Comparative Anatomy of Pig Arytenoid Cartilage and Human Arytenoid Cartilage

*Nan Gao, *Xidong Cui, *Guangbin Sun, *Guoliang Zhang, †Guomin Zhou, and *Xia Zhao, *†*Shanghai, China*

Summary: Objective. This study aims to investigate the feasibility of pig arytenoid cartilage as an animal model for simulating arytenoidectomy under microlaryngoscope by comparing the similarities and differences between pig arytenoid cartilage and human arytenoid cartilage.

Study Design. This is a methodological study on the excised pig arytenoid cartilage and human arytenoid cartilage.

Methods. Five excised human adult cadaver larynges and five adult excised porcine larynges were dissected and all the soft tissue and mucous membrane attached to the arytenoid and cricoarytenoid joint were removed. The anatomical structure and morphology of the arytenoid cartilage were observed and measured with a vernier caliper. Measurements included cricoarytenoid articular facet major and minor diameter, cricoarytenoid articular facet center distance, cricoarytenoid facet major and minor diameter, length of vocal process and muscular process, and distance between tip of vocal process, muscular process, and junction/apex of arytenoid cartilage. Data were then compared across these major anatomic markers using student *t* test.

Results. The gross anatomy of the pig arytenoid cartilage was similar to the human. However, the size of the pig larynx arytenoid cartilage was obviously larger in total, and there was statistical significance for almost all measurements ($P < 0.05$), except the mean value of cricoarytenoid articular facet center distance, the cricoarytenoid facet minor diameter, and the length of vocal process of pig and human, without statistically significant difference ($P > 0.05$). Moreover, the biggest differences between the pig arytenoid cartilage and the human arytenoid cartilage were that the pig arytenoid cartilage apex had the angle winding structure toward the back, and that the posterior part of the bilateral arytenoid cartilages was partially connected. Whereas after the angle winding was removed from the junction, pig arytenoid cartilage and human arytenoid cartilage were shaped both like a triangular pyramid.

Conclusion. The data of this metric comparative study indicate that pig arytenoid, after resecting the angle winding structure and incising the interarytenoid cartilage, is similar to the human's. Therefore, pig larynx is an appropriate experimental model for endoscopic arytenoidectomy. In addition, regarding the pig laryngeal angle winding structure, we still require further basic and clinical research to clarify its physiological function and significance.

Key Words: Porcine model—Endoscopic arytenoidectomy—Animal model—Pig arytenoid cartilage—Human arytenoid cartilage.

INTRODUCTION

Pigs were first used in biomedical research in ancient Greece, and pigs have genetic and physiological traits similar to human beings, which make them one of the most useful and versatile animal models.[1] Pigs can be used in translational research, biomedical research, toxicology testing, surgical models, and procedural training.[1–3] A lot of simulated operations are carried out on pigs, such as general surgery, laparoscopy, endoscopy,[4] xenotransplantation,[2] trauma procedures, and implantation devices.

As we all know, human larynx is especially complicated, and what needs to be mentioned is that the anatomic location of arytenoid cartilage is very deep. Therefore, it is extremely important and necessary for teaching and training of endoscopic arytenoidectomy.[5] Meanwhile, it is difficult to obtain fresh excised human larynges owing to legal, hygienic, and economic issues. As mentioned previously, simulating human arytenoidectomy under microlaryngoscope is scarcely possible, let alone surgery teaching.

There is a well-recognized need for simulating endoscopic human arytenoidectomy. On the one hand, simulated operation may make trainees work on a simulated equipment that is similar to live endoscopy, which will be beneficial to improve the technical skills. On the other hand, trainees may get a similar surgical experience on fresh tissue, which will give them real life-and-death consequences, actual biologic responses such as bleeding, and similar tactile feel. Fresh and similar animal larynx models to the human larynx may offer a good alternative to fulfill this purpose.

