G Model
RESUS 6402 1–8

ARTICLE IN PRESS

Resuscitation xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Resuscitation

journal homepage: www.elsevier.com/locate/resuscitation

ELSEVIER

EUROPEAN RESUSCITATION COUNCIL

Simulation and education

A radiographic comparison of human airway anatomy and airway manikins – Implications for manikin-based testing of artificial airways☆

Q1 Richard Schalk[a], Kathrin Eichler[b], Martin N. Bergold[a], Christian F. Weber[a], Kai Zacharowski[a], Dirk Meininger[a,c], Christian Byhahn[a,d], Haitham Mutlak[a,*]

[a] Department of Anaesthesiology, Intensive Care Medicine and Pain Therapy, University Hospital Frankfurt, Frankfurt a. Main, Germany
[b] Department of Radiology, University Hospital Frankfurt, Frankfurt a. Main, Germany
[c] Department of Anaesthesia, Main-Kinzig-Hospitals, Gelnhausen, Germany
[d] Medical Campus University of Oldenburg, European Medical School, Department of Anaesthesiology and Intensive Care Medicine, Evangelisches Krankenhaus, Oldenburg, Germany

ARTICLE INFO

Article history:
Received 14 January 2015
Received in revised form 27 April 2015
Accepted 3 May 2015

Keywords:
Airway management
Manikin
Intratracheal intubation
Anatomic models
Patient simulation

ABSTRACT

Objective: The aim of this prospective, single-center, observational study was to investigate the accuracy of modeling and reproduction of human anatomical dimensions in manikins by comparing radiographic upper airway measurements of 13 different models with humans.
Methods: 13 commonly used airway manikins (male or female anatomy based) and 47 controls (adult humans, 37 male, 10 female) were investigated using a mediosagittal and axial cervical spine CT scan. For anatomical comparison six human upper airway target structures, the following were measured: Q2 Oblique diameter of the tongue through the center, horizontal distance between the center point of the tongue and the posterior pharyngeal wall, horizontal distance between the vallecula and the posterior pharyngeal wall, distance of the upper oesophageal orifice length of epiglottis distance at the narrowest Q3 part of the trachea. Furthermore, the cross-section of the trachea in axial view and the cross-section of the upper oesophageal orifice in the same section was calculated. All measurements were compared gender specific, if the gender was non-specified with the whole sample.
Results: None of the included 13 different airway manikins matched anatomy in human controls ($n = 47$) in all of the six measurements. The Laerdal Airway Management Trainer, however, replicated human airway anatomy at least satisfactorily.
Conclusion: This investigation showed that all of the examined manikins did not replicate human anatomy. Manikins should therefore be selected cautiously, depending on the type of airway securing procedure. Their widespread use as a replacement for in vivo trials in the field of airway management needs to be reconsidered.

1. Introduction

Q4 Airway manikins are constructed as an artificial replication of the human airway and their use for training and research in airway management is widespread. They enable training of advanced airway skills and can be used to mimic clinical scenarios. When designing a study there are no adverse effects that need to be taken into account. Such an investigation can be completed within a couple of days, rather than years. The fact that manikins can be used without placing patients in critical situations in repeated training sessions leads to the acquirement of vital skills.[1,2] Timmermann and colleagues suggest that the applicability of acquired skills is highly dependent on a realistic setting, which also includes realistic anatomic structures of the manikins.[3] Currently, more than 20 different manikins from different manufacturers are available. These manikins vary in design and complexity and the most suitable manikin for learning difficult airway management has so far not been identified. However, little evidence exists whether anatomic properties of manikins are similar to the human anatomy. This

☆ A Spanish translated version of the abstract of this article appears as Appendix in the final online version at http://dx.doi.org/10.1016/j.resuscitation.2015.05.001.

* Corresponding author at: Department of Anaesthesiology, Intensive Care Medicine and Pain Therapy, University Hospital Frankfurt, Theodor-Stern-Kai 7, D-60596 Frankfurt, Germany.
E-mail address: haitham.mutlak@kgu.de (H. Mutlak).

http://dx.doi.org/10.1016/j.resuscitation.2015.05.001
0300-9572/© 2015 Published by Elsevier Ireland Ltd.

may have implications for the airway device evaluation as many preliminary studies are performed on manikins.

The aim of the present study was to investigate the accuracy of modeling by comparing radiographic upper airway measurements of 13 different manikins with human anatomy to determine if manikins are a reliable alternative when performing clinical airway management studies in humans.

2. Methods

After approval by the Institutional Review Board, data (462/11) of all adult patients admitted with major trauma was collected during a 3-months period. None of the patients were endotracheal intubated or required cervical immobilization with a stiffneck device. As a routine they underwent a whole body Computed Tomography (CT) scan after being admitted to the emergency room in accordance with Advanced Trauma Life Support (ATLS) and institutional protocols for trauma care. Patients with diagnosed or obvious craniofacial or cervical dysmorphia, head, neck and face trauma and upper airway anomalies were excluded from the trial.

