perpendicular distance between a horizontal line through the level of the glottis and a parallel line touching the tip of the EGA on sagittal images (Fig. 3A2 and 3).



**Fig 2** Fibreoptic view of the laryngeal inlet through the airway tube of the extraglottic airway device. (A) LMA-S and (B) i-gel<sup>TM</sup>. A, arytenoids; E, epiglottis; G, glottic inlet.



**Fig 3** Sagittal MRI of a female (A1–3, height 173 cm, weight 64 kg) and a male (B1–3, height 184 cm, weight 71 kg) volunteer. 1, native image; 2, with the LMA-S™ *in situ*; 3, with the i-gel™ *in situ*. (A1–3) Dashed lines are used to show the effect on the hyoid bone (HB) and the depth of insertion caudal to the glottic inlet (GI). (B1–3) Dashed lines are used to show the effect on the tongue and the effect of the device on tracheal diameter; the circle is used to indicate the position of the epiglottis (E) in relationship to the mask bowl and the upper margin of the EGA cuff.

### Relative to the spine

The depth of insertion relative to the spine was defined as the distance between a line through the inferior surface of the fifth cervical vertebra and a parallel line touching the tip of the EGA on sagittal images.

### Area of UOS occupied by the EGA

The cross-sectional area of the UOS was measured at three levels on axial T1: (i) the upper margin, (ii) the lower margin, and (iii) the middle of the cranio-caudal extension of the lamina of the cricoid on the sagittal T2 midline images (Fig. 4).

### Impact of the EGA device on the glottis

#### Glottic area and dimensions

The glottic area and the axial diagonal of the glottis were measured on axial T1 slices at the narrowest part of the

glottis after the images had been reoriented to be parallel to the vocal cords and the enclosed glottic area.

#### Distance between arytenoid cartilages

The distance between the arytenoid cartilages was measured on an axial T1 plane realigned as described above, with the points of measurement being the most medial part of the vocal process.

#### Deflection of the epiglottis

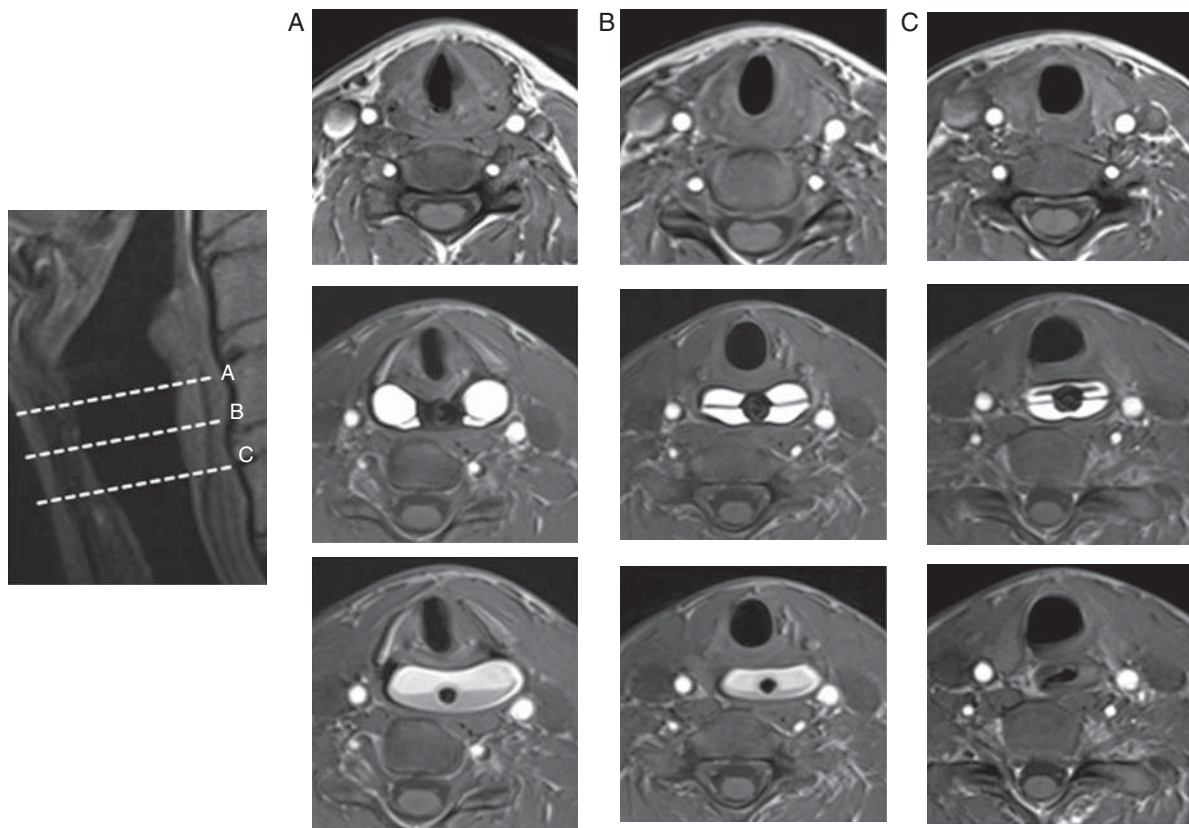
The angle between the proximal and distal part of the epiglottis was measured on sagittal T2 images at the midline position (Fig. 3B2 and 3).