Early studies have used the pig, dog, cat, sheep, deer, cow, monkey, or chicken wings as larynx models with variable results,[6–13] concluding that the pig is now regarded as a presumably suitable model in human phoniatria.[14–20] In 2016, Jiang et al compared the anatomy and biomechanical features of structures related to phonation in the pig, dog, and white-tailed deer with the human, concluding that the pig larynx is closest to the human.[10] In recent decades, there have been many studies about the anatomy and physiology of pig

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From the *Department of Otolaryngology-Head and Neck Surgery, Huashan Hospital, Fudan University, Shanghai, China; and the †Department of Anatomy, Fudan University, Shanghai, China.
Address correspondence and reprint requests to Xia Zhao, Huashan Hospital, Fudan University, 12 Wulumuqi Middle Road, Shanghai 200040, China. E-mail: zhaoxiaabc@126.com
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larynx.[21–27] Gayle Woodson, in 2012, a study regarding wound healing of vocal fold scar between four pigs and eight human cadavers, concluded that the process of wound healing in pigs is very similar to that of humans and the pig is a favorable model for the study of vocal fold scar.[20]

Despite the previous research work on histological and functional aspects of pig laryngeal, pig laryngeal model is not widely used for training courses in microlaryngeal surgical skills. The objectives of this study, therefore, are to obtain more detailed quantitative data concerning the similarities or differences in morphology and structures of pig and human arytenoid cartilage, and then to investigate the feasibility of pig arytenoid cartilage as an animal model for simulating arytenoidectomy under microlaryngoscope.

METHODS

Subjects

The samples consisted of five excised human adult cadaver larynges from the League of Red Cross Societies of Department of Anatomy, Shanghai Medical College in Fudan University and five adult excised porcine larynges from a slaughterhouse (Figure 1). All larynges were with no evidence of laryngeal trauma or diseases.

All cadavers were fixed in 10% formaldehyde solution. The dissection was conducted in the Department of Anatomy in Fudan University, Shanghai. None of the specimens used for the present study had any specific issue requiring approval from the ethics committees of Fudan University. This present work was performed in accordance with the ethical standards laid down in the 1995 Declaration of Helsinki (revised in Edinburgh, 2000).

Data collection

All the soft tissue and mucous membrane attached to the arytenoid and cricoarytenoid joint were removed (Figure 2).

All measurement points were defined and marked in Figures 3–5. Distance parameters were measured directly from the landmark locations, which were obtained with a handheld digital vernier caliper (SANTO, China, number 34463-150 8014) to the nearest 0.01 mm (Figures 3–5).

- C1: Cricoarytenoid articular facet major diameter
- C2: Cricoarytenoid articular facet minor diameter
- C3: Cricoarytenoid articular facet center distance
- A1: Cricoarytenoid facet major diameter
- A2: Cricoarytenoid facet minor diameter
- A3: Length of vocal process
- A4: Length of muscular process
- A5: Distance between tips of vocal process and muscular process
- A6: Distance between apex of arytenoid cartilage and cricoarytenoid facet center
- A7: Distance between tip of vocal process and junction/apex of arytenoid cartilage
- A8: Distance between tip of muscular process and junction/apex of arytenoid cartilage