To establish which types of manikins were used in clinical studies a Pubmed, Medline and Oldmedline investigation using the following mesh terms "intubation, tracheal", "airway management", "laryngeal mask", "supraglottic airways" and "manikin" with an additive filter "clinical trials" was performed. All publications during the period 1960–April 2011 were screened for the terms mentioned above. 151 publications were identified and, after excluding pediatric airway manikin studies, 121 publications evaluating different intubation tools in manikins were analyzed. The most commonly used manikins were identified and included for further investigation if possible (Table 1).

As manufacturers base their manikins on male or female dimensions we classified the manikins into female, male and if no information was available into not applicable (n/a). The 13 manikins were either property of the University Hospital Frankfurt or Paramedic School of the Frankfurt Fire Department, Germany. One manikin was obtained from the manufacturer for investigational use only.

For comparison of the anatomic properties the mediosagittal and axial cervical spine CT scans were analyzed. All CT-scans were performed with a Somatom Definition AS Sliding Gantry™ (Siemens, Erlangen, Germany) with a slice thickness of 3 mm. For anatomical comparison of six human upper airway target structures we used measurements as defined by Schebesta and co-authors[4] and additionally measured the narrowest tracheal diameter[5,6] (Fig. 1). To define this structure the epiglottis in the sagittal reconstruction was identified and correlated with the axial slices as some manikin are designed without cervical spine replication.

To compare the anatomic region of importance for the placement of supraglottic airway devices the upper oesophageal orifice (distance D in Fig. 1) was also measured.[7] All distances were measured in the mediosagittal plane. Furthermore we calculated the cross-section of the trachea in the axial view and the cross-section of the upper oesophageal orifice in the same section (Fig. 2). In all manikins the CT scans were performed in the same manner as in our patients and results were compared gender specifically. In manikins without gender specification anatomical comparison was based on the results of all included male and female patients.

Statistical analysis was performed with GraphPad Prism5 for Windows, Version 5.03 (GraphPad Software Inc., La Jolla/San Diego, CA, USA). To assess data distribution a Shapiro–Wilk test was performed. Results for the measurements in humans were summarized as mean ± standard deviation. Each manikin was only scanned once and measurements were only performed once on each device.

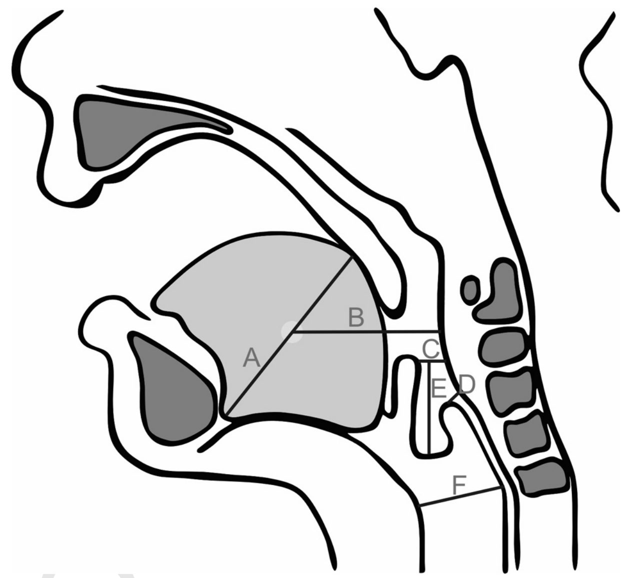

Fig. 1. Anatomical measurements: (A) oblique diameter of the tongue through the center; (B) horizontal distance between the center point of the tongue and the posterior pharyngeal wall; (C) horizontal distance between the vallecula and the posterior pharyngeal wall; (D) distance of the upper oesophageal mouth; (E) epiglottic length; (F) distance at the narrowest part of the trachea.

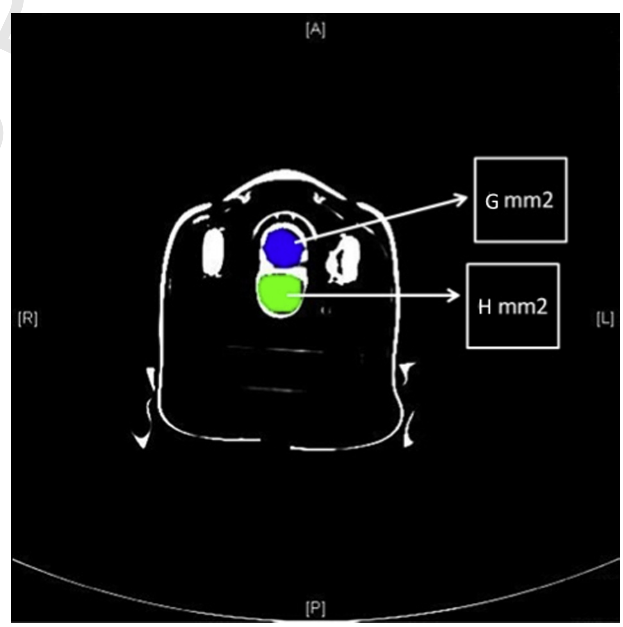

Fig. 2. Anatomical measures of the tracheal cross-section at the narrowest part (G, mm^2) and cross-section in the region of the upper oesophageal mouth (H, mm^2).

