CEO Clinical and Experimental Otorhinolaryngology Vol. 8, No. 2: 155-160, June 2015

http://dx.doi.org/10.3342/ceo.2015.8.2.155

pISSN 1976-8710 eISSN 2005-0720

Original Article

The Effect of Total Thyroidectomy on the Speech Production

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Objectives. Voice and speech alternations that can occur after total thyroidectomy are usually due to recurrent or superior laryngeal nerve injury. These alterations may also be associated with other extralaryngeal factors, such as neck muscle dysfunction and scar contracture of the neck. We performed a prospective acoustic analysis on speech changes after surgery, in the absence of laryngeal nerve injury.

Methods. Patients aged 19 to 58 years undergoing total thyroidectomy, in the absence of laryngeal/pulmonary disease, previous neck surgery, or other malignant diseases, were recruited prospectively. For the running speech analysis, the speaking fundamental frequencies (SFo), range of SFo and speaking intensity were evaluated before surgery, 7 days, and 1 and 3 months after surgery. For consonant analysis, the acoustic distinctions of stop consonant, the voice onset time (VOT), vowel duration and closure duration were evaluated at the same periods.

Results. SFo and range of SFo were specifically diminished after surgery, while speaking intensities were not changed significantly after surgery. The thyroidectomized speakers displayed systematically varied VOT for the consonant production, which was phonetically representative. However, VOT after surgery could be longer in the strong aspirated and glottalized stops, but not in the lax stop than before surgery. The vowel and closure durations were not affected before and after surgery.

Conclusion. Patients with thyroidectomy have some difficulty of pitch control and consonant articulation during speaking. VOT is also one of the meaningful acoustic parameters and provide a reference for comparing acoustic measures before and after thyroidectomy.

Keywords. *Thyroidectomy; Speech*

INTRODUCTION

Voice changes, such as easy fatigue, difficulty of singing and speaking in a loud voice, and hoarseness, can be frequent complaints after thyroidectomy. In addition, many patients complain of speech alterations such as difficulty of speech fluency and intonation following thyroidectomy. These alterations after uncomplicated thyroidectomy generally are not related to impaired nerve function of superior and inferior laryngeal nerves [1-3], but are attributed to other causes that include intubation trauma [2], cricothyroid dysfunction [3], local pain in the neck; and/or a psychologic reaction to the postoperative situation [4]. In addition, the extralaryngeal frame factors, such as laryngotracheal fixation with impairment of vertical movement and extrinsic laryngeal muscle malfunction [5,6], have tended to be attributed to voice and speech alterations after surgery.

The extrinsic laryngeal muscles may be damaged due to the lateral traction during the thyroid surgery or cutting of these muscles, or wound contracture with surrounding structures after

• Received October 16, 2013
Revised February 25, 2014
Accepted February 25, 2014

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surgery. The extrinsic laryngeal muscles participate indirectly or directly in the functioning of the larynx and their phonatory function is well defined. Sonninen [7] reported that the function of the extrinsic laryngeal muscles, the so called external frame function, lengthens or shortens the vocal folds changing the relationship of the thyroid to the cricoid cartilage. Hong et al. [8] also reported that the contraction of the sternohyoid and sternothyroid muscles causes a laryngotracheal downward pull, producing a high air volume in the subglottic air space, corresponding to increased subglottic pressure. This downward pull shortens the cricothyroid distance, and anterior downward bending shortens of the anterior cricothyroid distance, which lengthens the vocal folds and raises the frequency. Hong and Kim [5] suggested the importance of extralaryngeal frame function to the pitch control in patients with total thyroidectomy. The authors reported that the phonation time and fundamental frequency were not changed after surgery, but the speaking fundamental frequency (SFo), range of SFo and vocal range might be diminished after surgery. They suggested that the cause of voice dysfunction is not seen in a neural lesion, but in a disturbance of the extralaryngeal frame function.

