Kulak Burun Boğaz ve Baş Boyun Cerrahisi Dergisi
Journal of Ear Nose Throat and Head Neck Surgery
KBB ve BBC Dergisi. 2022;30(4):207-15

ORİJİNAL ARAŞTIRMA ORIGINAL RESEARCH

DOI: 10.24179/kbbbbc.2022-91142

Static and Dynamic Equilibrium and Postural Control in Adults with Cochlear Implants

Koklear İmplantlı Erişkinlerde Statik ve Dinamik Denge ve Postüral Kontrol

Hatice Kübra BOZKURT[a], Mehmet YARALI[a], Songül AKSOY[a]

[a]Department of Audiology, Hacettepe University Faculty of Health Sciences, Ankara, Türkiye

ABSTRACT Objective: Cochlear implantation is associated with vestibular impairment due to the close proximity of vestibular structures. This study aimed to explore the postural control of unilateral cochlear implant (CI) users compared to participants without hearing loss. **Material and Methods:** Twenty unilateral CI users and 20 healthy individuals with normal hearing were included in the study. Static posturography test (Modified Clinical Test of Sensory Interaction in Balance, Limits of Stability Test, Rhythmic Weight Shift Test, Weight Bearing Squat Test, Unilateral Stance Test, Sit To Stand Test, Walk Across Test, Tandem Walk Test, Step Quick Turn Test, Step Up Over Test and Forward Lunge Test), which includes both static and dynamic balance parameters, was applied to the participants. In order to assess subjective balance, Berg Balance Scale, Dizziness Handicap Inventory and Vestibular Disorders Activities of Daily Living Scale were used. **Results:** Results of objective and subjective tests of postural control were significantly weaker in CI users compared to control group ($p<0.05$). Results of different tests revealed that CI users are negatively affected in static and dynamic components of postural control. **Conclusion:** As the results show that CI users performed worse than control group on the subjective and objective balance parameters, exploration of standing balance is important in CI users.

Keywords: Balance; cochlear implant; posturography; vestibular function

ÖZET Amaç: Koklear implantasyon (KI), vestibüler yapılara yakınlığı nedeniyle vestibüler bozukluk ile ilişkilendirilir. Bu çalışma, tek taraflı KI kullanıcılarının, işitme kaybı olmayan katılımcılarla postüral kontrolünü karşılaştırmayı amaçladı. **Gereç ve Yöntemler:** Yirmi tek taraflı KI kullanıcısı ve normal işiten 20 sağlıklı birey çalışmaya dâhil edildi. Katılımcılara hem statik hem de dinamik denge parametrelerini içeren statik posturografi testi (Modifiye Denge Duyu İnteraksiyonu Klinik Testi, Stabilite Sınırları Testi, Ritmik Ağırlık Aktarma Testi, Ağırlık Aktarma Çömelme Testi, Tek Taraflı Duruş Testi, Otur Kalk Testi, Düz Yürüme Test, Tandem Yürüyüş Test, Adım Hızlı Dönme Testi, Adım Yukarı Aşağı Testi, Öne Hamle Testi) uygulandı. Subjektif dengeyi değerlendirmek için Berg Denge Ölçeği, Baş Dönmesi Engellilik Envanteri ve Vestibüler Bozukluklarda Günlük Yaşam Aktiviteleri Ölçeği kullanıldı. **Bulgular:** KI kullanıcılarında postüral kontrolün objektif ve subjektif testlerinin sonuçları, sağlıklı bireylere kıyasla önemli ölçüde daha zayıftı ($p<0,05$). Bu testlerin sonuçları, KI kullanıcıların da postüral kontrolün statik ve dinamik bileşenlerinden olumsuz etkilendiğini ortaya koydu. **Sonuç:** Çalışmada, KI kullanıcılarının subjektif ve objektif denge parametrelerinde kontrol grubundan daha kötü performans göstermesi, KI kullanıcılarında ayakta dengenin araştırılmasını önemli kılmaktadır.

Anahtar Kelimeler: Denge; koklear implant; posturografi; vestibüler fonksiyon

More than 300 million people worldwide are affected by hearing loss, and over 300,000 patients have received a cochlear implant (CI).[1] CIs are electronic prosthesis that feature a multichannel electrode array that is inserted in the cochlea and delivers hearing by electrically activating neural regions. Cochlear implantation has been an approved treatment for treating significant, bilateral sensorineural hearing loss since the mid-1980s.[2]

Some CI users report dizziness during the postoperative period, which sparked an interest in the relationship between CI and vestibular function. Since then, many studies have reported a relationship between cochlear implantation and vestibular dysfunction.[3,4] The incidence of vestibular complaints ranges from 0.33% to 74%, which is a vast probability range.[5] Numerous studies have investigated the effect of CI surgery on the vestibular system. However, few

Correspondence: Hatice Kübra BOZKURT
Department of Audiology, Hacettepe University Faculty of Health Sciences, Ankara, Türkiye
E-mail: odyhkbozkurt@gmail.com

Peer review under responsibility of Journal of Ear Nose Throat and Head Neck Surgery.