Multiple scans were not considered necessary due to the fact that manikins were placed in the scanner in a standardized and fixed position. Measurements obtained from humans were compared to those obtained from manikins.

For comparison of the above-mentioned measurements the results obtained from human anatomy were set as baseline and the percentage difference of the distances measured in manikins was calculated and compared if applicable.

3. Results

During a three-month period 68 patients admitted to the trauma emergency room of our hospital were screened for eligibility.

Please cite this article in press as: Schalk R, et al. A radiographic comparison of human airway anatomy and airway manikins – Implications for manikin-based testing of artificial airways. Resuscitation (2015), http://dx.doi.org/10.1016/j.resuscitation.2015.05.001

Table 1
Q6 List of the 13 manikins investigated with a sagittal and axial CT scan of the upper airway structures and comparison of the measurements in humans and manikins.

	Nr.	Sex	A, mm	B, mm	C, mm	D, mm	E, mm	F, mm	G, mm^2	H, mm^2
Human										
All ($n = 47$)			55 ± 5 (46–69)	48 ± 5 (37–60)	10 ± 3 (5–20)	0.06 ± 0.3 (0–1)	30 ± 5 (14–39)	16 ± 3 (10–23)	207 ± 66 (77–380)	0.0 ± 0
Male ($n = 37$)			56 ± 5 (48–69)	48 ± 5 (37–60)	10 ± 3 (6–20)	0.05 ± 0.2 (0–1)	31 ± 5 (14–39)	16 ± 3 (10–23)	210 ± 70 (77–380)	0.0 ± 0
Female ($n = 10$)			52 ± 5 (46–59)	44 ± 4 (38–49)	8 ± 2 (5–12)	0.1 ± 0.3 (0–1)	25 ± 2 (22–28)	16 ± 2 (12–18)	194 ± 41 (136–274)	0.0 ± 0
Manikin										
Laerdal Airway Management Trainer™ (Stavanger, Norway)	Dummy 1	Male	48	50	19	2	35	29	519	29
Laerdal Resusci Anne Simulator™ (Stavanger, Norway)	Dummy 2	Female	41	54	25	9	19	21	266	125
METI Human Patient Simulator HPS™ (CAE Healthcare, Florida, USA)	Dummy 3	N/A	46	56	20	2	7	19	612	121
VBM Atemwegssimulator BOB™ (Sulz-Neckar, Germany)	Dummy 4	Female	50	69	24	17	25	24	264	430
Gaumard Scientific NOELLE Birthing Simulator™ (Miami, USA)	Dummy 5	Female	32	67	37	20	15	20	242	443
AMBU Intubationstrainer Erwachsene™ (Bad Nauheim, Germany)	Dummy 6	N/A	38	52	16	11	20	16	208	334
AMBU MegaCode W™ (Bad Nauheim, Germany)	Dummy 7	N/A	37	60	12	2	37	15	197	109
VBM Atemwegssimulator Bob™ (Sulz-Neckar, Germany)	Dummy 8	Female	35	66	36	10	16	26	558	332
AMBU Airway Man I™ (Bad Nauheim, Germany)	Dummy 9	N/A	42	54	12	2	26	16	166	156
Laerdal Resusci Anne Advanced Skilltrainer™ (Stavanger, Norway)	Dummy 10	Female	46	59	24	12	17	21	224	379
Laerdal Sim Man™ (Stavanger, Norway)	Dummy 11	Male	46	44	7	6	36	17	206	113
Laerdal MegaCode Kelly ALS™ (Stavanger, Norway)	Dummy 12	Male	48	53	15	10	34	19	167	234
Trucorp AirSim Multi™ (Belfast, Northern Ireland)	Dummy 13	Male	37	52	6	7	30	22	309	148

(A) Oblique diameter of the tongue through the center; (B) horizontal distance between the center point of the tongue and the posterior pharyngeal wall; (C) horizontal distance between the vallecula and the posterior pharyngeal wall; (D) distance of the upper oesophageal mouth; (E) epiglottic length; (F) distance at the narrowest part of the trachea (G, mm^2) tracheal cross-section at the narrowest part and (H, mm^2) cross-section in the region of the upper oesophageal mouth. Human data are represented as mean and standard variation. Human measurements are displayed as range, mean and standard deviation.

Please cite this article in press as: Schalk R, et al. A radiographic comparison of human airway anatomy and airway manikins – Implications for manikin-based testing of artificial airways. Resuscitation (2015), http://dx.doi.org/10.1016/j.resuscitation.2015.05.001