### Impact of the EGA on adjacent soft tissues

#### Thickness of the tongue

The thickness of the tongue was defined as the greatest distance between the surface of the tongue and the lower





**Fig 4** Transversal MRI of one volunteer. Left image: sagittal image of the native status indicating the different levels of the measurements: (A) upper margin of the dorsal cricoid cartilage lamina, (B) mid-level of the dorsal cricoid cartilage lamina, and (C) lower margin of the dorsal cricoid cartilage lamina. Upper row: native status. Middle row: LMA-S™ *in situ*. Lower row: i-gel™ *in situ*.

margin of the geniohyoideus muscle measured on sagittal T2 midline images (Fig. 3B).

#### Position of the hyoid bone relative to the cervical spine

The position of the hyoid bone relative to cervical spine was determined by measuring the shortest distance between the dorsal margin of the hyoid bone and the ventral margin of the opposing vertebra body (Fig. 3A).

#### Distance between common carotids

The distance between the common carotids was defined as the distance between the medial margins of the common carotid arteries measured on the same axial T1 section used to determine the glottic area.

#### Tracheal diameter

The tracheal diameter was defined as the shortest distance between the anterior and posterior wall of the trachea and measured on sagittal midline T2 images (Fig. 3B2 and 3).

#### Statistical analysis

The data were recorded in an Excel™ spreadsheet (Microsoft Excel 2008; Microsoft Corp., Redmond, WA, USA) and analysed with SPSS Statistics™ (IBM SPSS Inc., Chicago, IL, USA).

The primary endpoint of the study was the depth of intrusion of the tip of the EGA device into the UOS. Secondary endpoints were the effect on the calibre of the airway and evidence of distortion of other anatomical structures. The fiberoptic assessments and determinations of leak pressure were not a primary topic of the study but were used solely as visual and functional confirmation of a correct and comparable seating of the EGA devices.

The MR images were assessed and measured independently by two senior radiologists. We documented the inter-rater reliability as correlation coefficients. The two independent measures per variable were averaged to minimize inter-rater effects.

T-tests for paired data were used to evaluate differences between the variables with and without the EGA device and between the effects of the individual EGA devices. Corrections for multiple testing were not required, as we did not test disjunctive hypotheses but instead report convergent results.

**Table 1** Biometric data of the participants. BMI, body mass index

	Minimum	Maximum	Mean	SD
Age (yr)	21	36	25.8	4
Height (cm)	160	184	173	8
Weight (kg)	60	80	67	7
BMI (kg m <sup>-2</sup> )	19.7	24.5	22.5	1.8

We performed a *post hoc* power analysis. Setting the assumed effect size at the conventionally used value of  $d=0.8$  (or  $r=0.5$ , respectively) and the  $\alpha$ -error at 0.05 in a two-tailed test gave a power of 0.70 for a sample size of 12.<sup>13</sup>

Descriptive statistics are presented as means (standard deviations) unless otherwise indicated.