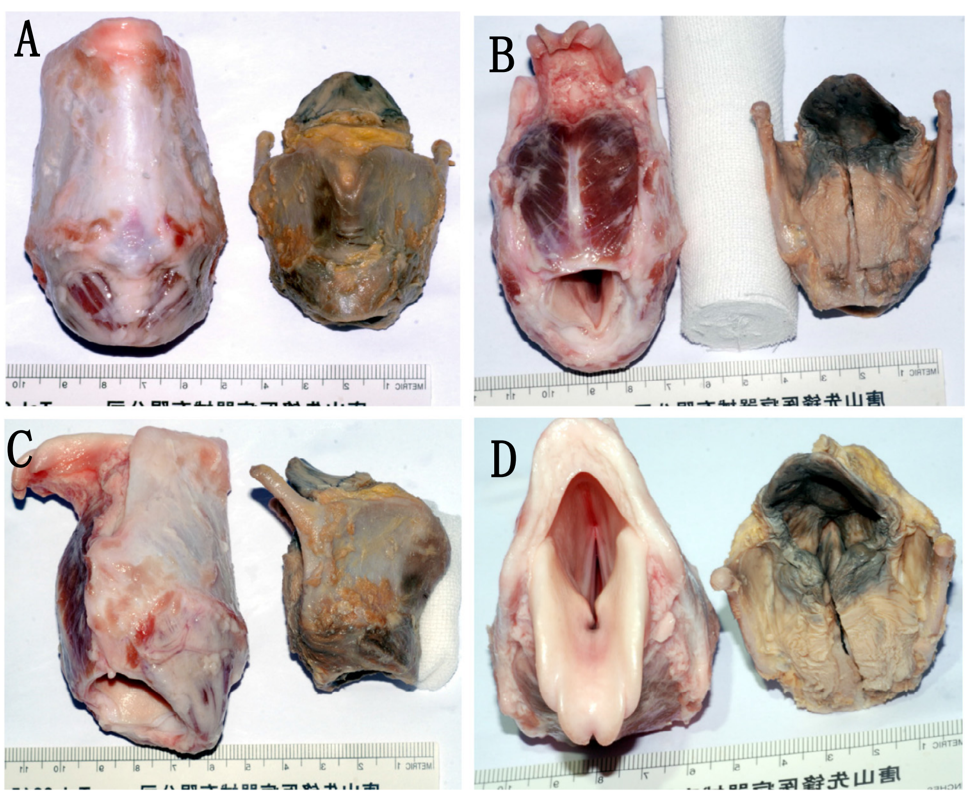

FIGURE 1. Anatomy of the pig larynx (left) and the human larynx (right): (A) anterior view; (B) posterior view; (C) lateral view; (D) superior view.

