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The Anatomical and Physiological Basis of the Mongolian Khuumii

Rentsendorj Tsagaankhuu[1], Ganchimeg Palamdorj[1], Byambasuren Luvsandagva[2], Nyamdorj Dagdanbazar[3]

[1]Department of Otorhinolaryngology, Mongolian National University of Medical Sciences, Ulaanbaatar, Mongolia; [2]Department of Otorhinolaryngology, The First Central Hospital of Mongolia, Ulaanbaatar, Mongolia; [3]Department of Anatomy, Mongolian National University of Medical Sciences, Ulaanbaatar, Mongolia

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Corresponding Author
Nyamdorj Dagdanbazar (MD, PhD, Assoc.Prof) Department of Anatomy, Mongolian National University of Medical Sciences, Ulaanbaatar 14210, Mongolia
Tel: +976-9911-4359
E-mail: nyamdorj@mnums.edu.mn
ORCID: https://orcid.org/0000-0002-7646-6865

Objectives: In order to examine each variety of khuumii used by Mongolians, this study compares the anatomical structures involved in the development of khuumii as well as the characteristics and patterns of their functioning.

Methods: 50 people between the ages of 18 and 60 were chosen for the cross-sectional study, using a non-random sampling procedure. Statistical analysis was performed using SPSS23 software using questionnaires, X-ray, endoscopy, and acoustic analysis.

Results: During the formation of khuumii sound, thoracic cavity, diaphragm, and lungs regulate the intensity of the air reaching the vocal folds, exert pressure on the airways and vibrate the sound waves through air flows passing through the larynx and vocal folds. The mouth-nose cavity as well as the pharynx are responsible for resonating the sound. Khuumii increases the workload of the cardiovascular system by 70-80%. Furthermore, the sound frequency is 2-4 times higher than that of normal speech, and sound volume is 0.5-1 times higher. 95.3% of throat singers do not have a sore throat, 88.4% do not experience heavy breathing, and 74.1% have no hoarseness.

Conclusion: The Mongolian throat singing khuumii, including mixed voices and multivoice, iss related to the presence of dual vibration sound sources. Its high overtone form of singing (isgeree khuumii) is related to stenosis at the resonance chambers initiation site (ventricular folds level).

Keywords: Larynx, Throat singing, Vocal fold, Voice source, Phoniatry

Introduction

The Mongolian throat singing "Khuumii" is a distinctive type of art that the nomadic people of Central Asia created by using their speech organs to produce two or more "simultaneous" sounds. It is a traditional polyphonic singing style from Mongolia [1]. In overtone chanting, the larynx's skeletal muscles are contracted to create a "polyphonic or bi-phonic sound" (bi-phonic means two voices). Scientists have determined the art of khuumii has been developed in about 15 countries of the world, and it has developed from nomadic art to professional stage art in Mongolia [2]. In recent years, a number of researchers studying khuumii in terms of medicine has emerged. A summary of literature review: In Mongolia, researcher Bat-Oyun.Ch, "Some Issues of Mongolian Khuumii", Enkhjargal.Sh "Features of Different Styles of Mongolian Khuumii", Mendbayar.J "Spread and Regional Features of Khuumii", Kherlen.L "Mongolian Khuumii Meaning", Zagd-Ochir.S "Some Issues on Skills of

Khuumii Performers", Tsogtgerel.Ts "About the Issues of Khuumii Methods", Odsuren.B "Characteristics of Professional Training Methods of Mongolian Khuumii" [3-9].

Foreign researchers: Sakakibara K. (Japan) "Vocal fold and false vocal fold vibrations in throat singing and synthesis of khoomei", Lindestad P. (Sweden) "Voice Source Characteristics in Mongolian "Throat Singing" Studied with High-Speed Imaging Technique, Acoustic Spectra, and Inverse Filtering", Kharuto AV. (Russia) "About The Musical And Acoustical Characteristics of Tuva Throat Singing", Aulanko R. (Finland) "Acoustic Characteristics of Different Styles of Overtone Singing In Altai", Grawunder S. (Germany) "Comparison of voice production types of 'western' overtone singing and South Siberian throat singing", Li G. (China) "The Physiological Basis of Chinese Höömii Generation" [10-15].

