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Evaluation of the articulatory characteristics of voice in cochlear implanted children

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Abstract

Objective: To investigate the effect of cochlear implantation on articulation by using voice- onset time (VOT).

Methods: At the first phase of this study, a total of 25 children without hearing loss were examined. VOT values of Turkish plosive consonants of /p/, /b/, /t/, /d/, /k/, /g/ specific to this age group were estimated, and their standardization was achieved. To this end, Kay Elemetrics CSL 4400 software (Key Elemetrics Ltd, Lincoln Park, NJ, USA) was used. Referencing these VOT values, 40 children ages ranging between 4 and 11 years who underwent cochlear implantation in our clinic were divided into six groups based on the duration of cochlear implantation, and VOT values were determined in these groups. These groups were compared within themselves, and with healthy children.

Results: VOT values of consonants increased as the duration of cochlear implantation increased and approached to those of the children with normal hearing, and at the end of four years of cochlear implant use, they caught up with those of the normal hearing group.

Conclusion: Our results have shown that early stage implantation, and use of implant for an adequate time period have a favorable impact on articulation in other words on comprehensibility of speech. We thought that VOT can be use in the evaluation of the effect of cochlear implant on the development of speech.

Keywords: Articulation, cochlear implantation.

Özet: Koklear implantlı çocuklarda sesin artikülasyon özelliklerinin değerlendirilmesi

Amaç: Çalışmanın amacı, koklear implantasyonun artikülasyona olan etkisini *voice onset time* (VOT) kullanarak araştırmaktır.

Yöntem: Bu çalışmanın ilk aşamasında işitme kaybı olmayan 25 çocuk ele alındı. Bu yaş grubuna ait /p/, /b/, /t/, /d/, /k/, /g/ Türkçe patlayıcı ünsüzlerinin VOT değerleri hesaplandı ve standardizasyon sağlandı. Bu amaç için Kay Elemetrics CSL 4400 (Key Elemetrics Ltd, Lincoln Park, NJ, ABD) programı kullanıldı. Bu VOT değerleri referans alınarak kliniğimizde koklear implant yapılmış olan ve yaşları 4–11 arasında değişen 40 çocuk, koklear implantasyon süresi baz alınarak 6 gruba ayrıldı ve bu gruplarda VOT çalışıldı. Bu gruplar hem kendi içerisinde hem de sağlıklı çocuklar ile karşılaştırıldı.

Bulgular: İmplant kullanım süresi arttıkça ünsüzlerin VOT değerlerinin yükselerek normal işiten çocuklara yaklaştığı, 4 yıl ve üzeri koklear implant kullanımı sonunda bu değerlerin normal grubu yakaladığı görüldü.

Sonuç: Bulgularımız erken implantasyonun ve yeterli süre implant kullanımının artikülasyon yani konuşmanın anlaşılabilirliği üzerine olumlu bir etkisi olduğunu gösterdi. Koklear implantın konuşma gelişimi üzerine olan etkisinin değerlendirilmesinde VOT'un kullanılabileceğini düşündük.

Anahtar sözcükler: Artikülasyon, koklear implantasyon.

Voice onset time (VOT) serves as an inferential appraise of speech motor control, necessitating delicate motor coordination of the articulatory, phonatory, and respiratory components.[1–3] VOT is an acoustic parameter described as the duration amongst the delivery of the oral constriction for plosive production and the beginning of vocal fold vibrations.[2,4] Amounts of VOT before the relief are specified as negative numbers and named a voicing lead, although after the release are specified as positive numbers and named voicing lag. If relief and voicing are synchronized, VOT is zero.[4] Negative VOT scores stand for vocal fold vibration before the release of the oral constriction and are related with the phrase pre-voicing. Zero VOT characterizes the beginning of the vocal fold vibration synchronized to the

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relief of the oral constriction. Positive VOT is correlated with the inception of vocal fold vibration after the release of oral constriction.[2] It is believed that VOT is effectual sign of subtle articulatory and phonatory interaction changes in speech production.[2] Hearing loss is a feature which can affect the significance of VOT.[4,5]

Since VOT is a useful method for documenting the articulatory-phonatory aspects during the speech, we investigated and compared VOT values for Turkish stop consonants in healthy children and children with cochlear implant (CI) to clarify the effect of CI and sequential hearing rehabilitation over VOT values.