For the normal consonant production, normal speakers systematically vary the voice onset time (VOT) values to characterize the prevocalic stops [9,10]. VOT is defined as the time interval from oral release of a consonant to the onset of glottal pulse for vowel, reflecting the complex timing of the glottal articulation. To the extent that VOT is an indirect measure of coordination between the extralaryngeal articulation and the vocal folds, it reflects some aspect of laryngeal function [11]. It is important to note that laryngeal gestures involved in the contrast between voiced and voiceless stops is only one aspect of the coordinated movements reflected in VOT [12]. As such, VOT can be only an indirect and imperfect measure of laryngeal function. Although the larynx is thought to behave as an active articulator in controlling the initiation and interruption of glottal pulsing, it must be coordinated with occlusion and release of the articulators. Control of the complex coordination between laryngeal and extralaryngeal movements that is reflected in VOT is not well understood.

The main purpose of this study is to clarify various parameters of acoustic analysis for the thyroidectomized patients especially focused on speech production. In this study, SFo, range of SFo and speaking intensity were evaluated during running speech production, and the characteristics of speech articulation with special reference to the consonant production, VOT, vowel duration and closure duration, were also evaluated.

MATERIALS AND METHODS

Subjects

A prospective study was designed to evaluate the changes of acoustic parameters before and after thyroidectomy. We selected 32 female patients with total thyroidectomy due to thyroid cancer under <60 years of age (range, 19 to 58 years; mean, 43.5 years). All patients showed normal voice function before surgery. Exclusion criteria included greater than 60 years of age, vocal fold paralysis, history of voice or speech disorders, previous neck surgery, and laryngeal disorders. All patients received total thyroidectomy with central neck dissection and showed papillary carcinoma pathologically. Among patients with central neck dissection, 5 patients received lateral neck dissection. During thyroid surgery, the strap muscles were dissected and retracted to the lateral side from the midline, but not cut. The recurrent laryngeal nerve was routinely identified and protected on the affected side. Because the external branch of the superior laryngeal nerve is not exposed routinely, the superior thyroid artery and vein are ligated very carefully, close to the thyroid capsule to avoid nerve injury. When this nerve is not readily identifiable, no further dissection is pursued to avoid inadvertent nerve injury. Postoperatively the movement of vocal folds was observed with laryngoscopic examination. No patient showed motion limitation of vocal folds during phonation, and laryngeal pathologies regarding to general anesthesia were not observed at all.

Acoustic analysis

Objective speech analysis was performed with a voice range profile program (model 4326, Kay Elemetrics, Montvale, NJ, USA), using a computerized speech lab (model 4300B, Kay Elemetrics) and recording with a unidirectional dynamic microphone (Shure, Evanston, IL, USA), positioned at a 45-degree angle and at distance of 20 cm from the patient's mouth. For the running sentence analysis, after 3 training emissions, an informed sentence was recorded with a sampling rate of 50 kHz produced at a comfortable pitch and loudness level. We evaluated SFo, range of SFo and speaking intensity. All speech samples were played from a digital audio-tape recorder at a constant playback level.

For the consonant analysis, the test words were prepared so as to place the consonants in different phonological environments. These words were uttered in the frame sentence " i k ∂s i **CVCV** i d a"(This is /**CVCV**/). The bilabial stops /p, $\mathbf{P^h}$, p'/ for the consonant /C/ were used, where vowels /V/ were /a/ and /i/. The /p/ stands for lax consonant, /$\mathbf{P^h}$/ for strong aspirated consonant and /p'/ for glottalized, nonaspirated, consonant. The utterances were repeated. The tested words were sampled at 8 kHz with 10-bit accuracy. Each word was displayed as a wide or narrow band spectrogram and acoustic waveform and, using a cursor, the duration of VOT in the word initial position (/CVCV/), vowel duration during vocal fold vibration (/CVCV/), oral closure time (/CVCV/) were measured accurately (Fig. 1). An amplitude display of the wave-form was used to measure the explosive sound intensity at the consonant's burst in the word initial position (/CVCV/). VOT in the /CVCV/ syllables is defined as the measurement between burst onset and the identifiable periodic vibration for a following vowel within the acoustic wave. Duration of oral closure time can be measured as the time from offset of vowel periodicity in a speech wave to consonant burst onset (/CVCV/), not at the word-initial position. Numerical results are presented as means and standard deviation of mean, and the tests of significance by using both paired and nonpaired *t*-tests as appropriate.