Researchers in our country have mostly studied the origin and development of khuumii from the perspective of history, geography, ethnography, art, culture and linguistics, while foreign researchers have conducted studies in terms of phonology and physics. In any of these cases, the number of research subjects is limited due to the small number of professional and amatuer khuumii performing artists. The lack of anatomical and physiological research and publications on khuumii indicates the need for a scientific study on the khuumii process, correction of some unscientific oral interpretations of khuumii, and resolution of disputes over classification. Therefore, the purpose of this study is to scientifically determine the features of structure and function of the organs involved in khuumii using modern diagnostic equipment, methods.

Material and Methods

Subjects

50 participants, ranging in age from 18 to 60, were included in the cross-sectional study, who were chosen using a non-random sampling technique. The performers are Mongolian khuumii artists from art organizations operating in Mongolia, both professional and amateur.

Three types of khuumii performance were used, namely shakhaa khuumii, isgeree khuumii, and kharkhiraa khuumii, in which the /i:/ vowel sound was selected for recording of the sound samples. The ordinary comfortable /i:/ sound was used as the control. We collected data for anatomical structures involved in the development of khuumii and the characteristics and patterns of their functioning. Questionnaire: The general information of the study participants was collected through a questionnaire with 22 variables. It includes variables such as age, gender, education, and how the Khuumii was learned.

Imaging: The Medien MT-RG (D) (Medien International of the Republic of Korea) digital X-ray equipment was used while performing which recorded the image of khuumii singing and the location, movement, and functional characteristics of the head and neck organs in producing khuumii.

Laryngoscope and endoscope: The Storz (Karl Storz, Tuttlingen, Baden-Württemberg, Germany) 700 KARL-STORZ straight laryngoscope and Fujifilm (Japan) flexible endoscope was used to visualize ventricular and vocal fold positioning, oscillation, and associated mucosal waves, movement of true and false vocal cords, glottal volume, movement of the epiglottis, arytenoid cartilage, and mucosa state. The soft palate was observed to check if it was vibrating during pronunciation.

Sound analysis: The Overtone Analyzer (Germany) a sound analyzer software was used to perform sound collection and acoustic analysis. Acoustic parameters such as sound frequency Hz, sound power Db, sound tone, amplitude, maximum sound output time, clear tone and noise ratio, and dynamic range were analyzed.

Statistical Analysis

Data from the study images and endoscopy were reviewed by professional physicians and the results were qualitatively analyzed. Quantitative analysis of voice acoustic quality and questionnaire data was performed. Statistical analysis was performed using IBM SPSS-23 for the standard quantitative data of the research results, improve the effect of arithmetic mean, error of the mean, standard deviation, maximum and minimum of variation. A repeated measures ANOVA analysis was used to compare the average of the acoustic quality parameters of the 3 study groups.

Ethics

The study conforms to the ethical guidelines of World Medical Association of Helsinki. The participants of the study have given their written consent and the study was approved by the Research Ethics Committee of the Mongolian National University of Medical Sciences (No.2017/3-08). All participants provided written informed consent before participating in the study.

Results

A total of 50 participated in the study, 45 (90%) male and 5 female (10%). Considering the age of the respondents, they were 18-70-year-old (mean age 29.5±10.8, male 29.9±11.1, female 26.4±7.4) (Table 1).

General chracteristics	Participants quantity (n)	Percentage (%)
Gender		
Male	45	90%
Female	5	10%
Age		
18-25	25	50%
26-34	13	26%
35<	12	24%
Khuumii learned method		
University	32	64%
Education center	5	10%
Home teachers	9	18%
Self studied	4	8%
Total time singing khuumii		
1-5 years	21	42%
6-10 years	10	20%
11-15 years	7	14%
16-20 years	7	14%
20< years	5	10%
Work		
Teacher of khuumii	8	16%
Professional art organization	12	24%
Freelance artist	11	22%
Band	4	8%
Student	15	30%

Results of X-ray

X-ray examination determined the state during each different styles of khuumii; shakhaa, isgeree and kharkhiraa. During shakhaa khuumii from a normal state, the larynx is raised, joining the sublingual bone and pressed up to the chin. The sublingual bone is lowered by tilting the trunk up to 45 degrees. The epiglottis cartilage is bent forward to the tongue root and its position is changed according to the movement of the tongue. The soft palate is lifted up, and the nasopharynx is completely separated and closed from the mouth. As the base note of shakhaa khuumii went up, the larynx raised up and the compression strength increased whereas as the base note went down, the larynx lowered. Sound of khuumii coming from the larynx resonated through the lower and middle parts of the pharynx and further through the mouth cavity (Figure 1).