Materials and Methods

All procedures performed in studies involving human participants complied with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

A total of 40 prelingual patients (18 female and 22 male) with CI and 25 healthy children (13 female and 12 male) were recruited for VOT analysis. All patients were using unilateral CI. None of the children in the control group had any hearing loss and speaking or understanding difficulties. The sound analysis was explained verbally to each child's family, and written consents were obtained for all of the patients and healthy children tested. Patients who underwent CI were between the ages of 2 and 4 years at the moment of implantation. During the study period, the ages of the children with CI were from 4 to 11 (7.075±2.017) years, while the ages of the children in the control group were 5 to 11 (8.04±1.74) years.

All patients were using their CI for at least one year and made regular visits to a rehabilitation center. All cases included in the study had multi-channel CI. The fittings for all patients were done at 4–6 weeks after surgery.

There is only one study in the literature that addresses the VOT analysis on children in the Turkish language. Therefore, in the first part of our study, we analyzed the VOT values for plosive consonants in children with normal speech and language development. The following words were used for that purpose: /pas/, /bal/, /taş/, /dam/, /kas/, /gaf/. The audio recordings were taken in a semi-soundproof room using Carol brand MUD-316 IMP.600 model microphone (Carol Brand, Highland Heights, KY, USA), which was placed 5cm away from the child's mouth. The individual VOT values of the following sounds /p/, /b/, /t/, /d/, /k/, /g/ were recorded onto spectrographic display with a wide-band spectrogram by using Kay Elemetrics CSL 4400 (Key Elemetrics Ltd, Lincoln Park, NJ, USA).

In the second part of our study, we studied a total of 40 patients with prelingual hearing loss. The microphone was placed 5cm away from the patients' mouth and those that could read were asked to read the following words: /pas/, /bal/, /taş/, /dam/, /kas/, /gaf/. For the subjects who could not read, they were asked to repeat the same words. The words were repeated by the same person. All audio was recorded digitally by using a computer. The VOT values of the sounds /p/, /b/, /t/, /d/, /k/, /g/ were measured in the wideband spectrogram by the procedures suggested by Lisker and Abramson.[6] In particular, time starting with energy burst corresponding to the relaxation of articular constriction and ending with the first vertical line of the regularly localized vocal cord vibrations was monitored.

The patients with the implants were divided into 6 groups according to the duration of implant use: 1 year, 2 years, 3 years, 4 years, 5 years, and >5 years. All groups were then compared to the control group in terms of VOT values for the sounds /p/, /b/, /t/, /d/, /k/, /g/. We investigated whether there was a correlation between duration of cochlear implant use and VOT values of the letters.

Statistical analysis

The MedCalc statistical software (MedCalc Software, Ostend, Belgium) was used for statistical analysis. Mann-Whitney U test (independent samples), frequency table and chi-square test were used. Pearson correlation analysis was performed. $P<0.05$ was considered significant.

Results

There was no significant difference between the groups in terms of age and gender ($p=0.0590$ and $p=0.8592$, respectively).

In the first part of our study, the VOT values of /p/, /b/, /t/, /d/, /k/, /g/ sounds were identified from the children in the control group. The VOT values obtained from control group are shown in Table 1, while the average VOT values are shown in Table 2.

In the second part of our study, children with cochlear implants were divided into six groups based on the duration of the implant use: 1 year, 2 years, 3 years, 4 years, 5 years and over 5 years. In each case, the VOT values were measured separately for the sounds /p/, /b/, /t/, /d/, /k/, /g/. Table 3 summarizes the VOT values obtained in all cases with cochlear implants.

Table 1. The voice-onset time values of patients in the control group.