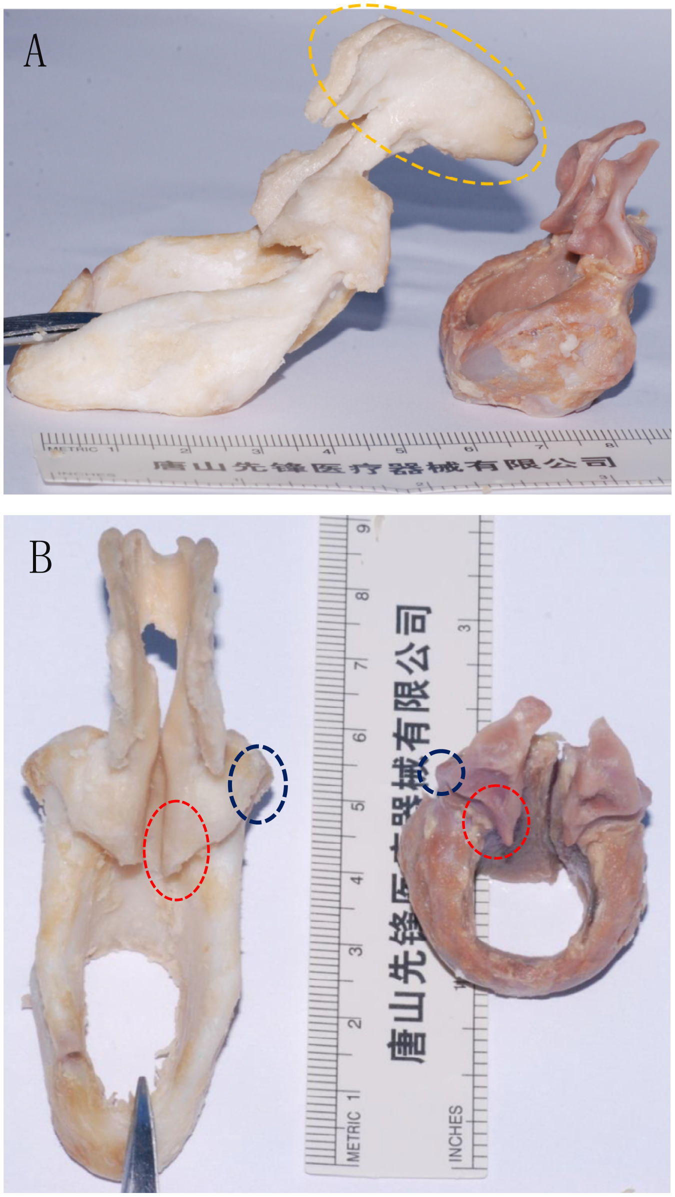

FIGURE 2. After resection of soft tissue and mucous membrane, anatomy of the pig arytenoid cartilage (left) and the human arytenoid cartilage (right): (A) lateral superior view; (B) anterior superior view. Red: vocal process; green: muscular process; yellow: the angle winding structure of arytenoid cartilage complex. (For interpretation of the references to color in Figure 2, the reader is referred to the Web version of this article.)

Statistical analysis

All measurements were made bilaterally, and were expressed as the mean, standard deviation, and range (minimum value-maximum value). Statistical analysis was performed using *SPSS software* version 24.0 (IBM Corp., Armonk, NY) to determine if there were significant differences between the different sides across species and between species. Student *t* test with the significance level of $P = 0.05$ were performed and $P < 0.05$ was considered statistically significant.

RESULTS

Comparing the pig larynx arytenoid cartilage with the human larynx arytenoid cartilage, the following differences were evident (Figures 1−2): (1) the gross anatomy of the pig arytenoid cartilage was similar to the human, which were both paired and located on both sides of the upper margin of the cricoid cartilage plate, including an apex, a bottom, and two processes (the vocal process and the muscular process). However, the size of the pig larynx arytenoid cartilage looked obviously larger in total, particularly at its muscular process and the arytenoid apex; and (2) there were no remarkable delimitation between arytenoid cartilage, cuneiform cartilage, and corniculate cartilage in the pig larynx, which were composed of the angle winding structure toward the back. Moreover, the left and right side of the pig arytenoid cartilage were also partially joined together, without obvious boundaries.

The detailed data of the measurements were listed in Tables 1 and 2 for the pig arytenoid cartilage and the human arytenoid cartilage. For the pig and the human, respectively, there was no significant difference between the left and right arytenoid cartilage ($P > 0.05$) (Table 1). Table 2 shows (1) the shapes of pig and human cricoarytenoid articular facet and cricoarytenoid facet were both oval; (2) the size of the pig larynx arytenoid cartilage overall was significantly larger than the human, and there was significant statistical significance for almost all measurements ($P < 0.05$), except the mean value of cricoarytenoid articular facet center distance, the cricoarytenoid facet minor diameter, and the length of vocal process of pig and human, without statistically significant difference ($P > 0.05$); (3) although the height of the pig's arytenoid cartilage was about twice as high as the human's, the distance from the junction to the vocal cords process (A7) was approximately the same as the distance from the junction to the muscle process (A8), and the ratio was approximately 1, that is, after the angle winding was removed from the junction, pig arytenoid cartilage and human arytenoid cartilage were shaped both like a triangular pyramid.

DISCUSSION

The arytenoid cartilage has important physiological significance and it plays a vital role in regulating sound, coordinating breathing, and preventing aspiration during swallowing. Bilateral vocal fold paralysis, with both vocal folds assuming a paramedian position due to the dyskinesia of the arytenoid cartilage, often accompanies by dyspnea, and endoscopic arytenoidectomy cannot only improve patients' respiration but can also maintain voice function to a certain extent. Therefore, it is the prerequisite for the surgical effect of the surgery to be familiar with the anatomy of the arytenoid cartilage and the accurate removal of the arytenoid cartilage.