## Results

Fourteen volunteers were screened for participation. Two did not meet all the inclusion criteria and were excluded. All 12 participants completed the study. For biometrical data, see Table 1. The airways were successfully secured with size 4 devices in all volunteers.

### Analysis of MRI scans

The MRI evaluations had a high degree of inter-rater agreement (mean inter-rater reliability coefficient  $r=0.911$ ). The inter-rater reliability coefficient was lower than 0.8 for three parameters: the distance between the arytenoid cartilages during the native scan ( $r=0.601$ ), the distance between the arytenoid cartilages with the LMA-S inserted ( $r=0.51$ ), and the area of the UOS occupied by the LMA-S on the upper margin ( $r=0.74$ ). The poorer agreement in the first two could be due to the difficulties in identifying the arytenoid cartilages, since they were rarely calcified in our young participants and were therefore difficult to distinguish.

The LMA-S protruded significantly deeper into the UOS than the i-gel<sup>TM</sup> both relative to the glottis ( $P<0.001$ ) and to the spine ( $P<0.001$ ) with a large effect-size of  $d=2.61$  and  $d=1.39$ , respectively, even when tested for independent parameters (Table 2). The i-gel<sup>TM</sup> caused a greater dilation at the upper level of the UOS, but no differences were found at the midlevel of the UOS. The i-gel<sup>TM</sup> does not regularly insert into the lower UOS and the average dilation at that level was significantly less with this device (Table 2).

Both devices had a significant impact on the glottis; the LMA-S influenced laryngeal structures to a significantly greater extent (Table 3).

Both devices caused a significant deflection of the epiglottis from the baseline angle of 180 (13)°. The angle after insertion was 120 (16)° (LMA-S) and 120 (25)° (i-gel<sup>TM</sup>) ( $P<0.001$ ).

The diameter of the trachea increased during positive pressure ventilation with PEEP from 1.29 (0.24) cm (native) to 1.34 (0.34) cm (LMA-S) and 1.49 (0.28) cm (i-gel<sup>TM</sup>), respectively. The MRI scans showed that the LMA-S but not the i-gel<sup>TM</sup> tended to indent the dorsal wall of the trachea

**Table 2** Depth of insertion and effect of the EGA device on the UOS. <sup>†</sup>Distance between the glottis and the distal tip of the EGA. <sup>‡</sup>Distance between the lower plate of vertebra C5 and the distal tip of the EGA. <sup>§</sup>Area occupied by the device dorsal to the cricoid cartilage's lamina (CC), corresponding to the entrance of the upper oesophageal sphincter; CS, ventral lamina of cervical spine; LMA-S, LMA-Supreme<sup>TM</sup>

	LMA-S [mean (sd)]	i-gel <sup>TM</sup> [mean (sd)]	LMA-S vs i-gel <sup>TM</sup> , P-value
Glottis to tip <sup>†</sup> (cm)	3.21 (0.41)	2.25 (0.32)	<0.001
C5 to tip <sup>‡</sup> (cm)	3.35 (0.71)	2.34 (0.74)	<0.001
Area dorsal CC— upper margin (cm <sup>2</sup> )	5.13 (0.5)	5.81 (0.57)	0.009
Area dorsal CC— midlevel (cm <sup>2</sup> )	3.69 (0.45)	3.79 (0.63)	0.65
Area dorsal CC— lower margin (cm <sup>2</sup> )	2.78 (0.3)	1.13 (1.04)	<0.001

contributing to the significantly narrower tracheal diameter with the LMA-S *in situ* ( $P<0.001$ ).

Further, the effects of the EGA devices on the hyoid bone, tongue, and common carotids detectable in the MRI scans are given in Table 4.