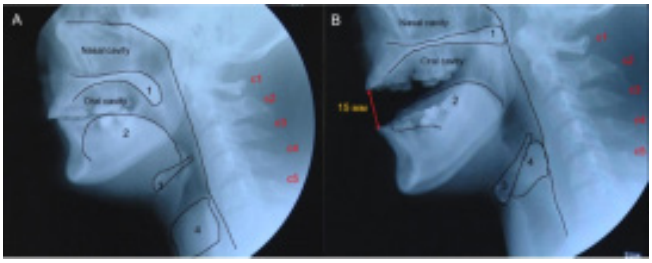

Figure 1. This figure illustrates the location of the organs of during Shakhaa khuumii. (A) Quiet breathing;(B) During Shakhaa khuumii.1. soft palate, 2. tongue, 3. hyoid bone, 4. larynx

During isgeree khuumii, in addition to the basic changes that occur on shakhaa khuumii, the position of the tongue is elevated and touches the hard palate making fine movements, the basic tone of shakhaa khuumii coming from the the larynx is shaped by changes in the position and movement of the tongue creating clear and soft isgeree (whistling) sound. As the tone of isgeree goes up, the position of the tongue shifts to the hard palate and upper anterior teeth, and as the tone comes down, the tongue weakens and moves backwards (Figure 2).

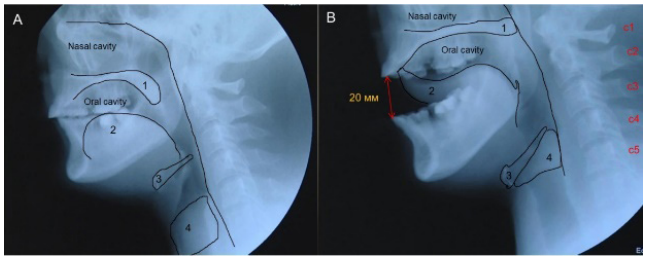

Figure 2. This figure illustrates the location of the organs of during Isgeree khuumii. (A) Quiet breathing;(B) During Isgeree khuumii. 1. soft palate, 2. tongue, 3. hyoid bone, 4. larynx

In the case of kharkhiraa khuumii, the larynx position was elevated to a relatively small extent compared to shakhaa khuumii and the distance between the sublingual bone and the larynx was large. The sublingual bone trunk lowered during shakhaa khuumii, while it was slightly elevated during kharkhiraa khuumii. As the tone of kharkhiraa khuumii goes up and down, the position of the larynx changes in direct proportion. X-rays showed that the soft palate was completely closed, the vocal cords made wave-like movements, and the frequency changed as the sound changed tone (Figure 3).

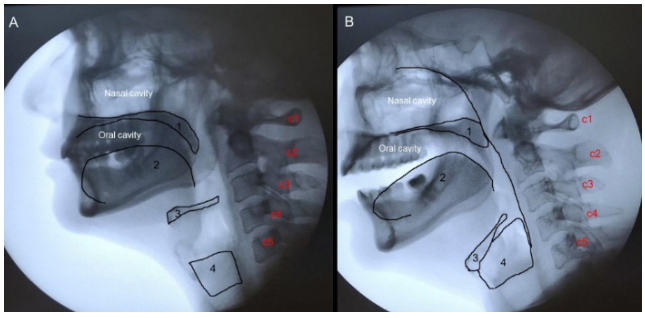

Figure 3. This figure illustrates the location of the organs of during Kharkhiraa khuumii. (A) Quiet breathing;(B) During Kharkhiraa khuumii. 1. soft palate, 2. tongue, 3. hyoid bone, 4. larynx

Results of laryngoscope and flexible endoscope

Shakhaa and Isgeree khuumii: During khuumii, the false vocal cords were closed on all sides. The glottis narrows and becomes a hole. Isgeree khuumii, on the other hand, produces a subtle whistling sound when the tongue touches the palate on top of the shakhaa khuumii method. Therefore, the position and movement of the larynx are similar to that of changes in shakhaa khuumii, but as the movement of the tongue is involved, the movement of the arytenoid cartilage is increased by the movement of the tongue. Isgeree khuumii is required to be forced with a higher tone to produce a subtle tone, so the gap between the glottis was compressed more and more. In other words, it was observed that a single khuumii tone is formed by vibrations in the middle third of the laryngeal vestibule or between the mucous membranes of the vocal folds (Figure 4, Figure 5).