In the field of medicine, young otolaryngology doctors urgently want to improve their surgical skills. At present, human cadavers, animals, and human-simulated plastic models have been widely used in medical training. Although the morphology of human laryngeal cartilage has been studied in

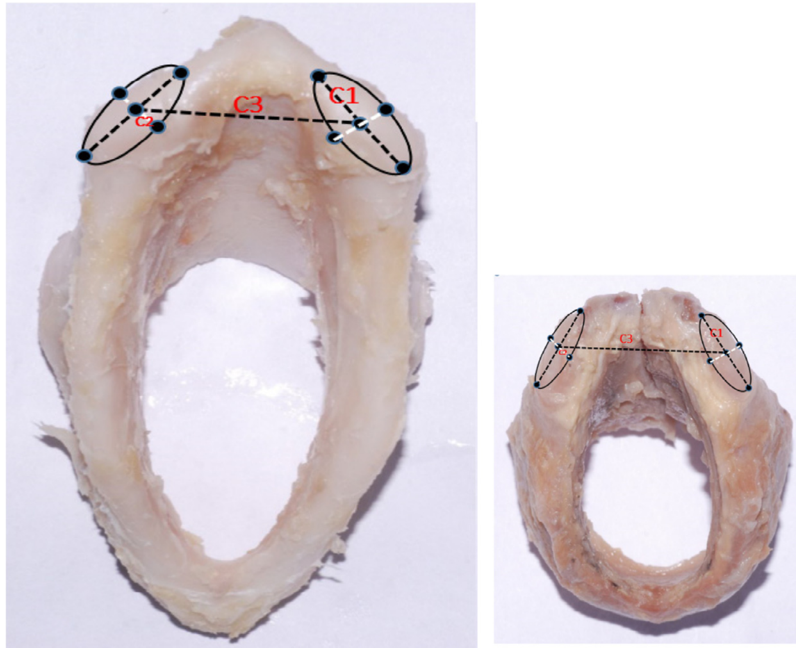

FIGURE 3. Anterior view: anatomy and morphometric measurements of the pig cricoarytenoid articular facet (left) and the human cricoarytenoid articular facet (right): C1, cricoarytenoid articular facet major diameter; C2, cricoarytenoid articular facet minor diameter; C3, cricoarytenoid articular facet center distance.

depth and the anatomical aspect of the human larynx arytenoid cartilage has been described in anatomy textbooks, the detailed morphological information and variability of the arytenoid cartilage remain obscure.[28–32] In addition, fresh human larynx is difficult to obtain, so suitable animal models of the larynx are needed to help study vocal function and to perform a simulated operation. In recent decades, it has been found that pig larynx can be used as a laryngeal model, and it is a good choice. However, there are few studies about the porcine arytenoid cartilage. To understand the anatomy and morphology of the porcine arytenoid cartilage, we have designed the subject.

In this study, we measured 10 arytenoid cartilages in 5 human cadaver larynxes, similar to those of previous measurements such as those of Eckel et al[30] and Sprinzl et al.[31] By dissecting and measuring the pig arytenoid cartilage, we noticed