Received: 05 May 2022 ***Accepted:*** 28 Jun 2022 ***Available online***: 02 Aug 2022

studies include evaluations that are performed using posturography. Buchman et al. for example, used pre- and postoperative computerized dynamic posturography to assess vestibular function in CI users. Moreover, the vestibular functions of CI users were evaluated with devices in the on and off positions. This work revealed the positive effects of activation of the CI on postural sway.[6] Brey et al. found a non-significant difference in computerized dynamic posturography findings before and after the implantation; in particular, only a slight difference was identified between condition 5 (eyes closed- sway referenced) and 6 (eyes open- visual and sway-referenced).[7] These results are similar to those presented by Buchman et al. Gao et al. found that there was no substantial difference between posturographic parameters of control and CI groups but the performance difference between most of the balance parameters in CI groups before and after surgery was quite significant.[6-8]

To sum up, it can be stated that cochlear implantation may have an effect on postural control in CI users. The goal of this study was to examine the postural sway and balance functions of CI users, as well as to assess the static and dynamic balance of CI users.

MATERIAL AND METHODS

Twenty CI users (study group) using their implants for at least 1 year (12 male, 8 female; age range 18-63 years) and satisfying the required conditions (normal vision, no additional problems that will cause dizziness and balance disorder, no neurological problems, normal radiological findings in terms of an inner ear anomaly), and 20 healthy individuals (7 male, 13 female; range 20-66 years) over the age of 18 (control group) who did not have any problems regarding their vestibular system participated in the study. Fifteen of the CI users had their implants on the right ear and the 5 users had CIs on the left ear. The university's non-invasive clinical research ethical council authorized the study procedure, and all subjects submitted written informed consent. The research was carried out in line with the Declaration of Helsinki. The Hacettepe University Non-invasive Clinical Research Ethics Committee approved the study with the registration number GO 18/115 (date: January 31, 2018).

POSTURAL CONTROL MEASURES

The Neurocom Balance Master Static Posturography device was used for an objective evaluation of postural control (NeuroCom, Clackamas, OR, USA). Three static balance tests [modified clinical test of Sensory Interaction in Balance (mCTSIB), Weight Bearing/Squat (WBS), Unilateral Stance (US)] and 8 dynamic balance tests [Limits of Stability (LOS), Rhythmic Weight Shift (RWS), Sit To Stand (STS), Walk Across (WA), Tandem Walk (TW), Step/Quick Turn (SQT), The Step Up/Over (SUO), Forward Lunge (FL)] were performed on the Balance Master.

A mCTSIB provided objective information regarding sensory balance problems. Three trials were carried out on each of the 4 positions, which were: Eyes closed on foam and firm surface; Eyes open on foam and firm surface. Every trial lasted 10 seconds.

Using LOS, voluntary motor control performance was evaluated. Eight targets were put on the test screen, each tilted 45 degrees.

RWS enabled us to determine the numerical values of the ability of individuals to transfer their center of gravity toward right-left (lateral) and front-back (anterior-posterior) directions at 3 different velocities (slow, medium, fast). The velocities equaled slow 3 seconds, medium 2 seconds and fast 1 second.

Using the WBS, the rate of body weight that is transferred on the feet in 4 different positions, which were: knee extension of 0° and knee flexions of 30°, 60° and 90° were measured.

During the US test, the individuals stood on one foot with their hands on their hips. The test was repeated 6 times, 3 times with open eyes and 3 times with closed eyes.

In the STS test, it is possible to measure balance parameters as objective data that are determined while individuals stand from a sitting position. For this test, the individuals are requested to sit on a platform, which was designed to give 90°/90° flexion on their hips and on their knees. They are requested to participate in 3 tests and the average is calculated.

The WA test enabled us to evaluate the balance parameters objectively that present themselves while the individuals walk. The individuals are requested to perform the test 3 times and the findings are evaluated as 4 parameters.

In the TW test, the individuals are requested to make sequential steps (tandem) to walk along the power platform during the test and thus, the balance parameters of the walk are determined objectively. The test is completed over 3 trials.

The SQT test enables us to objectively evaluate the balance parameters of motion performance of the individual as the participant rapidly turns 180 degrees from left and from right.

The SUO test enables us to objectively evaluate balance parameters that present themselves as the individual passes over a stair or a high obstacle. The height of the stair (10, 20 or 30 cm) is determined according to the individual. The participants are requested to perform three separate repetitions for each foot.