The volume of water used to fill the cuff of the LMA-S correlated significantly with the cross-sectional area of the device at the level of the upper ( $P=0.022$ ,  $r=0.65$ ), middle ( $P=0.02$ ,  $r=0.79$ ), and lower ( $P=0.009$ ,  $r=0.71$ ) margin of the UOS, that is, the cross-sectional area increased with increasing filling volumes. The change in the inter-arytenoid distance after placement of the LMA-S was negatively correlated with their original distance and the fluid volume injected into the cuff of the EGA ( $\beta=-0.674$ ,  $P=0.035$ ), that is, the distance decreased with increasing filling volumes.

### Fibreoptic and functional comparisons

The vocal cords and the arytenoids were visible in all cases. The epiglottis was folded into the mask bowl in 11 participants with the i-gel<sup>TM</sup> and in one with the LMA-S. No airway obstruction was observed. The tip of all devices was located distal to the arytenoids and extended into the hypopharynx (Fig. 3).

The devices were similar with regard to leak pressure [LMA-S 20 (5) cm H<sub>2</sub>O, i-gel<sup>TM</sup> 18 (5) cm H<sub>2</sub>O;  $P=0.47$ ]. For the LMA-S, the mean volume of saline needed to achieve a just-airtight seal was 20 (2) ml, to reach 60 cm H<sub>2</sub>O, 32 (3) ml we required.

## Discussion

In this study, the anatomical position of two EGA devices in human volunteers was evaluated for the first time using MRI in addition to clinical and fibreoptic assessments. Our

**Table 3** Effects of the EGA on the laryngeal structures. LMA-S, LMA-Supreme™; axial length corresponds to the width of the glottic inlet

	Native	LMA-S		i-gel™		LMA-S vs i-gel™, P-value
	Mean (sd)	Mean (sd)	LMA-S vs native, P-value	Mean (sd)	i-gel™ vs native, P-value	
Axial diameter of glottis (cm)	0.98 (0.14)	0.51 (0.13)	<0.001	0.62 (0.09)	<0.001	0.005
Glottic area (cm <sup>2</sup> )	1.35 (0.32)	0.80 (0.29)	<0.001	0.91 (0.29)	<0.001	0.041
Distance between arytenoids (cm)	1.4 (0.23)	1.2 (0.17)	<0.001	1.3 (0.21)	0.09	0.003

**Table 4** Impact of the EGA on adjacent soft tissues. CS, cervical spine; LMA-S, LMA-Supreme™

	Native	LMA-S		i-gel™		LMA-S vs i-gel™, P-value
	Mean (sd)	Mean (sd)	LMA-S vs native, P-value	Mean (sd)	i-gel™ vs native, P-value	
Distance between common carotids (cm)	4.3 (0.5)	4.7 (0.4)	0.008	4.3 (0.4)	0.56	<0.001
Distance between hyoid bone and CS (cm)	3.5 (6.1)	4.5 (3.3)	<0.001	4.7 (1.9)	<0.001	0.029
Distance from surface to floor of tongue (cm)	5.8 (6.1)	5.9 (5.9)	0.35	5.1 (4.5)	<0.001	<0.001

main findings were: (i) the tip of the LMA-S protrudes deeper into the UOS than that of the i-gel™, despite identical positions as determined by fibrescope and functional seating, (ii) the i-gel™ causes a greater dilation of the upper UOS and a dilation similar to the LMA-S at the midlevel UOS, and (iii) the LMA-S compresses the laryngeal inlet more than the i-gel™.

Correct tip positioning and a competent seal with the UOS are considered to be safety factors for the use of EGA devices.<sup>14–16</sup> Routinely performed fiberoptic evaluation of the EGA position does not give an accurate determination of the relationship of the device's tip with the UOS (see also Fig. 2). Schmidbauer and colleagues<sup>14</sup> studied the competence of the oesophageal seal in cadavers and found that of the i-gel™ to be significantly poorer than that of the classic laryngeal mask airway or the ProSeal™-LMA when the drainage tube was clamped. The authors speculated that this might be attributed to a poorer fit of the tip of the i-gel™ in the oesophagus compared with the laryngeal mask airway. This is in agreement with results of a study of our group, which evaluated a protocol to investigate the oesophageal seal in humans by instilling dye into the drainage tube of EGA devices. We observed any dye leakage for the i-gel™ or the LMA-S during pressure ventilation but noted dye leaking into the bowl during spontaneous breathing in some patients with the i-gel™ but none with the LMA-S.<sup>17</sup> However, the study of Schmidbauer and colleagues also showed that both the ProSeal™-LMA and i-gel™ allowed for fast and complete drainage of oesophageal fluids if the drainage tube and oesophageal lumens were open. It remains to be seen whether these results also apply to living humans.