TABLE 1.
Asymmetry in Pig and Human Arytenoid Cartilage*

	Pig (n = 5)			Human (n = 5)		
	Mean			Mean		
Measurement	Left	Right	*P*	Left	Right	*P*
Cricoarytenoid articular facet major diameter (C1)	8.848	8.662	0.847	7.540	7.382	0.687
Cricoarytenoid articular facet minor diameter (C2)	5.278	5.246	0.943	4.052	3.856	0.444
Cricoarytenoid articular facet center distance (C3)	19.568	19.568	1.000	18.640	18.640	1.000
Cricoarytenoid facet major diameter (A1)	7.006	6.856	0.609	4.396	4.382	0.964
Cricoarytenoid facet minor diameter (A2)	5.426	5.566	0.633	5.628	5.396	0.570
Length of vocal process (A3)	8.388	8.218	0.445	8.416	8.446	0.948
Length of muscular process (A4)	6.890	7.012	0.849	3.898	3.906	0.934
Distance between tips of vocal process and muscular process (A5)	17.876	17.834	0.956	13.392	13.028	0.580
Distance between apex of arytenoid cartilage and cricoarytenoid facet center (A6)	30.662	30.410	0.754	14.346	14.022	0.669
Distance between tip of vocal process and junction/apex of arytenoid cartilage (A7)	24.398	24.614	0.832	16.510	16.368	0.887
Distance between tip of muscular process and junction/apex of arytenoid cartilage (A8)	21.674	21.946	0.785	16.454	16.608	0.880

* The data are displayed separately for right and left side of pig and human arytenoid cartilage. Data were compared using *t* test between right and left side of pig and human arytenoid cartilage (significance < 0.05). All measurements are listed in millimeters. n = 5 for pig arytenoid cartilage; n = 5 for human arytenoid cartilage.