The FL test enabled us to objectively evaluate the balance parameters that present themselves as the individual makes a forward move with one leg and then returns back to the standing position. Three separate repetitions were performed for each foot.

In order to evaluate the complaints about balance problems, different scales were used. The scales determine the level of symptoms, the obstacles encountered (depending on the problem) and life quality. Berg Balance Scale, The Dizziness Handicap Inventory (DHI), Vestibular Disorders Activities of Daily Living (VADL) Scale were used for a subjective evaluation of postural control.

DHI consists of 25 articles that are aimed to determine the dizziness in patients and the factors that affect balance disorders along with emotional and functional outcomes vestibular system illnesses. The sub-scales are aimed to determine the physical, emotional and functional effects of vestibular system illnesses. The scoring is as follows: yes 4 points; sometimes 2 points and no 0 points.[9]

VADL consists of 28 articles and 3 sub-dimensions. Sub-dimensions are labeled as: functional-F, ambulation-A and instrumental. The activity that is performed on the scale is scored from 1 to 10, where 1 corresponds to totally dependent activity and 10 corresponds to totally independent activity.[10,11]

The Berg Balance Scale consists of 14 different activities that measure the ability of the participant to maintain balance in different positions and during postural changes. The individual's ability to perform every activity independently and/or in a limited timeframe or over a certain distance was evaluated. The scaling was done between 0 and 4 and the execution was completed in 15-20 minutes.[12]

STATISTICAL ANALYSIS

The data's conformity to normal distributions was analyzed using the Kolmogorov-Smirnov test. For inter-group comparisons, Student's t-test and Mann-Whitney U test was utilized. For all analyses, the threshold to determine significance was $p \leq 0.05$.

RESULTS

The descriptive data from 20 CI users and 20 healthy individuals are shown in Table 1. There were no statistically significant differences between the groups in terms of gender or age ($p>0.05$).

THE DIFFERENCES IN POSTURAL CONTROL PARAMETERS BETWEEN GROUPS

Table 2 summarizes the results of all postural tests. In mCTSIB parameters, the foam surface (eyes open/closed) condition score and the combined balance score were significantly better in healthy adults than in CI group ($p<0.05$) (Figure 1).

Statistically significant differences were found for LOS test in the anterior, right anterior, right lateral, left, left lateral transitional parameters ($p<0.05$). The sub-parameter of this test, reaction time, was significantly better in healthy adults than in CI group ($p<0.05$).

TABLE 1: Baseline characteristics.

	Patients $\bar{X}$±SD (n=20)	Controls $\bar{X}$±SD (n=20)	p value
Age (years)	31.8±15.2	29.9±14.2	p>0.05
Gender (female/male)	8/12	13/7	p>0.05
Implant side (right/left)	15/5		
Duration of implant use (years)	10.3±4.9		

p<0.05.

TABLE 2: Static posturography test results.

		Study X̄±SD (n=20)	Control X̄±SD (n=20)	p value
mCTSIB (deg/sec)	EO Firm	0.23±0.14	0.26±0.14	0.54
	EC Firm	0.27±0.29	0.24±0.09	0.46
	EO Foam	0.68±0.55	0.51±0.16	0.040*
	EC Foam	2.51±1.8	0.77±0.16	0.000*
	Composite	0.94±0.63	0.46±0.10	0.002*
LOS	RT (sec)	1.27±0.64	1.06±0.49	0.26
Anterior	MVL (deg/sec)	2.98±1.98	3.83±1.92	0.17
	EPE (%)	75.3±26.7	90.7±16.1	0.034*
	MXE (%)	90.4±23.1	102.5±8.4	0.035*
	DCL (%)	83.5±10.2	84.6±12.2	0.77
LOS	RT (sec)	0.95±0.62	0.6±0.25	0.026*
Right-anterior	MVL (deg/sec)	4.68±1.81	6.05±2.92	0.08
	EPE (%)	83±23.8	93.1±31.3	0.26
	MXE (%)	102.3±12.8	109.1±8.3	0.05*
	DCL (%)	77.8±14.2	79.5±9.02	0.64
LOS	RT (sec)	1.21±0.61	0.8±0.36	0.014*
Right-lateral	MVL (deg/sec)	4.83±2.48	6.51±3.48	0.08
	EPE (%)	71.4±16.4	86.4±16.1	0.006*
	MXE (%)	100.1±10.6	101.8±5.63	0.53
	DCL (%)	78.5±11.8	85.6±5.1	0.019*
LOS	RT (sec)	1.05±0.56	0.84±0.43	0.18
Right-posterior	MVL (deg/sec)	3.49±1.76	4.45±1.77	0.09
	EPE (%)	59.2±19.83	73.5±24.64	0.05*
	MXE (%)	84.3±20.22	89.5±10.35	0.31
	DCL (%)	52.2±27.1	55.4±19.70	0.67
LOS	RT (sec)	0.93±0.45	0.88±0.39	0.70
Posterior	MVL (deg/sec)	2.64±1.51	2.94±1.04	0.47
	EPE (%)	48.7±18.5	50.6±17.1	0.73
	MXE (%)	69.2±23.7	72.1±12.2	0.62
	DCL (%)	54.9±31.8	63.7±20.3	0.30
LOS	RT (sec)	0.94±0.57	0.73±0.4	0.19
Left-posterior	MVL (deg/sec)	4.02±1.91	6.2±3.05	0.008*
	EPE (%)	78.5±28.07	92.2±20.8	0.08
	MXE (%)	95.6±24.9	104.5±15.1	0.18
	DCL (%)	59.2±24	56.2±22	0.68
LOS	RT (sec)	1.14±0.55	0.72±0.49	0.015*
Left-lateral	MVL (deg/sec)	4.98±1.59	8.43±4.23	0.002*
	EPE (%)	72.9±23.4	94.6±11.3	0.001*
	MXE (%)	92.4±17.8	103.7±7.7	0.013*
	DCL (%)	77.8±18.04	80.7±9.09	0.51
LOS	RT (sec)	1.08±0.43	0.72±0.33	0.006*
Left-anterior	MVL (deg/sec)	4.96±2.49	6.72±2.16	0.022*
	EPE (%)	81.6±23.5	99.5±17.9	0.010*
	MXE (%)	98.6±13.09	107.3±8.4	0.017*
	DCL (%)	73.3±15.1	79.9±9.7	0.11
RWS	Slow	3.18±0.62	3.0±0.31	0.25
Left-right	Medium	4.20±1.11	4.56±0.58	0.20
On-axis velocity (deg/sec)	Fast	6.92±1.37	7.82±2.08	0.11
	Composite	4.77±0.76	5.13±0.76	0.14