No	Age	Sex	/p/	/b/(-)	/t/	/d/(-)	/k/	/g/(-)
1	7	Male	82	57	74	61	82	94
2	7	Male	83	62	85	59	82	96
3	8	Female	89	67	84	66	82	92
4	9	Female	73	62	85	62	82	96
5	10	Male	79	67	74	51	82	92
6	6	Female	83	61	85	53	89	95
7	8	Male	79	67	74	71	88	91
8	7	Male	83	63	86	63	83	95
9	10	Male	79	67	73	59	82	91
10	5	Female	84	43	85	61	82	96
11	11	Male	79	67	74	58	82	96
12	10	Female	83	62	82	52	82	96
13	9	Female	79	68	84	60	89	92
14	6	Male	82	63	88	62	88	96
15	6	Female	79	67	74	61	87	92
16	5	Female	83	62	85	62	84	96
17	9	Female	82	63	88	61	82	92
18	8	Male	83	64	81	61	85	95
19	8	Female	84	65	81	61	85	95
20	7	Female	81	64	81	65	86	94
21	7	Male	83	65	84	62	85	95
22	8	Male	86	67	83	62	86	96
23	9	Male	87	67	86	65	82	91
24	10	Female	79	63	81	61	83	93
25	11	Female	79	61	80	60	84	96

When we compared the VOT values of /p/, /b/, /t/, /d/, /k/, /g/ sounds of patients using the implants for 1 year with the control group, there was a statistically significant difference ($p<0.05$). In addition, the VOT values of /p/, /b/, /t/, /d/, /k/, /g/ sounds of patients using the implants for 2 years were significantly different from the control group ($p<0.05$). Furthermore, the VOT values of /p/, /b/, /t/, /d/, /k/, /g/ sounds of patients using the implants for 3 years were also significantly different from the control group ($p<0.05$). The VOT values of /p/, /t/, /k/, /g/ sounds of patients using the implants for 4 years were significantly different from the control group ($p<0.05$). However, the VOT values of /b/ and /d/ sounds were not significantly different from the control group ($p<0.05$). For patients using the implants for 5 years, the VOT values of /p/, /b/, /t/, /d/, /k/ sounds were not significantly different from the control group ($p<0.05$). However, the VOT value for /g/ sound was significantly different in the 5-year group compared to the control group ($p<0.05$) (Tables 4 and 5).

The VOT values of /b/, /t/, /d/, /g/ sounds of patients using the implants for more than 5 years were not significantly different from the control group ($p<0.05$). However, the VOT value for /p/ and /k/ sounds were significantly different from the control group ($p<0.05$).

The VOT values for /p/ sound were significantly different in the first 4 groups compared to the control group ($p<0.05$). The VOT values for /p/ sound increased with duration of implant use, but they only reached the values of the children from the control group following 5-year use of implant. However, in patients who used the cochlear implants for more than 5 years, the VOT value of /p/ sound were significantly different from the control group ($p=0.0474$).

Table 2. The mean voice-onset time values of control group.

	Mean voice-onset time value
/p/	81.72±3.27 ms
/b/	63.36±5.03 ms
/t/	81.48±4.84 ms
/d/	60.76±4.22 ms
/k/	84.16±2.47 ms
/g/	94.12±1.92 ms

Table 3. The voice-onset time values of patients with cochlear implants.