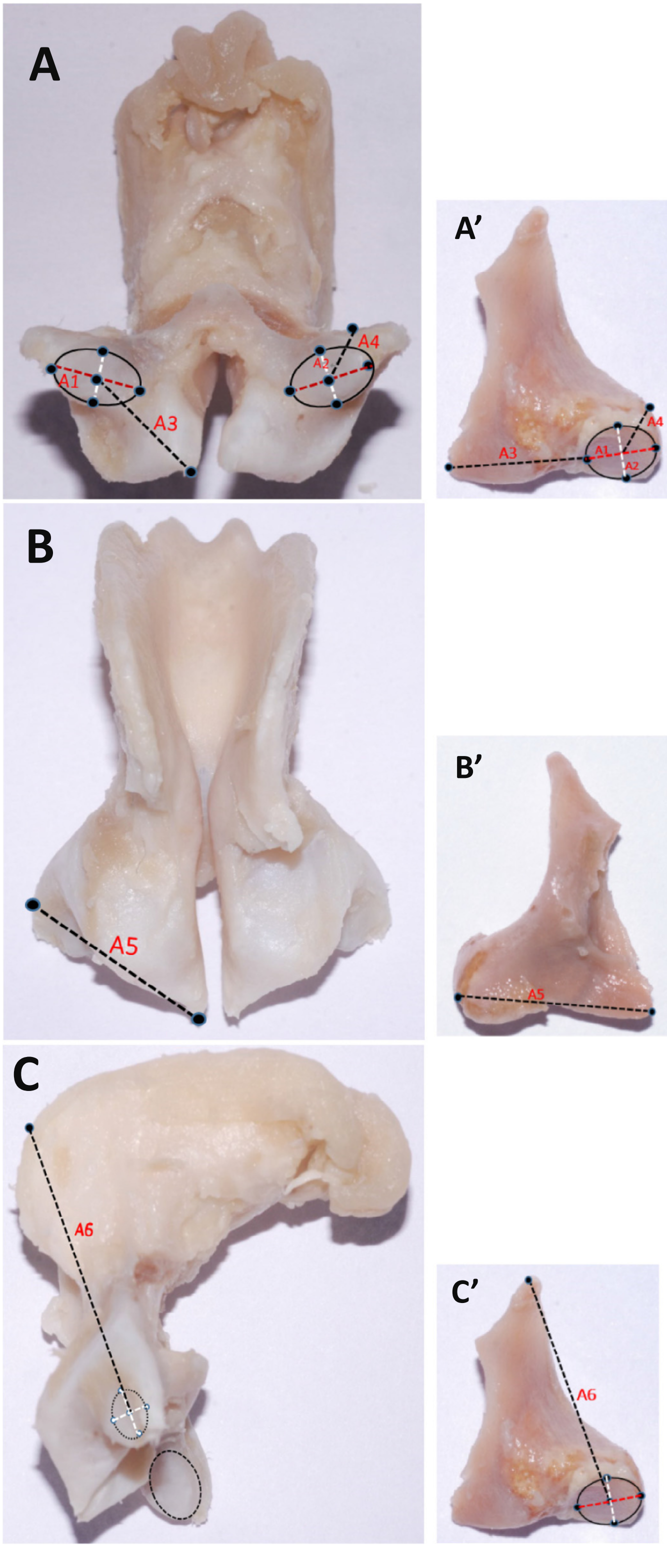

FIGURE 4. Anatomy and morphometric measurements of the pig arytenoid cartilage (left) and the human arytenoid cartilage (right): (A, A', C') posterior inferior view; (B) anterior view; (B', C) lateral view. A1, cricoarytenoid facet major diameter; A2, cricoarytenoid facet minor diameter; A3, length of vocal process; A4, length of muscular process; A5, distance between tips of vocal process and muscular process; A6, distance between apex of arytenoid cartilage and cricoarytenoid facet center.

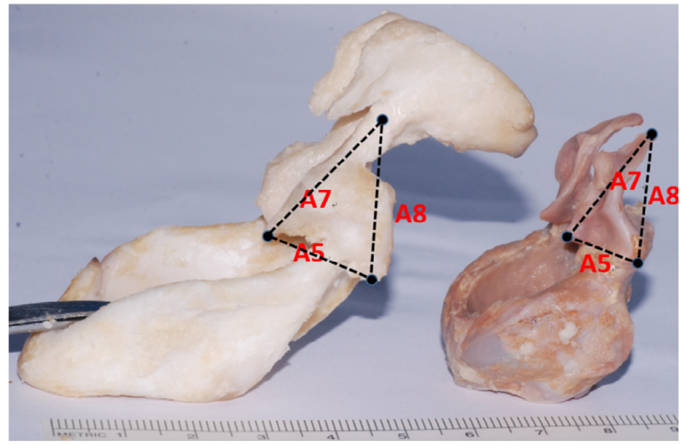

FIGURE 5. Lateral view: anatomy and morphometric measurements of the pig arytenoid cartilage (left) and the human arytenoid cartilage (right). Junction: the turning point of the pig laryngeal angle winding structure toward the back. A5, distance between tips of vocal process and muscular process; A7, distance between tip of vocal process and junction/apex of arytenoid cartilage; A8, distance between tip of muscular process and junction/apex of arytenoid cartilage.

that the gross anatomy of the pig arytenoid cartilage was similar to the human's, which were both paired, located on both sides of the upper margin of the cricoid cartilage plate, and shaped both like a triangular pyramid. However, there were still significant differences between the pig arytenoid cartilage and the human arytenoid cartilage. First, although the size of the pig larynx arytenoid cartilage was significantly larger than the human's in total and most of the measurements were significantly larger than those of human arytenoid cartilage, there were still three measured data of the pig arytenoid cartilage (the cricoarytenoid articular facet center distance, the cricoarytenoid facet minor diameter, and the length of vocal process) that were close to the human's, which mean that the proportion of some measured data of the porcine arytenoid cartilage was different from that of the human laryngeal arytenoid cartilage. Whether or not the similarities and differences of the measured data were related to the pronunciation, such as the basic frequency and amplitude, needs to be further studied. If we want to further explore the relationship between human and pig voice parameters and arytenoid morphology, it is necessary to expand the sample size. Second, the biggest differences between the pig arytenoid cartilage and the human arytenoid cartilage were that the pig arytenoid cartilage apex had the angle winding structure toward the back, and that the posterior part of the bilateral arytenoid cartilages was partially connected. Considering the difference of the position or the angle of food through the larynx between human and pig, the pig laryngeal angle winding structure may be helpful to close the larynx better when swallowing to prevent aspiration. Whether or not the pig interarytenoid cartilage affects the activity of arytenoid cartilage needs further study. The specific physiological significance of the different anatomic structures also needs further clinical study. Because we chose adult excised porcine larynges in the study, the size of the pig arytenoid cartilage was