continue →

TABLE 2: Static posturography test results *(continue).*

		Study $\bar{X}$±SD (n=20)	Control $\bar{X}$±SD (n=20)	p value
RWS	Slow	69.2±10.25	76.6±7.74	0.015*
Left-right	Medium	73.7±9.84	82.1±4.54	0.001*
Directional control (%)	Fast	83.05±5.78	85.50±6.10	0.20
	Composite	75.3±6.57	81.4±4.77	0.002*
RWS	Slow	2.22±0.44	1.98±0.21	0.038*
Front-back	Medium	2.83±0.51	2.86±0.48	0.87
On-axis velocity (deg/sec)	Fast	4.0±1.41	4.56±1.08	0.16
	Composite	3.02±0.66	3.14±0.47	0.51
RWS	Slow	70.2±15.3	70.1±12.9	0.99
Front-back	Medium	69.5±22.26	75.5±10.01	0.27
Directional control (%)	Fast	75.6±22.1	76.2±14.3	0.91
	Composite	71.7±18.8	73.9±10.7	0.64
WBS	0º	51.4±9.3	50.8±3.3	0.78
Left	30º	50.7±7.01	49.2±4.02	0.42
	60º	51.7±6.2	49.1±4.5	0.13
	90º	51±5.4	48.5±3.6	0.10
WBS	0º	48.6±9.3	49.2±3.3	0.78
Right	30º	49.3±7.01	50.7±4.02	0.42
	60º	48.2±6.2	50.9±4.5	0.13
	90º	49±5.4	51.4±3.6	0.10
US	Left-EO	4.8±4.6	0.7±0.13	0.002*
(deg/sec)	Right-EO	3.91±4.49	0.62±0.12	0.000*
	Left-EC	11±1.8	2.8±2.3	0.000*
	Right-EC	10.3±3.08	2.26±1.85	0.000*
Sit to stand	WT transfer (sec)	0.53±0.37	0.56±0.28	0.78
	Rising index (Body Wt)	21.5±7.23	24.5±8.45	0.24
	Sway velocity (deg/sec)	2.91±1.27	2.77±1.08	0.71
	Left/right weight symmetry (%)	0.7±10.4	-2.17±13.2	0.45
Walk across	Step width (cm)	16.3±3.8	12.7±4.9	0.014*
	Step length (cm)	56.5±10.4	61.1±10.9	0.18
	Speed (cm/sec)	74.3±12.8	81.4±11.5	0.07
	Step length symmetry (%)	-13.7±30	10.7±35.3	0.024*
Tandem walk	Step width (cm)	11.1±4.7	7.9±1.6	0.008*
	Speed (cm/sec)	26.3±9.4	28.6±6.7	0.38
	End sway (deg/sec)	6.06±3.67	4.74±1.53	0.14
Step/quick turn	Left	1.65±0.51	1.15±0.54	0.005*
Turn time (sec)	Right	1.46±0.49	1.17±0.41	0.05
	L-R difference (%)	10.20±7.13	10.05±9.34	0.95
Step/quick turn	Left	36.9±9.9	31.2±9.6	0.07
Turn sway (deg)	Right	33.9±10.1	31.9±15.4	0.62
	L-R difference (%)	8.40±6.15	8.95±8	0.80
Step up/over	Left	32.9±8.4	44.1±11.9	0.002*
Lift-up index (% Body Wt)	Right	36.08±9.2	42.05±10.1	0.05
	L-R difference (%)	7.05±5.37	7.85±6.58	0.67
Step up/over	Left	1.56±0.22	1.41±0.19	0.027*
Movement time (sec)	Right	1.48±0.20	1.43±0.24	0.49
	L-R difference (%)	4.50±3.20	4.90±4.64	0.75