RESULTS

As in Table 1 and Fig. 2, the mean value of SFo during speech was 200.3 Hz before surgery, and 173.4, 180.0, 190.9 Hz at 7 days, 1 month, and 3 months, retrospectively, after surgery. SFo was significantly decreased 7 days and 1 month after surgery, but not at 3 months after surgery. The ranges of SFo during speech were 171.4 Hz before surgery, and 140.3, 156.3, 161.7 Hz at 7 days, 1 month, and 3 months, retrospectively, after surgery. The range of SFo was significantly decreased 7 days and 1 month after surgery, but not 3 months after surgery. The mean values of sound intensity during speech were 51.7 dB before surgery, and 46.9, 55.3, 50.3 at 7 days, 1 month, and 3 months, retrospectively, after surgery. The sound intensities were not significantly changed postoperatively.

VOT, vowel duration and closure time during reading of test words were analyzed. The mean VOTs for the bilabial **/p/** with vowel /a/ production indicated 53.4 msec before surgery, and 61.9, 60.5, and 55.7 msec at 7 days, 1 month, and 3 months, retrospectively, after surgery (Table 2, Fig. 3). The VOTs for /p/ were not significantly changed, but tend to increase 7 days after surgery. The mean VOTs for the bilabial **/P^h/** with vowel /a/ production indicated 60.1 msec before surgery, and 72.1, 65.1, and 66.2 msec 7 days, 1 month, and 3 months after surgery. The VOTs for **/P/** were not significantly changed, but tend to increase after surgery. The mean VOTs for the bilabial **/P'/** with vowel /a/ production indicated 18.0 msec before surgery, and 24.5, 20.5, and 21.7 msec at 7 days, 1 month, and 3 months, retrospectively, after surgery. The VOTs for **/P'/** were significantly increased at 7 days and 3 months after surgery. The mean VOTs for the bilabial **/P/** with vowel /i/ production indicated 62.4 msec before surgery, and 67.8, 62.7, and 65.1 msec at 7 days, 1 month, 3 months, retrospectively, after surgery, and were not significantly changed after surgery (Table 3 and Fig. 4). The mean VOTs for the bilabial / **P^h**/ with vowel /i/ production indicate 66.1 msec before surgery, and 71.8, 68.3, and 67.2 msec at 7 days, 1 month, and 3 months, retrospectively, after surgery. There were not significantly changed, but tend to increase at 7 days and 3 months after surgery. The

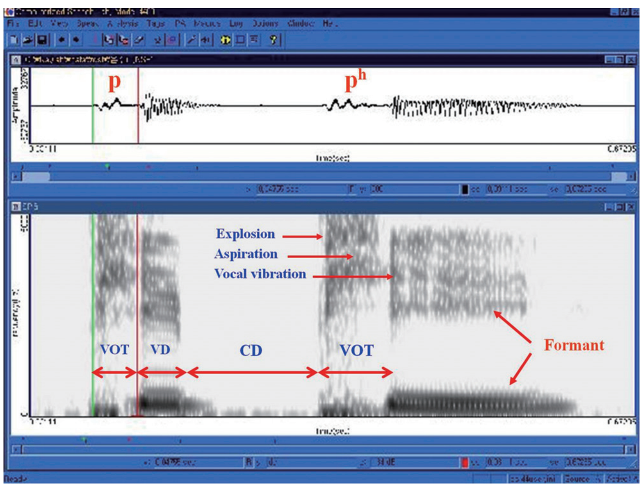

Fig. 1. Acoustic waveforms and wide-band spectrogram for presenting voice onset time (VOT), vowel duration (VD) and closure duration (CD) with /pip^{h}i/ phonation.

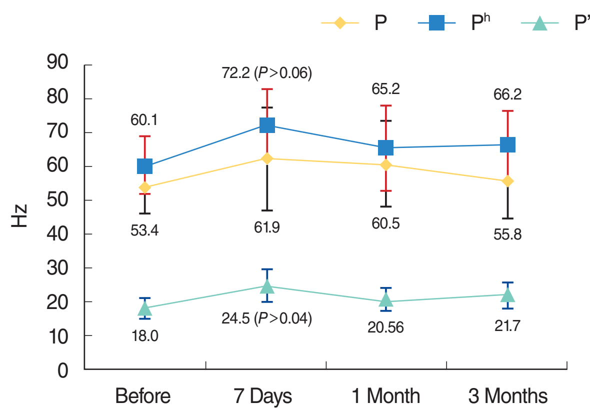

Fig. 2. Changes of speaking frequencies (SFo) and SFo ranges during speaking with running sentence. The SFo and SFo range were significantly diminished after surgery.