In this study, the UOS of our volunteers were always closed in the native scans. We retrospectively checked the diagnostic head and neck MR scans of 25 spontaneously breathing, sedated paediatric patients in our neuro-MRI database. In every case, the UOS was closed as well (data not shown). Thus, the increased areas of the UOS observed in this study were likely caused solely by the EGA itself and not by anaesthesia. Protrusion of the EGA into the UOS will quite likely contribute to a tight and reliable seal with gastrointestinal tract but may also provoke physiological relaxation reflexes of the lower oesophageal sphincter<sup>18</sup> with a potential reflux of gastric contents.<sup>19–20</sup> Roux and colleagues<sup>19</sup> found an increased incidence of reflux into the distal oesophagus when the cuff of the laryngeal mask airway was inflated to a larger volume, but this was not seen at the level of the mid-oesophagus. It thus appears that not only depth of intrusion into but also the degree of distension of the UOS may affect the relaxation reflex of the lower oesophageal sphincter. However, such gastric reflux seems to be limited to the lower oesophagus<sup>19–20</sup> and is therefore of doubtful relevance to the risk of aspiration.

Our results show that while the tip of the LMA-S actually intrudes into the UOS, the tip of the i-gel™ remains on the upper margin of the UOS and might therefore have less effect on LOS reflexes. This potential advantage of the i-gel™ could be offset by the significantly larger volume it displaces on the upper level of the UOS (Table 2). The LMA-S initially distends the UOS to a lesser degree, but over-inflation of the cuff cancels out the effect. The latter also has the adverse effect of reducing the area of the glottic aperture (see below). However, to the best of our knowledge, there are no direct data in humans proving whether it would be better

if the tip of an EGA inserted deeply into the UOS or if it should rest against the UOS.

The area of the glottic aperture decreased during general anaesthesia and ventilation with an EGA device. The LMA-S caused a greater reduction, but we found no evidence of impaired ventilation. This is in agreement with a previous study of our group in which we found fiberoptic evidence of glottic narrowing in up to 10% of the patients with an LMA-S.<sup>21</sup> Whether the observed compression of the dorsal wall of the trachea and the dorsal part of the cricoid cartilage by the tip of the LMA-S (Fig. 3) attributes mechanically to a glottic narrowing can only be speculated. Nevertheless, the cuff of the LMA-S lies laterally to the arytenoids and increased cuff filling tended to push them together and reduce the width of the glottis. However, the inter-rater agreement in assessing the arytenoids' position was relatively low, and the results must be interpreted with caution.

Damage to the lingual, hypoglossal, recurrent, and glossopharyngeal nerves and also to the tongue has been reported after the use of EGA devices.<sup>22–24</sup> This is thought to be due to compression by the cuff of the device. The lingual arteries and the hypoglossal nerve lie in close proximity to the hyoid bone. Both devices caused a significant ventral displacement of the hyoid bone, which could potentially compress important structures. The displacement caused by the LMA-S was independent on the filling volume of the cuff. The i-gel<sup>TM</sup> compressed the tongue, whereas the pre-curved airway tube of the LMA-S had little effect on lingual soft tissue. Our results are supported by recent findings from Eschertzhuber and colleagues<sup>25</sup> who found a higher mucosal pressure at the base of the tongue for the i-gel<sup>TM</sup> compared with the LMA-S. Whether the different effects on the tongue and the hyoid bone influence the incidence of side-effects is speculative and the subject of future studies.

In 11 of the inserted i-gel<sup>TM</sup> devices, the epiglottis did not rest in the intended position outside the bowl. But the sagittal MRI scans showed that the deflection of the epiglottis by the i-gel<sup>TM</sup> was not greater than with the LMA-S, even though the epiglottis was positioned in the mask bowl.