continue →

TABLE 2: Static posturography test results *(continued)*.

		Study X̄±SD (n=20)	Control X̄±SD (n=20)	p value
Step up/over	Left	44.8±16.07	52.3±15.62	0.14
Impact index (% Body Wt)	Right	42.4±12.9	48.8±15.6	0.16
	L-R difference (%)	11±6.67	8.50±9.41	0.33
Forward lunge	Left	38.04±5.17	42.09±7.45	0.05
Distance (% Body Wt)	Right	37.81±5.88	41.9±7.07	0.05
	L-R difference (%)	4.20±3.10	2.80±2.14	0.10
Forward lunge	Left	17.65±8.45	19.16±5.02	0.49
Impact index (% Body Wt)	Right	18.76±6.19	20.96±5.73	0.25
	L-R difference (%)	13.20±9.06	9.85±6.98	0.19
Forward lunge	Left	1.67±0.54	1.51±0.44	0.31
Contact time (sec)	Right	1.5 ± 0.44	1.31±0.40	0.18
	L-R difference (%)	6.70±6.57	7.30±7.26	0.78
Forward lunge	Left	169.9±50.1	152.3±41.6	0.23
Force impulse (% body Wt-sec)	Right	153.4±40.4	136.4±36.9	0.17
	L-R difference (%)	6±6.37	6.75±6.66	0.71

*p<0.05; SD: Standard deviation; mCTSIB: Modified clinical test of Sensory Interaction in Balance; EO: Eyes open; EC: Eyes closed; LOS: Limits of Stability; RT: Reaction time; MVL: Movement velocity; EPE: End point excursion; MXE: Maximum excursion; DCL: Directional control; RWS: Rhythmic Weight Shift; WBS: Weight Bearing/Squat; US: Unilateral Stance.

A statistically significant difference was found between the groups in the RWS test. The sub parameter of right-left directional control, slow, medium velocity and combined balance point figures and in the sway velocity sub-parameter of the front-back and in the slow velocity figures, a statistically significantly better results were found in healthy adults than in CI group (p<0.05).

In healthy adults, static postural control was considerably better than in the CI group under all 4 situations (p<0.05). Figure 1 depicts 4 conditions.

When the subjects were asked to walk from one end of the force plate to the other by the WA test, the step width and step length symmetry was significantly better in the healthy adults than in CI group (p<0.05). The step length and speed were not different (p>0.05).

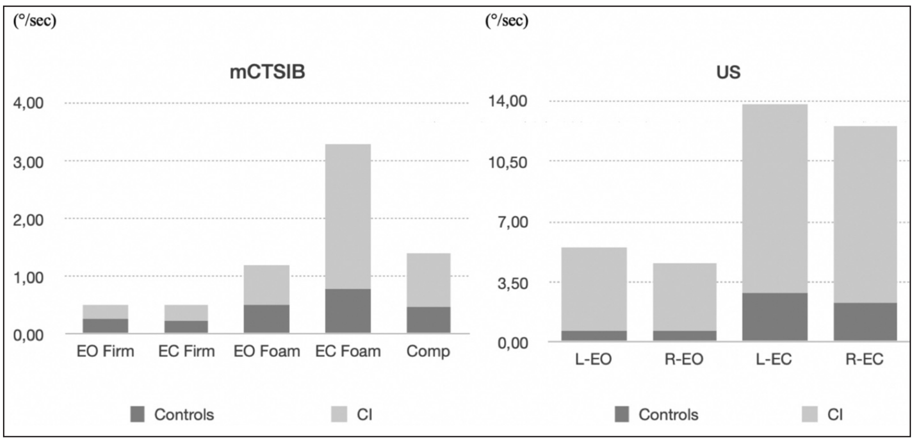

FIGURE 1: When two groups were compared, EO/EC foam and composit p<0.05 in mCTSIB test; all parameters p<0.05 in US test. EC indicates eyes closed; EO, eyes open; L, left; R, right; firm, firm surface; foam, foam pad; Comp, composite.