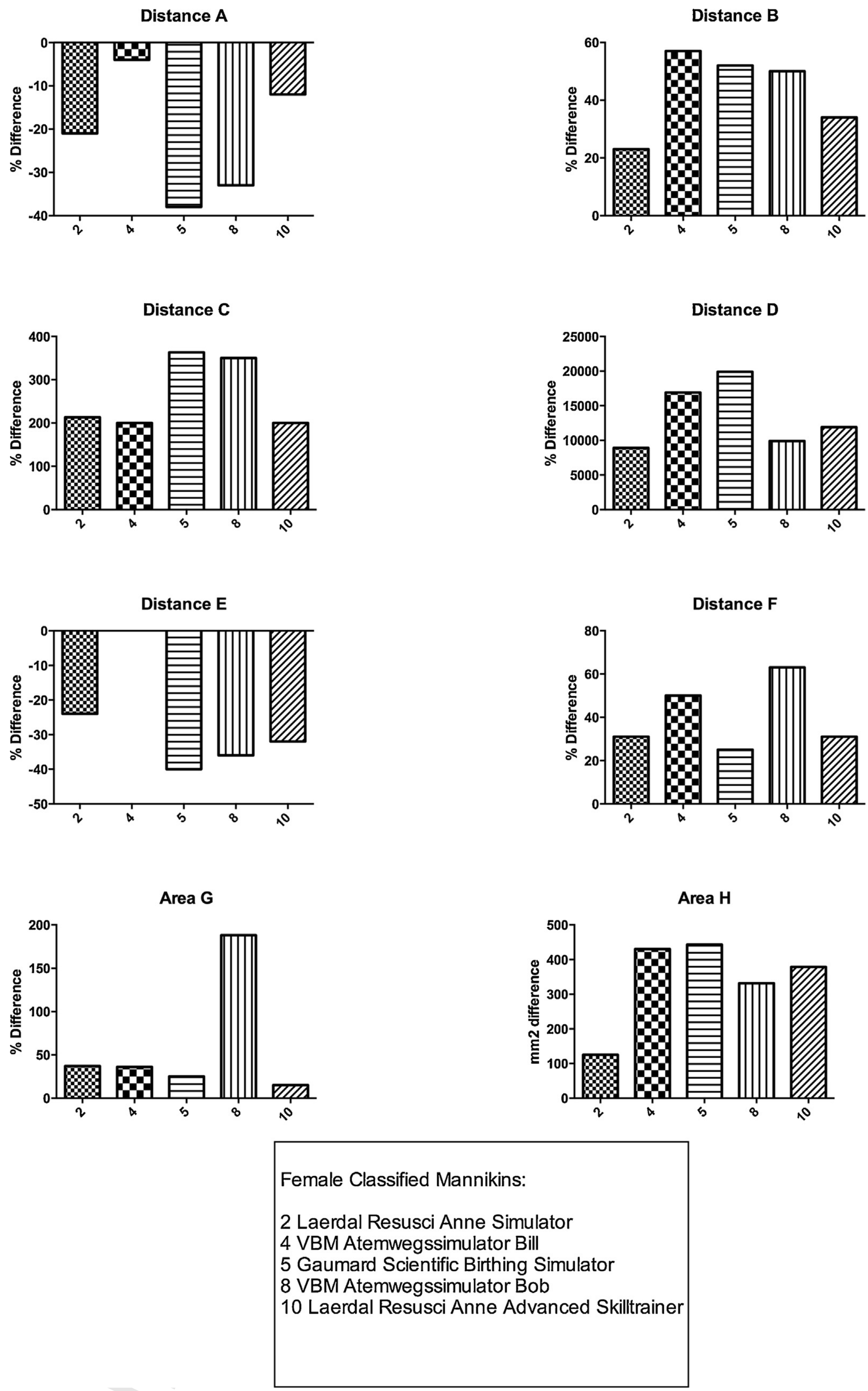

Fig. 3. Comparison of the measurements (mm) in females with each manikin classified as female. (A) Oblique diameter of the tongue through the center; (B) horizontal distance between the center point of the tongue and the posterior pharyngeal wall; (C) horizontal distance between the vallecula and the posterior pharyngeal wall; (D) distance of the upper oesophageal orifice; (E) epiglottic length; (F) distance at the narrowest part of the trachea (G, mm^2) tracheal cross-section at the narrowest part and (H, mm^2) cross-section in the region of the upper oesophageal orifice.

47 patients (37 male/10 female) met the inclusion criteria and 21 patients were excluded according to the study protocol. The patient age was 39.6 ± 13.5 years (21–67 years). A whole body CT scan including mediosagittal and axial cervical spine imaging was performed on all patients.

We compared each single manikin with the average anatomy of either male or female patients and, if no specification was given by the manufacturer, with the average anatomy of all 47 patients (Table 1 and Figs. 3–5). None of the included manikins matched human anatomy in all of the six measured distances and 2 measured cross-sections. It became obvious that each manikin may have advantages or disadvantages for different procedures in managing the airway.

Comparison by gender showed that female human anatomy (Fig. 3) was best displayed by the Laerdal Resusci Anne Simulator and the Laerdal Resusci Anned Advanced Skilltrainer. Notably only two distances were within range of the human measurements. For insertion of a supraglottic device we focused on the upper oesophageal orifice (distance D, Fig. 1) and its cross-section (cross-section H, Fig. 2). The Laerdal Resusci Anne Simulator resembled female anatomy the closest.

The closest replication of male anatomy was observed in the Laerdal Sim Man and the Laerdal Airway Management Trainer (Fig. 4). Five measured distances of the Laerdal Resusci Anne Simulator, Laerdal Resusci Anned Advanced Skilltrainer and the Trucorp Airsim Multi were within the range of human measurements. The upper oesophageal orifice (distance D, Fig. 1) and its cross-section (cross-section H, Fig. 2) were best reflected by the Laerdal Airway Management Trainer.