Finally, MRI, which is valuable for studying upper airway physiology,<sup>26</sup> is also useful for studies of the position of EGA devices *in situ*. MRI avoids the radiation exposure of CT scans and permits visualization of structures behind air-tissue boundaries (in contrast to ultrasound). Filling inflatable cuffs with water with or without contrast medium allows an exact localization of the device in the MRI scan as opposed to filling it with air.<sup>27–28</sup> Future studies with this method could not only help determine whether cadaver-based results can be transferred to living humans, but could also aid in the design of more effective EGA devices.

### Limitations

In contrast to fluids, air is compressible and may therefore be compressed and displaced in a different manner to saline. Thus, we cannot exclude that filling the cuff of the LMA-S with fluids up to 60 cm H<sub>2</sub>O may lead to differences in

performance and effects on surrounding tissues compared with inflation with air. However, determining the exact position of air-filled devices is extremely difficult.

We strictly followed the manufacturer's recommendations regarding the correct size selection. We cannot exclude the possibility that a size 5 device would have also been a suitable choice, especially for male subjects at the upper limits of the height and weight range. Therefore, our results may have differed slightly had larger devices been used. The cuff of the size 5 i-gel<sup>TM</sup> is larger and might therefore have had a greater impact not only on the depth of insertion but also on the other studied variables. On the other hand, the sizes 4 and 5 of the LMA-S differ only in the length of the airway tube and not in the size or design of the cuff.

### Conclusions

MRI is a useful tool for investigating the position of EGA devices *in situ* in living humans as it visualizes the device and the adjacent structures. With the LMA-S and the i-gel<sup>TM</sup> both in fiberoptically and functionally determined similar positions, their anatomical positions relative to the spine and the UOS, and their effects on adjacent soft tissue and calibre of the glottic aperture differed statistically significantly. These differences may affect the oesophageal seal quality, laryngeal inlet physiology, and soft-tissue morbidity. The results of this study may be useful in the design of future EGA devices.

### Author's contribution

S.G.R. designed the study, performed the experiments, analysed and interpreted the data, and drafted the manuscript. S.C. and C.E. performed the experiments, helped during data interpretation, and drafted the manuscript. M.J. assisted during the experiments. M.S. performed the statistical analyses, helped to interpret the data, and drafted the manuscript. J.C. analysed the MRI scans. M.Q. substantially contributed intellectually during manuscript preparation. A.M. performed the MRI scans, processed the images, analysed and interpreted the data, and drafted the manuscript.

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### Declaration of interest

None declared.