In the TW test, while a statistically significant difference was found in healthy adults than in CI group regarding step width ($p<0.05$), no statistically significant difference was found in other measured parameters ($p>0.05$).

In the SQT test, a statistically significantly better results were found in the healthy adults than in CI group, regarding the turning left, which is the sub parameter of the turning time ($p<0.05$). The other parameters were not significantly different ($p>0.05$).

A statistically significant difference was found between the groups in the SUO test. The lift-up index parameter at the left side and the movement time parameter at the left side were statistically significantly better in healthy adults than in CI group ($p<0.05$).

A statistically significant difference was not found between the groups in the FL test.

SUBJECTIVE BALANCE EVALUATION RESULTS

A statistically significant difference was obtained between the groups regarding the physical and functional sub-parameters of the Berg Balance Scale and the DHI, which were 2 of the scales used ($p<0.05$). CI users had worse results.

DISCUSSION

Many studies have reported a relationship between cochlear implantation and vestibular dysfunction. The incidence of vestibular complaints among CI users ranges from 0.33% to 74%, which is a vast probability range.[5] Regardless of the severity of the impairment, 2-49% of people have subjective dizziness.[13] This wide range of findings might be due to the number of patients in the studies and tests applied.

In line with the previous work, the findings of this study show that CI patients have more impairments in postural control compared to healthy individuals. We found both static and dynamic balance are significantly affected in CI patients. In fact, due to the close anatomical and physiological relations with the cochlea, the CI surgery and CI electrical activity are associated with the effects on the vestibular system.[3] Trauma caused by electrode insertion, endolymphatic hydrops, cochleostomy-induced acute serous labyrinthitis and electrical activation from the implant itself have all been proposed as causes of vestibular impairment during and/or after CI surgery.[14]

According to our evaluation of the static posturography device that was used in this study, no statistically significant differences were observed between the groups ($p\geq0.05$) in the WBS, STS and FL subtests. Finding no difference between groups on these 3 sub-tests can be explained by participants's use of the somatosensory and visual inputs in order to complete the tests and the reduced need for vestibular inputs when compared to other tests. In line with this, in mCTSIB test on the foam surface, significant impairments were observed in CI group particularly in the eyes closed condition. In this condition where the somatosensory information is faulty due to foam surface, vestibular information is the only accurate feedback. As the performance of CI group on this test reflects the inability of sensory integration, the results obtained can be explained by the lack of vestibular inputs and the vestibular system not being used efficiently. In fact, Kluenter et al. found that in the mCTSIB test, the results of the CI candidates were distinctively lower compared to the results of the healthy group, and CI group performance was lower even after CI surgery.[15]

When the results of the US test were analyzed, statistically significant differences were found between the study group and the control group in all the positions. Similar to mCTSIB test, particularly the eyes closed conditions showed apparent differences compared to the eyes open conditions. US test may present more sway compared to the bilateral stance; in addition, the studies which report that sway increases even more with eyes closed, showing similarities with our findings.[16] The observation of more apparent differences in the eyes closed conditions may be interpreted as an indication of more problems for CI users in their daily activities because they are unable to use visual inputs in dark or less illuminated environments.

When RWS test was considered, direction control in swaying right to left was worse in CI group compared to control group. The inability of CI users to accelerate and to decelerate their sway in the requested direction, and to adapt their sway to the defined time frame may imply limited abilities required for normal postural control.

In our study, during the WA and TW tests, CI users were observed to have a wider step width compared to the average step width of the control group, revealing their need for a wider support surface to maintain their postural balance. In other words, they experience problems on narrow support surfaces. In fact, Kluenter et al. found similar results in the RWS, WA and TW tests.[15]

When SQT test results are considered, the CI users needed more time to complete turning to both sides (right/left) when compared to the control group, which may be yet another an indication of their higher probability to encounter more problems in their daily lives.

Considering the previously mentioned findings, statistically significant differences between study and control group were found on the parameters that evaluate dynamic balance. In the previous studies with the exception of only one study, the studies by Brey et al., Fina et al. and Buchmann et al. who used posturographic sensory organization test and by Kluenter et al. who used static and dynamic posturography, reported that the CI candidates's balance function was affected negatively in the preoperative tests, and was not additionally affected after the CI surgeries.[6-8,15,17] While some of the researchers claim that CI intervenes and affects vestibular function, others state that CI does not have any negative effect on vestibular function. On the contrary, some researchers state that CI will improve body balance.[3,6,7,18-27] There are also studies showing that CI users may have vestibular defects before implantation as a result of lesions that cause sensorineural hearing loss. These studies focused mainly on the adult population and reported vestibular dysfunction (range 25-100% hypofunction).[28] One limitation of the current study to be acknowledged at this point is that pre-operative vestibular function and long term follow up of vestibular function of the participants were not assessed. Nevertheless, a significant difference was observed between CI and control groups.