All manikins without gender specification were classified as N/A and compared to anatomic measurements of all participants. The METI Human Patient Simulator and the AMBU Airman I present the human anatomy best (Fig. 5). The METI Human Patient Simulator was five times within the range and the AMBU Airman I followed with four distances within the range of human measurements. The upper oesophageal orifice (distance D, Fig. 1) and its cross section (cross section H, Fig. 2) was reflected best by the AMBU Intubation Trainer adults.

Considering all manikins tested, female anatomy was mimicked the closest by Laerdal Resusci Anne Simulator and the Laerdal Resusci Anned Advanced Skilltrainer, male anatomy by the Laerdal Airway Management Trainer and in unspecified by the METI Human Patient Simulator and the AMBU Airman I.

4. Discussion

Our obtained data demonstrated that the airway anatomy of the most commonly used manikins rarely reflected human airway anatomy in adults. In particular, the oesophageal orifice, an anatomical landmark for the placement of supraglottic airway devices and the narrowest part of the trachea differed significantly in most of the manikins compared to human anatomy. Based on our results supraglottic airway management training should ideally be performed with manikins reflecting the anatomy of the oropharyngeal and oesophageal cross section.

Manikins or so called patient simulators are commonly used as standardized airway models and were part of the process for the evaluation of new airway devices and airway management techniques for routine and emergency situations in the past. Nowadays, emphasis is set on teaching purposes and airway management training for novices and experts.[1,3,4,8–10]

It has to be taken into account that anatomy and physiology of a real patient cannot be replaced by simple manikins and even sophisticated simulators.[11] Manikins cannot represent easy or difficult anatomy in its vast diversity. In manikins the upper airway is stiff, non-compliant, static and "open" rather than soft, fragile, dynamic or collapsible as in humans. Secretions, lubrications, bleeding, coughing reflexes and modeling of regurgitation are nearly impossible to simulate.[12]

Nevertheless, several manikin studies investigating different tools for tracheal intubation or supraglottic airway management, either in apparently normal airways or proposed difficult scenarios have been published in recent years.[13–19] As informed patient consent is not required such studies are not impeded by administrative or ethical concerns. Rai criticized that many authors are aware of this issue and comment on the limitation of studies performed on manikins in their discussions and that verification in a clinical setting is necessary.[10] However, the evaluation process of a new airway device is often solely limited to manikin studies, as independent subsequent clinical trials rarely follow the initial in vitro studies. Considering the enormous discrepancy between human and manikin anatomy, this issue should raise concern regarding validity and transferability of manikin trials.

The incidence of a difficult airway in an operating room setting and in emergencies has not changed much in the past decades. It remains a major cause for morbidity and mortality in clinical anesthesia and emergency medicine.[20,21] Regular training of complex airway management scenarios to achieve familiarity when experiencing these obstacles in a clinical setting is therefore essential, especially for novices. This can be achieved by simulating these scenarios using manikins.

Jackson and colleagues[8] evaluated the performance of eight supraglottic airway devices in four different manikins (Airway Management Trainer™ – Ambu, UK; Airway Trainer™ – Laerdal, Norway; Airsim™ – Trucorp, Ireland; Bill1™ – VBM-Germany). Insertion of the respective supraglottic airway was graded with a defined score, in which ease of insertion, ability of ventilation and persistence in the midline after insertion were graded from 0 (impossible), 1 (difficult) to 2 (easy). In contrast to our study, Jackson primarily focused on the practical applicability and subjective grading of the devices and manikins. In accordance with the results of the present study they concluded that no manikin performed "best" for all individual supraglottic airway devices and performance for a particular supraglottic airway device varied. This becomes relevant when selecting a manikin for training and evaluation of a specific airway device.

Jordan evaluated the performance of 16 non-surgical Difficult Airway Society (DAS) Guideline techniques and 9 non-DAS techniques in the mentioned manikins. Among other techniques, intubation with different blades, application of external laryngeal manipulations, application of different fiber optic techniques, simulation of a difficult airway and insertion of different supraglottic airway devices were performed and graded by ten experienced participants.[9] The following grading was used: ability to perform with a sufficient amount of realism, to perform, ability to perform or unable to perform. Similar to Jackson they concluded, without formally investigating anatomic properties, that there were significant differences between the respective manikins. Differences were either of a subjective nature or on the basis of anatomical differences in crucial regions of interests. In contrast to our study anatomical differences were only described briefly but not measured using diagnostic imaging. A priori knowledge which supraglottic airway performs well or poorly in a specific manikin will allow for a better interpretation of previous manikin studies comparing different SAD and will contribute to improved and more valid future trials.