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## References

- Brain AI. The laryngeal mask—a new concept in airway management. *Br J Anaesth* 1983; **55**: 801–5
- Keller C, Brimacombe J, Radler C, Pühringer F. Do laryngeal mask airway devices attenuate liquid flow between the esophagus and pharynx? A randomized, controlled cadaver study. *Anesth Analg* 1999; **88**: 904–7
- Timmermann A, Cremer S, Eich C, et al. Prospective clinical and fiberoptic evaluation of the Supreme laryngeal mask airway. *Anesthesiology* 2009; **110**: 262–5
- van Zundert A, Brimacombe J. The LMA Supreme—a pilot study. *Anaesthesia* 2008; **63**: 209–10
- Levitan RM, Kinkle WC. Initial anatomic investigations of the I-gel airway: a novel supraglottic airway without inflatable cuff. *Anaesthesia* 2005; **60**: 1022–6
- Townsend R, Brimacombe J, Keller C, Wenzel V, Herff H. Jaw thrust as a predictor of insertion conditions for the proSeal laryngeal mask airway. *Middle East J Anesthesiol* 2009; **20**: 59–62
- Instruction for Use—LMA Supreme. Available from <http://www.lmana.com/viewufuphp?ifu=18>, 2010
- User Guide—i-gel. Available from [http://www.i-gel.com/lib/docs/userguides/i-gel\\_User\\_Guide\\_Englishpdf](http://www.i-gel.com/lib/docs/userguides/i-gel_User_Guide_Englishpdf), 2010
- Coorey A, Brimacombe J, Keller C. Saline as an alternative to air for filling the laryngeal mask airway cuff. *Br J Anaesth* 1998; **81**: 398–400
- Brimacombe J, Keller C. Prime the ProSeal drain tube with lube from a tube! *Can J Anaesth* 2005; **52**: 338–9
- Keller C, Brimacombe JR, Keller K, Morris R. Comparison of four methods for assessing airway sealing pressure with the laryngeal mask airway in adult patients. *Br J Anaesth* 1999; **82**: 286–7
- Verghese C, Berlet J, Kapila A, Pollard R. Clinical assessment of the single use laryngeal mask airway—the LMA-unique. *Br J Anaesth* 1998; **80**: 677–9
- Faul F, Erdfelder E, Lang AG, Buchner A. G\*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods* 2007; **39**: 175–91
- Schmidbauer W, Bercker S, Volk T, et al. Oesophageal seal of the novel supralaryngeal airway device I-Gel in comparison with the laryngeal mask airways Classic and ProSeal using a cadaver model. *Br J Anaesth* 2009; **102**: 135–9
- Cook T, Howes B. Supraglottic airway devices: recent advances. *Contin Educ Anaesth Crit Care Pain* 2010; **29**: 1–6
- Cook TM, Lee G, Nolan JP. The ProSeal laryngeal mask airway: a review of the literature. *Can J Anaesth* 2005; **52**: 739–60
- Russo SG, Cremer S, Mühlhäuser U, et al. Investigating the fluid seal of supraglottic airway devices in humans using indicator dye via the drainage tube: a potential roadmap for future studies. *Open J Anesthesiol* 2012; **2**: 18–22
- Rabey PG, Murphy PJ, Langton JA, Barker P, Rowbotham DJ. Effect of the laryngeal mask airway on lower oesophageal sphincter pressure in patients during general anaesthesia. *Br J Anaesth* 1992; **69**: 346–8
- Roux M, Drolet P, Girard M, Grenier Y, Petit B. Effect of the laryngeal mask airway on oesophageal pH: influence of the volume and pressure inside the cuff. *Br J Anaesth* 1999; **82**: 566–9
- Sideri AI, Galatos AD, Kazakos GM, Gouletsou PG. Gastro-oesophageal reflux during anaesthesia in the kitten: comparison between use of a laryngeal mask airway or an endotracheal tube. *Vet Anaesth Analg* 2009; **36**: 547–54
- Timmermann A. Modernes Atemwegsmanagement—Aktuelle Konzepte für mehr Patientensicherheit. *Anesthesiol Intensivmed Notfallmed Schmerzther* 2009; **44**: 246–55; quiz 56
- Brimacombe J. Problems. In: Brimacombe J, ed. *Laryngeal Mask Anaesthesia*. Philadelphia: Saunders, 2005; 551–75
- Michalek P, Donaldson WJ, Hinds JD. Tongue trauma associated with the i-gel supraglottic airway. *Anaesthesia* 2009; **64**: 692; discussion 3
- Renes SH, Zwart R, Scheffer GJ, Renes S. Lingual nerve injury following the use of an i-gel laryngeal mask. *Anaesthesia* 2011; **66**: 226–7
- Eschertzhuber S, Brimacombe J, Kaufmann M, Keller C, Tiefenthaler W. Directly measured mucosal pressures produced by the i-gel and Laryngeal Mask Airway Supreme in paralysed anaesthetised patients. *Anaesthesia* 2012; **67**: 407–10
- Eikermann M, Vogt FM, Herbstreit F, et al. The predisposition to inspiratory upper airway collapse during partial neuromuscular blockade. *Am J Respir Crit Care Med* 2007; **175**: 9–15
- Goudsouzian NG, Denman W, Cleveland R, Shorten G. Radiologic localization of the laryngeal mask airway in children. *Anesthesiology* 1992; **77**: 1085–9
- Monclus E, Garces A, De Jose Maria B, Artes D, Mabrock M. Study of the adjustment of the Ambu laryngeal mask under magnetic resonance imaging. *Paediatr Anaesth* 2007; **17**: 1182–6