Table 1. Changes of speaking fundamental frequency and intensity during production of running speech sentence

Period	SFo (Hz)		SFo range (Hz)		SI (dB)	
	Mean±SD	*P*-value	Mean±SD	*P*-value	Mean±SD	*P*-value
Before	200.3±48.7	-	171.4±31.9	-	51.7±10.2	-
7 Days	173.4±40.5	0.01*	140.3±38.2	0.04*	46.9±13.4	0.43
1 Month	180.0±55.2	0.01*	156.3±29.6	0.02*	55.3±11.0	0.39
3 Months	190.9±40.8	0.12	161.7±47.3	0.28	50.3±9.9	0.61

SFo, speaking fundamental frequency; SI, speaking intensity.
*P<0.05, statistically significance.

Table 2. Changes of voice onset time, msec, of /p, p^h, p'/ during test words, bilabial /<u>C</u>VCV/ with vowel /a/, production

Period	P		P^h		P'	
	Mean±SD	*P*-value	Mean±SD	*P*-value	Mean±SD	*P*-value
Before	53.41±17.21	-	60.14±15.12	-	18.03±5.89	-
7 Days	61.97±21.70	0.10	72.17±30.25	0.06	24.59±9.83	0.04*
1 Month	60.57±25.16	0.45	65.19±25.36	0.19	20.56±7.20	0.15
3 Months	55.79±20.31	0.63	66.24±22.59	0.11	21.72±7.9	0.05*

CV, consonant vowel.
**P*<0.05, statistically significance.

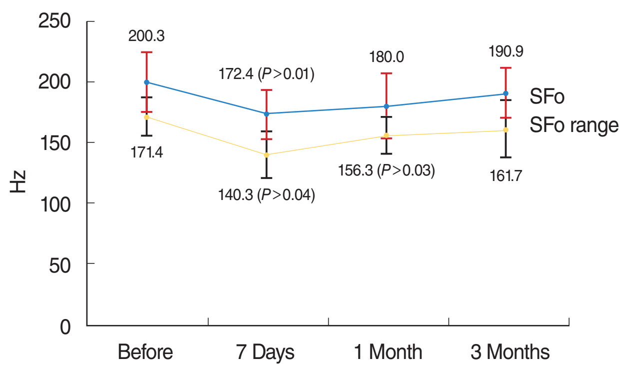

Fig. 3. Changes of voice onset times (VOT) for bilabial stops with vowel /a/ production. The VOTs tend to increase after surgery and VOT for unaspireated /p'/ was significantly increased at 7 days after surgery. SFo, speaking frequencies.

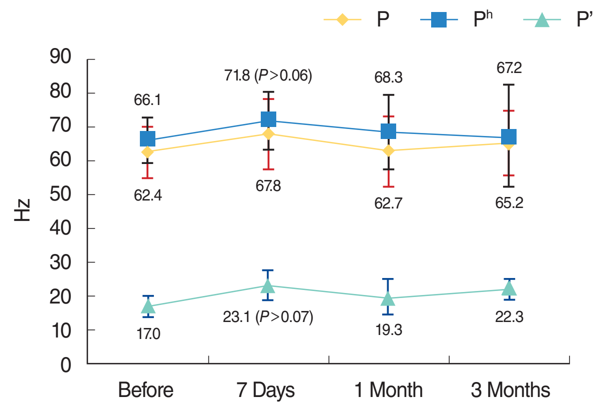

Fig. 4. Changes of voice onset times (VOT) for bilabial stops with vowel /i/ production. The VOTs tend to increase after surgery, especially at 7 days after surgery, but not significant statistically.