In addition to objective tests of balance function, 3 subjective scales for balance function were used in our study. The significant results we obtained from the subjective scales, such as the Berg Balance Scale and the DHI indicating that even if the individuals don't mention any vertigo or dizziness in their daily lives these problems can be detected with the aid of subjective assessments. In this sense, obtaining similar results between the groups on the VADL Scale can be explained by the self-adaptation of the individuals to daily life activities by developing appropriate strategies.

In their pilot study, le Nobel et al. stated that there is no statistically significant difference between the DHI score results of many patients before and after CI.[29] On the other hand, Batuecas-Caletrio et al. evaluated 30 CI users using video Head Impulse Test after CI surgery, and detected changes in the vestibular functions of 30 % of the patients. Additionally, they observed increament in the DHI scores.[13]

CONCLUSION

As previously stated, the most important limitation of this study is the lack of pre-op balance evaluations and long-term follow-up monitorization of changes in postural control and balance of the CI users. Keeping in mind the wide range of findings in terms of differences between pre-op and post-op balance function and effect of cochlear implantation on existing balance function among CI users, comparision of pre and postop balance functions and long term-follow-up assessments of CI users may be recommended. By monitoring balance function after the CI surgery, appropriate rehabilitation programs for improvement can be applied.

Acknowledgements

Special thanks to many cochlear implant users and controls for their support during the data collection of my study. This documnet was edited by a team of American Manuscript Editors who are all native English speakers.

Source of Finance

During this study, no financial or spiritual support was received neither from any pharmaceutical company that has a direct connection with the research subject, nor from a company that pro-

vides or produces medical instruments and materials which may negatively affect the evaluation process of this study.

Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

***Idea/Concept:** Songül Aksoy; **Design:** Mehmet Yaralı, Songül Aksoy; **Control/Supervision:** Mehmet Yaralı, Songül Aksoy; **Data Collection and/or Processing:** Hatice Kübra Bozkurt; **Analysis and/or Interpretation:** Hatice Kübra Bozkurt, Songül Aksoy, Mehmet Yaralı; **Literature Review:** Hatice Kübra Bozkurt; **Writing the Article:** Hatice Kübra Bozkurt; **Critical Review:** Songül Aksoy, Mehmet Yaralı; **Materials:**Hatice Kübra Bozkurt.*