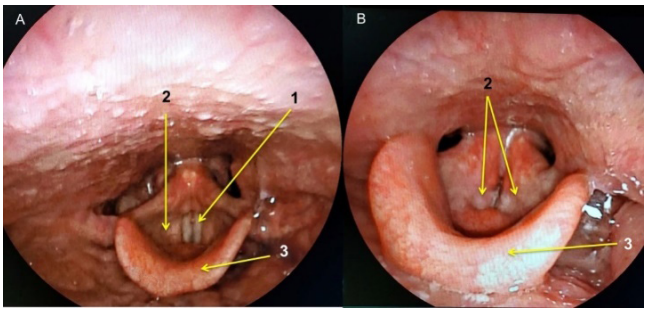

Figure 4. (A)Normal phonation; (B)During Shakhaa khuumii. 1. True vocal cord, 2. False vocal cord, 3. Epiglottis

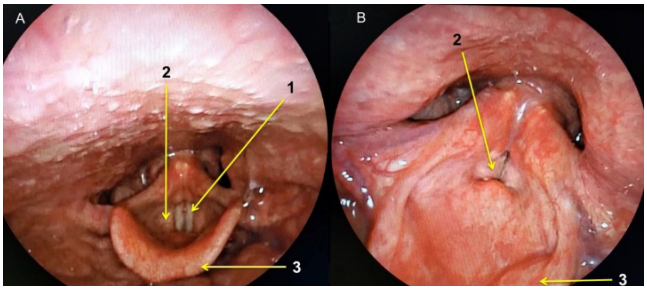

Figure 5. (A)Normal phonation; (B)During Isgeree khuumii. 1. True vocal cord, 2. False vocal cord, 3. Epiglottis

Kharkhiraa khuumii: The contraction force of the false vocal cords is relatively weak compared to that of the shakhaa khuumii, and glottis is slightly visible. The vocal cords are intermittently contracted and sound is heard as vibration during kharkhiraa khuumii. In other words, at this time, creating vibrations in the anterior third of the laryngeal vestibule or between the mucous membranes of the vocal folds were observed to form kharkhiraa khuumii sound. The mucous membrane of the posterior third of the laryngeal vestibule can also vibrate, and if these structures vibrate at once, simultaneous sound and melody of khuumii is produced (Figure 6).

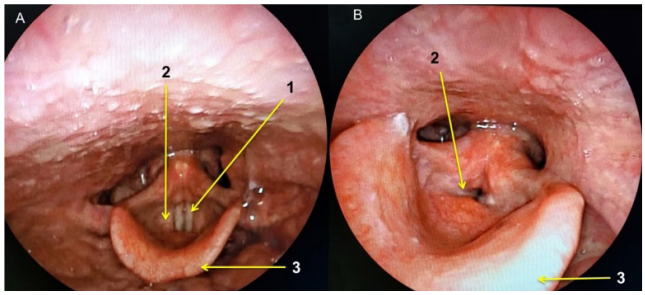

Figure 6. (A)Normal phonation; (B)During Kharkhiraa khuumii. 1. True vocal cord, 2. False vocal cord, 3. Epiglottis