Although the performance of specific SAD-techniques was not investigated in our trial, we reached a similar conclusion. In terms of lifelike anatomical reproduction, the Laerdal Airway Management Trainer matched most anatomical landmarks, distances and cross sections of live patients. This is in accordance with the results

Please cite this article in press as: Schalk R, et al. A radiographic comparison of human airway anatomy and airway manikins – Implications for manikin-based testing of artificial airways. Resuscitation (2015), http://dx.doi.org/10.1016/j.resuscitation.2015.05.001

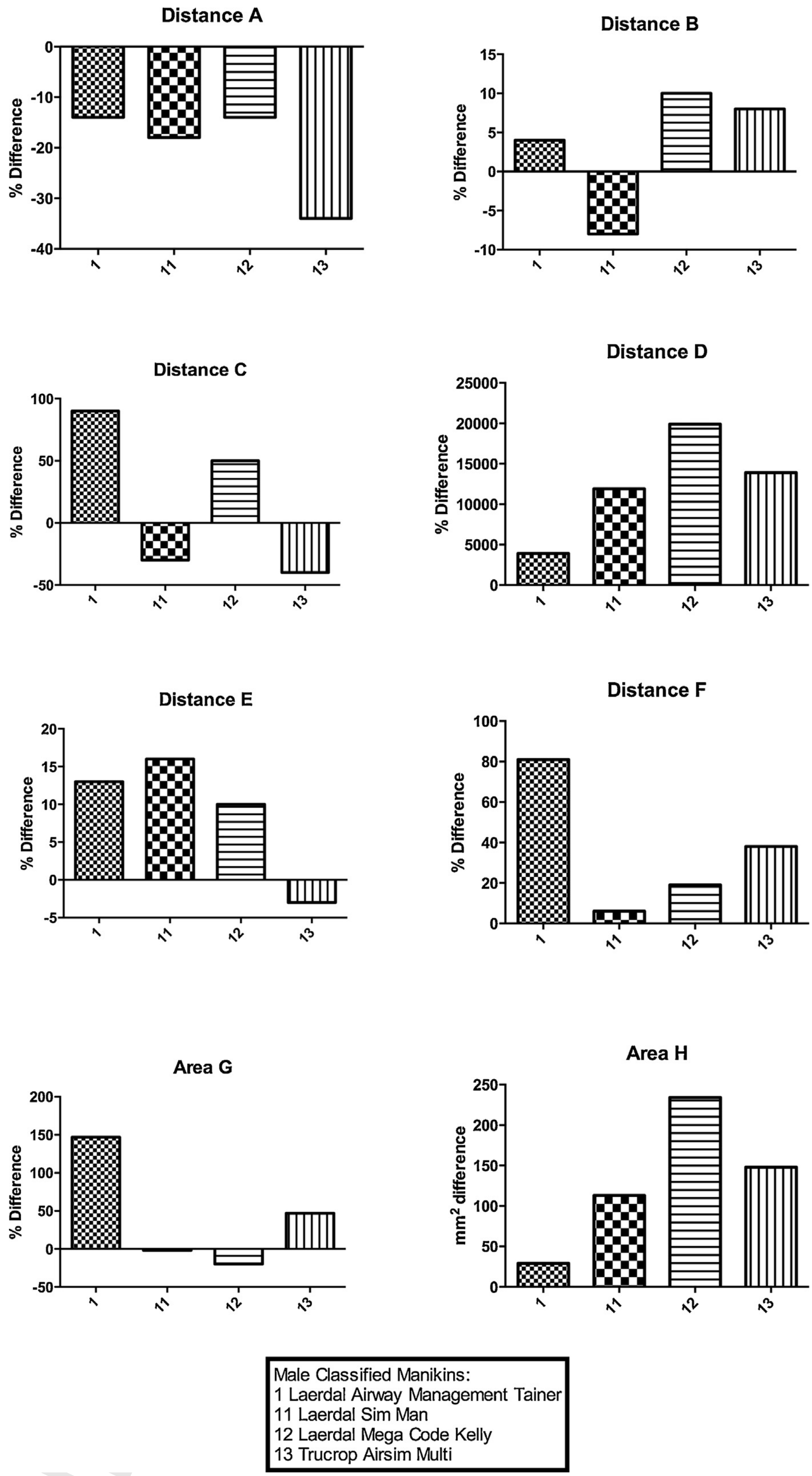

Fig. 4. Comparison of the measurements (mm) in males with each manikin classified as male. (A) Oblique diameter of the tongue through the center; (B) horizontal distance between the center point of the tongue and the posterior pharyngeal wall; (C) horizontal distance between the vallecula and the posterior pharyngeal wall; (D) distance of the upper oesophageal orifice; (E) epiglottic length; (F) distance at the narrowest part of the trachea (G, mm^2) tracheal cross-section at the narrowest part and (H, mm^2) cross-section in the region of the upper oesophageal orifice.