No	Age	Sex	Duration of implant	/p/	/b/(-)	/t/	/d/(-)	/k/	/g/(-)
1	5	Male	1 year	52	55	56	50	66	68
2	5	Male	1 year	55	58	51	58	65	55
3	4	Female	1 year	53	48	48	59	57	49
4	5	Male	1 year	48	43	52	37	65	35
5	5	Female	1 year	43	40	58	34	61	56
6	4	Male	1 year	48	43	48	56	45	45
7	5	Male	1 year	51	44	55	51	75	44
8	5	Male	1 year	49	52	56	56	69	55
9	4	Female	1 year	54	47	60	49	77	56
10	5	Female	1 year	44	60	61	58	70	43
11	4	Female	2 years	56	44	50	49	67	61
12	6	Male	2 years	44	48	52	48	72	68
13	6	Female	2 years	52	52	58	45	61	63
14	6	Male	2 years	51	49	53	47	66	64
15	6	Male	2 years	55	49	54	48	67	64
16	6	Male	3 years	59	54	50	47	60	65
17	7	Male	3 years	54	49	59	46	54	59
18	7	Female	3 years	59	51	53	50	63	71
19	7	Female	3 years	52	44	61	56	68	59
20	6	Male	3 years	62	58	62	57	72	69
21	7	Female	4 years	69	55	59	62	61	75
22	8	Female	4 years	77	51	50	64	63	77
23	8	Male	4 years	74	56	50	62	62	72
24	7	Female	4 years	69	49	44	58	73	80
25	7	Male	4 years	55	69	54	67	69	73
26	8	Male	4 years	68	71	58	62	75	69
27	9	Male	5 years	76	65	82	67	75	87
28	9	Male	5 years	79	70	79	68	79	88
29	9	Female	5 years	78	63	80	61	85	89
30	9	Male	5 years	76	59	86	56	88	92
31	9	Female	5 years	82	72	84	58	87	87
32	8	Female	5 years	89	68	79	70	89	87
33	8	Male	5 years	81	79	87	71	76	91
34	10	Male	6 years	87	69	60	57	78	89
35	9	Female	6 years	87	84	84	56	76	93
36	8	Female	7 years	88	75	78	65	81	86
37	10	Male	7 years	79	76	86	76	80	99
38	11	Female	7 years	87	65	88	58	86	98
39	11	Female	8 years	85	57	91	76	81	87
40	10	Male	8 years	80	51	87	71	92	91

The VOT values of /b/ sound approached the VOT values of the control group after 4 years of implant use. Moreover, in patients with 4 years, 5 years, and over 5 years of implant use, the VOT values were not significantly different from the control group ($p>0.05$).

The VOT values of /t/ sound of patients with the implant approached the VOT values of the control group after 5 years of implant use. There was no significant difference between the patients from the control group and the patients who had implants for 5 years and more than 5 years ($p>0.05$).

In patients using implant for 4 years, the VOT values of /d/ sound have reached the VOT values of the control group. There was no significant difference in VOT values between the control group patients and patients who have had the implant for 4, 5, and more than 5 years ($p>0.05$).

The VOT values of /k/ sound in the first four groups were significantly different compared to the control group (p<0.05). The VOT values of /k/ sound approached the control group's VOT values when the patients used the implants for at least 5 years. In patients using the cochlear implant for more than 5 years, the VOT values of /k/ sound were statistically different from the control group (p=0.440).

When the VOT values of /g/ sound were analyzed, we got the following results: for the patients who used the implants for less than 5 years, the VOT values were not significantly different from the control group (p<0.05); with over 5 years of implant use, the VOT values of /g/ sound have reached those of the control group (p>0.05).

There was a positive correlation between the increase in duration of implant use and VOT values for /p/, /b/, /t/, /d/, /k/, /g/ sounds (p<0.0001).

In addition, when we compared the increase of age to VOT values of all sounds, we found that they were positively correlated (p<0.0001).

The frequency table and chi-square test that were done to compare the VOT values in terms of the gender did not show any significant difference (p=0.8592).

In all patients that used the cochlear implant for 1, 2, and 3 years, the VOT values were significantly different than those of the control group (p<0.05).

With up to a 4-year use of the implant, the VOT values of /b/ and /d/ sounds reached the VOT values of the control group. In groups that used the implant for 4 years, 5 years, and more than 5 years, the VOT values of /b/ and /d/ sounds were statistically indistinguishable from the control group (p>0.05).

With the use of a cochlear implant for 5 years, the VOT values of /p/, /t/, /k/ sounds reached the VOT values of the control group. However, in the group that used the implant for more than 5 years, the VOT values of /p/ and /k/ sounds were significantly different from the control group (p=0.0474 and p=0.0440, respectively). Meanwhile, the VOT value of /t/ sound in patients that used the implants for 5 years and more than 5 years were statistically indistinguishable from the control group (p>0.05).

Table 4. The mean voice-onset time values patients with implant.