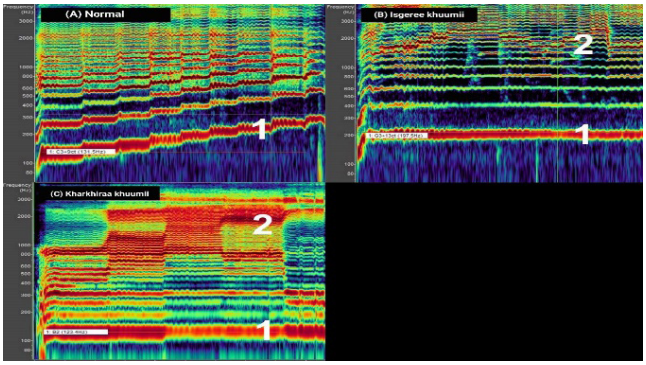

Figure 7. (A) Normal voice(B) Isgeree khuumii; (C) Kharkhiraa khuumii; 1. Spectrogram of fundamental sound, 2. Spectrogram of melodic sound

Results of acoustic analysis of Khuumii

We used "Overtone" acoustic analyzer software to determine and compare the structure of normal and harmonic sounds from spectrogram recordings. While 1 type of sound track was recorded when producing normal sounds, 2 types of sound tracks were recorded when producing harmonic sounds: fundamental sound and melodic sound (Figure 7).

The average frequency of normal sounds was 147±18 Hz, sound level was 51±5 dB. The average sound frequency of the fundamental sound of the isgeree khuumii was 197.5±25.6 Hz, the average sound frequency of the harmonic sound was 2742.1±149.9 Hz, and the average sound level was 95.4±5.2 dB. The average sound frequency of the kharkhiraa khuumii fundamental sound was 125.4±25.9 Hz, the average sound frequency of the harmonic sound was 574±134 Hz, sound level was 82±5 dB (Table 2).

Table 2. The acoustic characteristics of Khuumii sound

Characteristics	Frequency of fundamental sound (Hz)	Frequency of harmonic sound (Hz)	Sound level (Db)
Normal voice	147±18	-	51±5
Isgeree khuumii	197.5±25.6	2742.1±149.9	95.4±5.2
Kharkhiraa khuumii	125.4±25.9	574±134	82±5
P Value	0.036	0.042	0.027

Discussion

There are two theories that explain khuumii: the "double-source" theory and the "resonance theory". Chernov and Maslov's (1989) "double-source" theory proposes that along with the vibration of the vocal cords, a narrow primary pitch similar to whistling is produced at the rear of the vocal cords [16]. However, Bloothoof's (1992) "resonance theory" suggests that the primary pitch is formed from oscillations of the vocal cords, melody resonates and that the narrow high note is heard separately from the other components of the sound. The study observed Tuva's ethnic Sygyt throat singing through inserting a flexible laryngoscopy into the nasal cavity and found that both true and false vocal cords were tightly closed, creating a whistling sound with a narrow gap in the rear. Furthermore, function of the pharynx, larynx, and arytenoid cartilage were examined each time the sound changed. Stroboscopic examination of the throat with a direct laryngoscope pulling the khuumii performer's tongue revealed a continuous khuumii sound without a melody [17]. This was similar to the process of shakhaa khuumii in our study, but the fact that the lower part of the tongue and pharynx play an important role in the formation of shakhaa khuumii shows that it is similar to the isgeree style of Mongolian khuumii. It also proves that the melody of khuumii is formed by a mechanism or by the involvement of other resonating structures, rather than the double pitch produced by the larynx. Adachi and Yamada (1999) concluded that MRI images of khuumii shows that the tongue is raised to form a melody [18]. These researchers also conclude that the true vocal cords comes in close contact and joins with false vocal cords to form basic note, and further primary pitch

resonates when the tongue is lifted, which is unquestionably in line with the results of X-ray and laryngoscope of our research. Klingholz (1993) determined that the basic sound frequency was 202Hz for shakhaa (Sygyt) khuumii and 100-200Hz for kargyraa (kharkhiraa), which is close to the result of acoustic parameters of isgeree and kharkhiraa khuumii in our research [19].

Conclusion

During the formation of khuumii sound, thoracic cavity, diaphragm, and lungs regulate the intensity of the air reaching the vocal folds, exert pressure on the airways and vibrate the sound waves through air flows passing through the larynx and vocal folds. Mouth-nose cavity as well as pharynx are responsible for resonating the sound. It is proposed to classify khuumii into two main styles of shakhaa and kharkhiraa according to the structural and functional changes in the organs involved in khuumii.

Conflict of Interest

The authors have no conflicts of interest to declare.

Acknowledgments

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