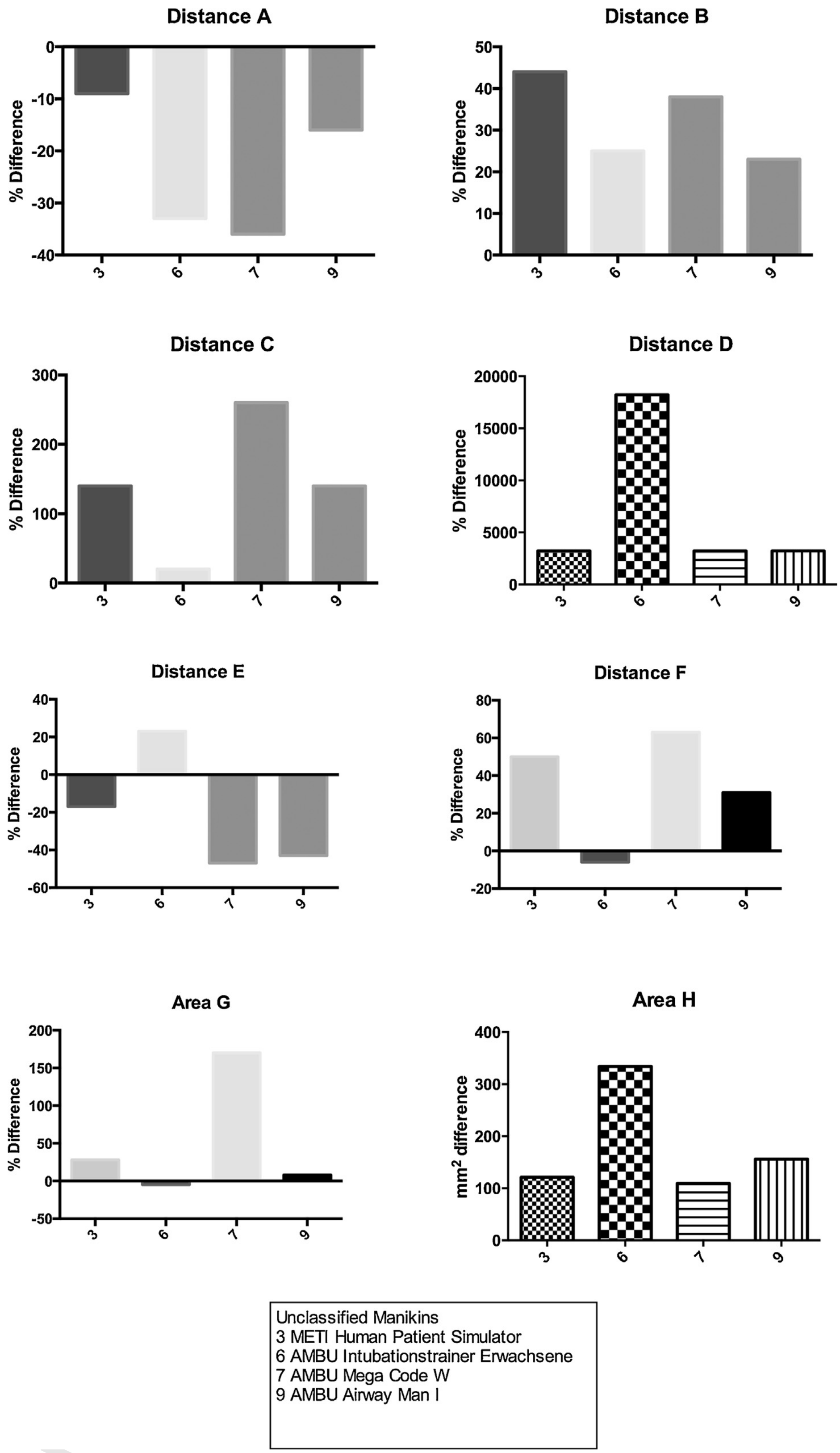

Fig. 5. Comparison of the measurements (mm) in all patients with each not classified manikin. (A) Oblique diameter of the tongue through the center; (B) horizontal distance between the center point of the tongue and the posterior pharyngeal wall; (C) horizontal distance between the vallecula and the posterior pharyngeal wall; (D) distance of the upper oesophageal orifice; (E) epiglottic length; (F) distance at the narrowest part of the trachea (G, mm^2) tracheal cross-section at the narrowest part and (H, mm^2) cross-section in the region of the upper oesophageal orifice.

published by Jordan and may serve as an explanation for the favorable grading of this simulator when evaluating SAD-techniques.

The presented study has limitations. A merely comatose patient who is about to undergo intubation may present a loss of muscular tone and therefore altered anatomy. With current technical limitations a manikin will be unable to simulate such variations. We evaluated only one of each manikin. Possible variations in design between individual manikins of the same type and from the same manufacturer may not be accounted for. In addition, possible errors during the CT scans may have been missed or underestimated. As manikins were placed in a standardized and fixed position, multiple scans were not considered necessary. Furthermore, this study simply examines the dimensions of the manikins and not their performance. Therefore, a device that mimics the real life insertion of an SAD the closest for a practitioner may deviate considerably from human anatomy. Such difference may be due to the materials used for construction of the manikin.

With this investigation we were able to show that most of the investigated manikins did not reflect actual human anatomy and thus their widespread use as a replacement for in vivo trials in the field of airway management needs to be carefully debated. Manikins for training have to be chosen with care and consideration for the airway management tool to be trained. Their use as a training tool is unquestioned, but as a research tool for the evaluation of airway devices they are insufficient.

5. Conclusion

This investigation shows that all of the investigated manikins did not reflect human anatomy. Manikins should therefore be selected cautiously depending on the type of airway securing procedure. Their widespread use as a replacement for in vivo trials in the field of airway management needs to be reconsidered.