Table 3. Changes of voice onset time, msec, of /p, p^h, p'/ during test words, bilabial /<u>C</u>VCV/ with vowel /i/, production

Period	P		P^h		P'	
	Mean±SD	*P*-value	Mean±SD	*P*-value	Mean±SD	*P*-value
Before	62.47±15.17	-	66.17±13.48	-	17.02±6.17	-
7 Days	67.85±20.92	0.26	71.82±17.01	0.08	23.18±9.17	0.07
1 Month	62.79±20.29	0.61	68.31±22.40	0.51	19.38±10.34	0.25
3 Months	65.19±19.58	0.43	67.20±30.19	0.59	22.38±6.29	0.10

CV, consonant vowel.
**P*<0.05, statistically significance.

mean VOTs for the bilabial /P'/ with vowel /i/ production indicate 17.0 msec before surgery, and 23.1, 19.3, and 22.3 msec at 7 days, 1 month, and 3 months, retrospectively, after surgery. The VOTs for /P'/ were significantly increased at 7 days and 3 months after surgery.

The mean vowel durations for the bilabial **/P^h/** with vowel /a/ production indicated 45.2 msec before surgery, and 50.4, 43.8, and 46.1 msec at 7 days, 1 month, and 3 months, retrospectively, after surgery, and were not significantly changed after surgery (Table 4). The mean vowel durations for the bilabial **/P'/** with vowel /a/ production indicated 46.2 msec before surgery, and 44.3, 50.4, and 47.9 msec at 7 days, 1 month, and 3 months, retrospectively, after surgery, and were not significantly changed after surgery. The mean closure durations for the bilabial **/P^h/** with vowel /a/ production indicated 108.3 msec before surgery, and 115.3, 102.3, 104.6 msec at 7 days, 1 month, 3 months after surgery, and were not significantly changed after surgery (Table 5). The mean vowel durations for the bilabial **/P'/** with vowel /a/ production indicated 128.9 msec before surgery, and 119.4, 110.5, and 127.3 msec at 7 days, 1 month, and 3 months, retrospectively, after surgery, and were not significantly changed after surgery.

DISCUSSION

The voice and speech alternations after thyroidectomy have been historically accepted as being due to the iatrogenic trauma of the superior and recurrent laryngeal nerves, during thyroidectomy. When the recurrent laryngeal nerves damaged, the limited motion or fixation of the vocal folds is noted and the edge of the vo-

Table 4. Changes of vowel duration, msec, of /p, p^h, p'/ during test words, bilabial /C<u>V</u>CV/ with vowel /a/, production

Period	P^h		P'	
	Mean±SD	*P*-value	Mean±SD	*P*-value
Before	45.23±8.27	-	46.20±6.87	-
7 Days	50.42±10.61	0.56	44.38±7.51	0.71
1 Month	43.80±7.44	0.82	50.43±8.91	0.58
3 Months	46.12±9.30	0.79	47.91±10.26	0.61

CV, consonant vowel.

Table 5. Changes of closure duration, msec, of /p, p^h, p'/ during test words, bilabial /CV<u>C</u>V/ with vowel /a/, production

Period	P^h		P'	
	Mean±SD	*P*-value	Mean±SD	*P*-value
Before	108.34±20.13	-	128.91±23.25	-
7 Days	115.34±17.38	0.58	119.45±15.19	0.48
1 Month	102.39±14.76	0.69	110.58±12.69	0.71
3 Months	104.65±18.12	0.71	127.39±17.67	0.59

CV, consonant vowel.

cal fold affected may be irregular or wavy. When the vocal folds abduct and adduct normally after thyroidectomy, the cause of voice change is not a palsy of the recurrent laryngeal nerve [13]. In contrast, in the cricothyroid paralysis [14,15], the loss of this function may lead to lowered pitch, vocal fatigue, hoarseness, loss of upper range, loss of projection, and breathiness. Flaccidity of the affected vocal fold may cause irregular vertical movements during respiration, which in turn causes various configulation of the glottis. However, the entire preservation of the superior and recurrent laryngeal nerves is not the only factor in the postoperative preservation of a normal voice and speech after operation. Other causes have been postulated, so called extralaryngeal frame factors, such as muscle tightness and laryngotracheal fixation with impairment of vertical movement and strap muscle malfunction [2,5,6].