REFERENCES

1. Litovsky RY, Moua K, Godar S, Kan A, Misurelli SM, Lee DJ. Restoration of spatial hearing in adult cochlear implant users with single-sided deafness. Hear Res. 2019;372:69-79. [Crossref] [PubMed] [PMC]
2. House WF, Berliner KI. Cochlear implants: from idea to clinical practice. In: Cooper H, ed. Cochlear Implants: A Practical Guide. 1st ed. San Diego, CA: Singular Publishing;1991. p.9-33.
3. Abramides PA, Bento RF, Bitar RSM, Brito Neto RV, Tsuji RK. How can the cochlear implant interfere with the vestibular function. Int. Arch. Otorhinolaryngol. 2009;13(2):195-200. [Link]
4. Aksoy S. Evaluation of balance in children with congenital sensorineural hearing loss using computerized dynamic posturography. Fizyoter Rehabil. 2011;22(2):81-5. [Link]
5. González-Navarro M, Manrique-Huarte R, Manrique-Rodríguez M, Huarte-Irujo A, Pérez-Fernández N. Long-term follow-up of late onset vestibular complaints in patients with cochlear implant. Acta Otolaryngol. 2015;135(12): 1245-52. [Crossref] [PubMed]
6. Buchman CA, Joy J, Hodges A, Telischi FF, Balkany TJ. Vestibular effects of cochlear implantation. Laryngoscope. 2004;114(10 Pt 2 Suppl 103):1-22. [Crossref] [PubMed]
7. Brey RH, Facer GW, Trine MB, Lynn SG, Peterson AM, Suman VJ. Vestibular effects associated with implantation of a multiple channel cochlear prosthesis. Am J Otol. 1995;16(4):424-30. [PubMed]
8. Gao Y, Zhang Q, Yan J, Niu X, Han P, Yuan H, et al. Sudden onset of static equilibrium dysfunction in patients receiving a cochlear implant. Medicine (Baltimore). 2017;96(44):e8465. [Crossref] [PubMed] [PMC]
9. Jacobson GP, Newman CW. The development of the Dizziness Handicap Inventory. Arch Otolaryngol Head Neck Surg. 1990;116(4):424-7. [Crossref] [PubMed]
10. Cohen HS, Kimball KT, Adams AS. Application of the vestibular disorders activities of daily living scale. Laryngoscope. 2000;110(7):1204-9. [Crossref] [PubMed]
11. Çınar BÇ, Kaya Ş, Sjöstrand AP, Alpar R, Aksoy S. [Turkish validity and reliability of vestibular disorders activities of daily life]. Fizyoterapi Rehabilitasyon. 2017;28(1):1-11. [Link]
12. Berg KO, Maki BE, Williams JI, Holliday PJ, Wood-Dauphinee SL. Clinical and laboratory measures of postural balance in an elderly population. Arch Phys Med Rehabil. 1992;73(11):1073-80. [PubMed]
13. Batuecas-Caletrio A, Klumpp M, Santacruz-Ruiz S, Benito Gonzalez F, Gonzalez Sánchez E, Arriaga M. Vestibular function in cochlear implantation: Correlating objectiveness and subjectiveness. Laryngoscope. 2015;125(10): 2371-5. [Crossref] [PubMed]
14. Ibrahim I, da Silva SD, Segal B, Zeitouni A. Effect of cochlear implant surgery on vestibular function: meta-analysis study. J Otolaryngol Head Neck Surg. 2017;46(1):44. [Crossref] [PubMed] [PMC]
15. Kluenter HD, Lang-Roth R, Guntinas-Lichius O. Static and dynamic postural control before and after cochlear implantation in adult patients. Eur Arch Otorhinolaryngol. 2009;266(10):1521-5. [Crossref] [PubMed]
16. Krause DA, Jacobs RS, Pilger KE, Sather BR, Sibunka SP, Hollman JH. Electromyographic analysis of the gluteus medius in five weight-bearing exercises. J Strength Cond Res. 2009;23(9):2689-94. [Crossref] [PubMed]
17. Fina M, Skinner M, Goebel JA, Piccirillo JF, Neely JG, Black O. Vestibular dysfunction after cochlear implantation. Otol Neurotol. 2003;24(2):234-42; discussion 242. [Crossref] [PubMed]
18. Vibert D, Häusler R, Kompis M, Vischer M. Vestibular function in patients with cochlear implantation. Acta Otolaryngol Suppl. 2001;545:29-34. [Crossref] [PubMed]
19. Enticott JC, Tari S, Koh SM, Dowell RC, O'Leary SJ. Cochlear implant and vestibular function. Otol Neurotol. 2006;27(6):824-30. [Crossref] [PubMed]
20. Huygen PL, Hinderink JB, van den Broek P, van den Borne S, Brokx JP, Mens LH, et al. The risk of vestibular function loss after intracochlear implantation. Acta Otolaryngol Suppl. 1995;520 Pt 2:270-2. [Crossref] [PubMed]
21. Steenerson RL, Cronin GW, Gary LB. Vertigo after cochlear implantation. Otol Neurotol. 2001;22(6):842-3. [Crossref] [PubMed]
22. Eisenberg LS, Nelson JR, House WF. Effects of the single-electrode cochlear implant on the vestibular system of the profoundly deaf adult. Ann Otol Rhinol Laryngol Suppl. 1982;91(2 Pt 3):47-54. [PubMed]
23. Migliaccio AA, Della Santina CC, Carey JP, Niparko JK, Minor LB. The vestibulo-ocular reflex response to head impulses rarely decreases after cochlear implantation. Otol Neurotol. 2005;26(4):655-60. [Crossref] [PubMed]
24. Suarez H, Angeli S, Suarez A, Rosales B, Carrera X, Alonso R. Balance sensory organization in children with profound hearing loss and cochlear implants. Int J Pediatr Otorhinolaryngol. 2007;71(4):629-37. [Crossref] [PubMed]
25. Szirmai A, Ribári O, Répássy G. Air caloric computer system application in monitoring vestibular function changes after cochlear implantation. Otolaryngol Head Neck Surg. 2001;125(6):631-4. [Crossref] [PubMed]
26. Bance ML, O'Driscoll M, Giles E, Ramsden RT. Vestibular stimulation by multichannel cochlear implants. Laryngoscope. 1998;108(2):291-4. [Crossref] [PubMed]
27. Ribári O, Szirmai A, Küstel M, Répássy G. How does cochlear implantation affect the contralateral vestibular system? Int Tinnitus J. 2002;8(2):108-10. [PubMed]
28. Cushing SL, Chia R, James AL, Papsin BC, Gordon KA. A test of static and dynamic balance function in children with cochlear implants: the vestibular olympics. Arch Otolaryngol Head Neck Surg. 2008;134(1):34-8. [Crossref] [PubMed]
29. le Nobel GJ, Hwang E, Wu A, Cushing S, Lin VY. Vestibular function following unilateral cochlear implantation for profound sensorineural hearing loss. J Otolaryngol Head Neck Surg. 2016;45(1):38. [Crossref] [PubMed] [PMC]