Conflict of interest statement

The investigation was solely funded by departmental sources. However, R.S. and C.B. receive material support for research from VBM Medizintechnik GmbH and Karl Storz GmbH & Co. KG, the manufacturers of the laryngeal tube and the C-MAC video laryngoscope and Bonfils intubation fiberscope, respectively. C.B. received educational grants from Karl Storz GmbH & Co. KG, and C.B. is a member of the Karl Storz advisory board. None of the other authors has any conflict of interest with products and/or companies mentioned in the manuscript.

Acknowledgment

We thank Marina Heibel from the Department of Neurosurgery, University Hospital Frankfurt, for her efforts in creating the drawing of the human anatomy and all other participating investigators.

References

1. McFetrich J. A structured literature review on the use of high fidelity patient simulators for teaching in emergency medicine. Emerg Med J 2006;23:509–11.
2. Park CS, Rochlen LR, Yaghmour E, et al. Acquisition of critical intraoperative event management skills in novice anesthesiology residents by using high-fidelity simulation-based training. Anesthesiology 2010;112:202–11.
3. Timmermann A, Eich C, Nickel E, et al. Simulation and airway management. Anaesthesist 2005;54:582–7.
4. Schebesta K, Hupfl M, Ringl H, Machata AM, Chiari A, Kimberger O. A comparison of paediatric airway anatomy with the SimBaby high-fidelity patient simulator. Resuscitation 2011;82:468–72.
5. Breatnach E, Abbott GC, Fraser RG. Dimensions of the normal human trachea. AJR Am J Roentgenol 1984;142:903–6.
6. Shibasaki M, Nakajima Y, Shime N, Sawa T, Sessler DI. Prediction of optimal endotracheal tube cuff volume from tracheal diameter and from patient height and age: a prospective cohort trial. J Anesth 2012;26:536–40.
7. Schalk R, Engel S, Meininger D, et al. Disposable laryngeal tube suction: standard insertion technique versus two modified insertion techniques for patients with a simulated difficult airway. Resuscitation 2011;82:199–202.
8. Jackson KM, Cook TM. Evaluation of four airway training manikins as patient simulators for the insertion of eight types of supraglottic airway devices. Anaesthesia 2007;62:388–93.
9. Jordan GM, Silsby J, Bayley G, Cook TM, Difficult Airway Society. Evaluation of four manikins as simulators for teaching airway management procedures specified in the Difficult Airway Society guidelines, and other advanced airway skills. Anaesthesia 2007;62:708–12.
10. Rai MR, Popat MT. Evaluation of airway equipment: man or manikin? Anaesthesia 2011;66:1–3.
11. Hesselfeldt R, Kristensen MS, Rasmussen LS. Evaluation of the airway of the SimMan full-scale patient simulator. Acta Anaesthesiol Scand 2005;49:1339–45.
12. Timmermann A. Supraglottic airways in difficult airway management: successes, failures, use and misuse. Anaesthesia 2011;66:45–56.
13. Howes BW, Wharton NM, Gibbison B, Cook TM. LMA Supreme insertion by novices in manikins and patients. Anaesthesia 2010;65:343–7.
14. Maassen R, van Zundert A. Comparison of the C-MAC videolaryngoscope with the Macintosh, Glidescope and Airtraq laryngoscopes in easy and difficult laryngoscopy scenarios in manikins. Anaesthesia 2010;65:955.
15. Maharaj CH, Costello JF, Higgins BD, Harte BH, Laffey JG. Learning and performance of tracheal intubation by novice personnel: a comparison of the Airtraq and Macintosh laryngoscope. Anaesthesia 2006;61:671–7.
16. Maharaj CH, Higgins BD, Harte BH, Laffey JG. Evaluation of intubation using the Airtraq or Macintosh laryngoscope by anaesthetists in easy and simulated difficult laryngoscopy – a manikin study. Anaesthesia 2006;61:469–77.
17. Maharaj CH, Ni Chonghaile M, Higgins BD, Harte BH, Laffey JG. Tracheal intubation by inexperienced medical residents using the Airtraq and Macintosh laryngoscopes – a manikin study. Am J Emerg Med 2006;24:769–74.
18. Nasim S, Maharaj CH, Malik MA, O'Donnell J, Higgins BD, Laffey JG. Comparison of the Glidescope and Pentax AWS laryngoscopes to the Macintosh laryngoscope for use by advanced paramedics in easy and simulated difficult intubation. BMC Emerg Med 2009;9.
19. Timmermann A, Russo SG, Crozier TA, et al. Laryngoscopic versus intubating LMA guided tracheal intubation by novice users – a manikin study. Resuscitation 2007;73:412–6.
20. Cook TM, MacDougall-Davis SR. Complications and failure of airway management. Br J Anaesth 2012;109:i68–85.
21. Cook TM, Woodall N, Frerk C, Fourth National Audit Project. Major complications of airway management in the UK: results of the Fourth National Audit Project of the Royal College of Anaesthetists and the Difficult Airway Society. Part 1: Anaesthesia. Br J Anaesth 2011;106:617–31.

Please cite this article in press as: Schalk R, et al. A radiographic comparison of human airway anatomy and airway manikins – Implications for manikin-based testing of artificial airways. Resuscitation (2015), http://dx.doi.org/10.1016/j.resuscitation.2015.05.001