On concerning external laryngeal frame function, the external laryngeal muscles have also a laryngeal function for phonation and speech production. The literature has described several human studies relating the functional role of the strap muscles to the larynx, attributing changes in the length of the vocal folds to external forces like contraction of the strap muscles [8,15]. There were also reports that the strap muscles have a positive relationship to frequency with stimulation of strap muscles resulting in pitch elevation [16-18]. During the thyroid surgery, although a large gland or heavy musculature often necessitates division, retraction as a rule has provided adequate exposure. If muscles are divided, resuture is advisable, though this may not always be possible if only thinned out sternothyroid is cut. These structures became adhered to the strap muscle with scar formation between laryngotracheal and strap muscles, and the strap muscle and subcutaneous soft tissue were also adhered together. So the movement of larynx during speech production was impaired and resulted in impairment of laryngeal control during speech or singing.

Most of acoustic data after thyroidectomy are using sustained vowels [19]. Phonation time and pitch perturbations are typically not significantly changed before thyroidectomy. These results suggested that the recurrent and superior laryngeal nerves were not damaged during surgery. Generally the phonation time and pitch pertubations are affected by the status of recurrent laryngeal nerve, and the fundamental frequency of sustained vowel is affected by the superior laryngeal nerve. On the running speech analysis, SFo has been implicated as one of the parameters of speech production signaling dysphonia or laryngeal pathology [20]. The change of speaking frequency range may also explain the characteristic of monotonic voice of unilateral vocal fold paralysis or impairment of extralaryngeal frame function. In this study SFo and range of this SFo were specifically diminished at 1 and 3 months after surgery. These results were highly suggested that it may be associated with the external frame dysfunction of the larynx, such as laryngotracheal fixation by scar-impairing vertical movement or by malfunction of the strap muscles after surgery temporarily, but not with vocal fold paralysis. These results emphasize the importance of the extralaryngeal mechanism for pitch control.

Concerning the normal production for consonant articulation, the intrinsic laryngeal muscles have major role to produce an appropriately timed approximation and inhibition of vocal fold vibration for consonant productions. The temporal change in glottal width occurs at the explosion of consonants in the initial phase of utterance. Narrowing of the glottis begins immediately after the glottal width has reached its local maximum. The glottal widths are largest in the aspirated consonant and a small gap during the production of the unaspirated consonant. These differences of glottal width and condition result from the different activities of the intrinsic laryngeal muscles. Hirose et al. [11] reported that the strong aspirated consonant appeared to be characterized by a marked suppression of all the adductor muscles immediately before the stop release, and the slight aspirated consonant by a less predominant suppression of the adductor activities before release. Hong et al. [12] reported that during the strong aspirated consonant the marked and earliest activation of the posterior cricoarytenoid muscle before activation of the thyroarytenoid muscle was most characteristic. The authors also found a more moderated activation of the posterior cricoarytenoid muscle and the least reactivation of the thyroarytenoid muscle in the slight aspirated consonant.

During speech production, the proper articulation of consonants are not absolutely depends on intrinsic laryngeal function, but result from an appropriate cooperation of the intrinsic and extrinsic laryngeal functions. In the abnormal condition of extralaryngeal frame function, such as neck muscle tightness and impaired vertical movement, the intrinsic laryngeal muscles may be somewhat tightened or pressed. These phenomena result in the inappropriate control of phonation and speech. Most patients complain of vocal fatigue after thyroidectomy, which may be caused by the additional effort required to raise vocal pitch and to project by hyperfunctional compensatory [21]. These abnormal conditions of the intrinsic and extrinsic laryngeal structures, increased tension and abnormal movement, might be disturbing the laryngeal control for consonant production. This results in inappropriate approximation and inhibition of vocal fold during consonant production [22,23]. In this study, VOT values after surgery might be longer than before surgery, in the strong aspirated and unaspirated stops. But, mean VOT values for the stop consonants after surgery were sufficient to achieve voiceless stops and were important cues for voiceless stop distinction.

In conclusion, the superior and recurrent laryngeal nerves are infrequently damaged during thyroid surgery. However, the voice and speech alterations after thyroidectomy may be not associated with damage of these laryngeal nerves generally. In the abnormal condition of extralaryngeal frame function, the increased tensions of the intrinsic and extrinsic laryngeal structures might be disturbing the laryngeal role for speaking pitch control and consonant production. In this study, VOT, in addition to speaking frequencies, was also one of the numerous acoustic parameters and provide a reference for comparing acoustic measures from patients with thyroidectomy.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

ACKNOWLEDGMENTS

This paper was supported by Fund of Biomedical Institute, Chonbuk National University Hospital, Jeonju, Korea.

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