TABLE 2.
Comparisons of Pig and Human Arytenoid Cartilage*

Measurement	Pig (n = 10)			Human (n = 10)			*P*
	Mean	SD	Range	Mean	SD	Range	
Cricoarytenoid articular facet major diameter (C1)	8.755	1.393	6.07–10.12	7.461	0.570	6.64–8.05	<0.05
Cricoarytenoid articular facet minor diameter (C2)	5.262	0.654	4.02–5.96	3.954	0.377	3.34–4.55	<0.001
Cricoarytenoid articular facet center distance (C3)	19.568	0.734	18.49–20.36	18.640	1.480	16.40–20.76	0.093
Cricoarytenoid facet major diameter (A1)	6.931	0.428	6.23–7.55	4.389	0.448	3.62–4.89	<0.001
Cricoarytenoid facet minor diameter (A2)	5.496	0.427	4.82–6.06	5.521	0.596	4.52–6.44	0.946
Length of vocal process (A3)	8.303	0.327	7.79–8.97	8.431	0.669	7.80–9.71	0.593
Length of muscular process (A4)	6.951	0.925	5.77–8.52	3.902	0.139	3.75–4.16	<0.001
Distance between tips of vocal process and muscular process (A5)	17.855	1.105	16.33–19.78	13.210	0.961	12.21–15.47	<0.001
Distance between apex of arytenoid cartilage and cricoarytenoid facet center (A6)	30.536	1.166	28.69–32.66	14.184	1.101	12.68–15.58	<0.001
Distance between tip of vocal process and junction/apex of arytenoid cartilage (A7)	24.506	1.472	22.34–27.19	16.439	1.442	14.27–18.81	<0.001
Distance between tip of muscular process and junction/apex of arytenoid cartilage (A8)	21.810	1.444	19.30–23.09	16.531	1.476	14.76–18.47	<0.001

* The data are displayed separately for pig and human arytenoid cartilage. Data were compared using *t* test between pig and human arytenoid cartilage (significance < 0.05). All measurements are listed in millimeters. n = 10 for pig arytenoid cartilage; n = 10 for human arytenoid cartilage.
Abbreviation: SD, standard deviation.

significantly larger than the human's in total. Considering that the porcine larynx will also increase with age, in future research, we need to compare porcine larynges with different age and weight, so as to find the most suitable ones for the simulated operation. Except for the different sizes and some differences in specific anatomic measurements, it was similar to the human's after the resection of the angle winding structure and the incision of interarytenoid cartilage of the pig arytenoid cartilage. Moreover, the pig larynx was obtained from the slaughterhouse, cheap and easy to get. It is concluded that taking into account the similarities and differences between the pig arytenoid cartilage and the human arytenoid cartilage, it is feasible and economical to use the pig larynx to simulate endoscopic arytenoidectomy.

The limitation of the current study was that the sample size was small because of the lack of human larynx. The similarities and differences between the porcine arytenoid cartilage and the human arytenoid cartilage and its deep physiological significance still need to be studied in depth.

CONCLUSION

The data of this metric comparative study indicate that pig arytenoid, after resecting the angle winding structure and incising the interarytenoid cartilage, is similar to the human's, and pig larynx is cheap and easy to get. Therefore, pig larynx is an appropriate experimental model for endoscopic arytenoidectomy. During simulating operation teaching, some differences such as the size and the angle winding should be taken into account. In addition, regarding the pig laryngeal angle winding structure, we still require further basic and clinical research to clarify its physiological function and significance.

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