	/p/	/b/(-)	/t/	/d/(-)	/k/	/g/(-)
Control group	81.72	63.36	81.48	60.76	84.16	94.12
1 year	49.7	49	54.5	50.8	65	50.6
2 years	50.66	48.4	53.4	47.4	66.66	64
3 years	57.2	51.2	57	51.2	63.4	64.6
4 years	68.66	58.5	52.5	62.5	67.16	74.33
5 years	80.14	68	82.42	64.42	82.71	88.71
>5 years	84.71	68.14	82	65.57	82	91.85

In patients with more than 5 years of implant use, only the VOT value of /g/ consonant was able to reach that of the control group. In patients with over 5 years of implant use, the VOT value of /g/ sound was statistically indistinguishable from the control group (p>0.05).

The VOT values of /p/ sound in the first four groups were significantly different when compared with the control group (p<0.05). VOT values of /p/ sound increased with duration of implant use, but only reached the VOT values of the control group following the 5-year implant use. However, in patients using CI for over 5 years, the VOT value of /p/ sound was significantly different from the control group (p=0.0474).

The VOT values of /b/ sound in patients who used the implant for up to 4 years reached the VOT values of the patients in the control group. In patients who used the implants for 4 years, 5 years and more than 5 years, there was no significant difference in the VOT values of /b/ sound compared to the control group's VOT values (p>0.05).

Table 5. Comparison of the mean VOT values of CI patients and the control group.

Duration	/p/	/b/(-)	/t/	/d/(-)	/k/	/g/(-)	Number of patients
1 year	p<0.0001	p<0.0001	p<0.0001	p=0.0001	p<0.0001	p<0.0001	10
2 years	p=0.004	p=0.0013	p=0.0005	p=0.0005	p=0.0004	p=0.0004	5
3 years	p=0.0004	p=0.0015	p=0.0005	p=0.0015	p=0.0004	p=0.0004	5
4 years	p=0.0002	**p=0.2906**	p=0.0002	**p=0.1895**	p=0.0001	p=0.0002	6
5 years	**p=0.1170**	**p=0.0735**	**p=0.9272**	**p=0.2156**	**p=0.8349**	p=0.0002	7
>5 years	p=0.0474	**p=0.1689**	**p=0.2171**	**p=0.3971**	p=0.0440	**p=0.2055**	7

Furthermore, patients' VOT values of /t/ sound reached those of the control group only after 5 years of implant use. However, patients who used the implants for 5 years and more than 5 years did not show any significant difference in terms of the VOT values compared to the control group ($p>0.05$).

Next, patients' VOT values of /d/ sound reached those of the control group with the 4-year implant use. There was no significant difference between the control group and patients who used the implants for 4 years, 5 years, and more than 5 years ($p>0.05$).

In patients who used the implants for 1, 2, 3, and 4 years, the VOT values of /k/ sound were significantly different from the control group ($p<0.05$). With the 5-year implant use, the VOT values of /k/ sound have reached those of the control group. However, the use of cochlear implants for more than 5 years resulted in significant differences from the control group's VOT values of /k/ sound ($p=0.440$).

Lastly, there was a significant difference in VOT values of /g/ sound between patients who used the implants for less than 5 years and the control group ($p<0.05$). With over 5 years of implant use, the VOT values of /g/ sound reached those of the control group ($p>0.05$).

Discussion

The relation between hearing and speaking has been known for many years. Partial or total hearing loss affects the speech and acoustic parameters. VOT is one of the objective acoustic parameter and a useful non-invasive method for documenting the articulatory-phonatory aspects during a speech.[2] VOT is effected by some factors including physiological differences (age, gender, lung volume, vocal fold tension), pathological diseases (hearing loss, depression) and different linguistic status (speech task, speech rate, phoneme environment).[4,5] VOT values are different between languages because of their differences in structure due to originating from different language families.[4,7] There are few studies which reported about VOT in cochlear implant users. Most of them have focused on English language analysis. One of the recent studies in other languages compared 15 Hindi-speaking CI children with 15 normal hearing age matched peers.[8] They measured VOT and other acoustic parameters using words including /e/, /i/, /u/ vowels and VOT values for /p/ and /b/. They found significant differences in VOT for /b/ in Hindi speaking children. Grandon et al. reported VOT values for French-speaking CI children comparing with 13 CI users and 20 children with normal hearing.[9] They compared /p/, /t/, /k/, /b/, /d/, /g/ sounds and significance reached only for /k/. The present study, as far as we know, is including the largest number of cochlear implant users.

In our previous study, we investigated VOT values for Turkish stop consonants in adult CI patients to clarify the effect of CI and sequential hearing rehabilitation over voice onset time values and revealed that VOT may be an effective measure for examining the effect of CI over the articulatory accuracy.[7]

The speaking and understanding skills continued to increase with the use of the implant for approximately four years after the cochlear implantation operation in children with prelingual hearing loss.[10–18] For this reason, the early diagnosis of a hearing loss is very important for the child's auditory rehabilitation. Our study is the first one determining the VOT values of Turkish plosive consonants in this population.

Ogut et al. reported that gender did not affect the VOT values.[4] Similarly, we did not observe any statistically significant difference between boys and girls regarding VOT values. All children participating in the study were prepubertal. For our audio recordings, we only used the following words that had a letter /a/ following the plosive consonants: pas/, /bal/, /taş/, /dam/, /kas/, /gaf/. We did not use words with other vowels. This decision was based on the studies performed by Ogut et al. and because children quickly get bored during the long-term voice recordings.[4] So we preferred letter /a/, but other vowels can be used in the further studies.

All children participating in our study had the cochlear implants for at least 1 year and regularly visited our cochlear implant training center. In our study, we determined that with prolonged implant use, e.g. 4 years and more, the VOT values are getting closer those of the control group. The first two sounds that reached the control groups' VOT values were /b/ and /d/ sounds. The VOT values of /b/ and /d/ sounds in patients that used the implants for 4 years, 5 year, and more than 5 years were not significantly different from those of the control group ($p>0.05$).

With the 5-year use of implants, the VOT values of /p/, /t/, /k/ sounds also reached the VOT values of the control group. However, the VOT values of /p/ and /k/ sounds in patients who used the implants for more than five years were significantly different from the control

group (p=0.0474 and p=0.0440, respectively). The duration of implant use and the age at the time of the operation are important factors in the success of the cochlear implant. The results showed that up to 5-year implant use, VOT values of /p/ and /k/ sounds reached the VOT values of the control group. However, more than 5-year use resulted in the VOT values that were significantly different from the control group. This might be due to patients' differences. In patients that used the implants for more than five years, only /g/ sound had the VOT values similar to the control group.

Patients with cochlear implants had the most difficulty with /k/ and /g/ letters during the audio recordings. This might be because the children were not familiar enough with the words used in this test. In some cases, the children in the control group also had difficulties with the letter /g/. For the most part, the easiest letters to say were /p/ and /b/. All children pronounced the words /pas/ and /bal/ very easily. In addition, they did not have difficulties with the letters /t/ and /d/. It was thought that the least amount of mistakes was done with /p/ and /b/ because articulation of these bilabial sounds (p, b) can be seen.

The increase in the duration of implant use might have positive effects on voice development. In particular, patients demonstrated an increase in the ingress of the auditory information and sensitization to the electrical stimulation from the cochlear implant. All patients participating in the study received the same training at the same center.

As a result, we determined that the use of cochlear implant for at least 4 years resulted in VOT values that reach those of the control group. The age at the time of the operation and the duration of implant use are important factors in the success of the CI. The patients' VOT values of /p/ and /k/ sounds caught up to the VOT values of the control group when the implant was used for at least 5 years. Moreover, the fact that the VOT values of the patients who used the implant for more than 5 years were significantly different from the control group's VOT values might be due to patients' individual characteristics. We determined that the increased duration of implant use was associated with an increase in the VOT values of the letters. In addition, there was a positive correlation between the VOT values and increasing age. In both the control group and the patient groups, age did not have an impact on the VOT values.

Conclusion

This study is the first one to determine the VOT values of Turkish plosive consonants in children with normal hearing. With the increased duration of CI, the VOT values of Turkish plosive consonants increase and reach to those of the control group. Moreover, we showed that there was no significant relationship between the VOT values and the gender. Early implantation and adequate time of implant use may show positive effects on speech and articulation. Furthermore, VOT values can be used as an objective method in the follow-up of implant efficiency. It should also be kept in mind that the we performed our study in Turkish language which is a member of ugric language family.

Conflict of Interest: No conflicts declared.

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