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# Balance function after cochlear implant and inner ear anomaly: Comparison of dynamic posturography

Farideh Hosseinzadeh MD[1] | Alimohamad Asghari MD[2] | Maziar Moradi-Lakeh MD, MPH[3] | Mohammad Farhadi MD[1] | Ahmad Daneshi MD[1] | Mohammad Mohseni MD[1] | S.Saeed Mohammadi MD[4]

[1]ENT and Head and Neck Research Center, The Five Senses Institute, Iran University of Medical Sciences, Tehran, Iran

[2]Skull Base Research Center, The Five Senses Institute, Iran University of Medical Sciences, Tehran, Iran

[3]Preventive Medicine and Public Health Research Center, Iran University of Medical Sciences and Health Services, Tehran, Iran

[4]Farabi Eye Hospital, Tehran University of Medical Sciences, Tehran, Iran

**Correspondence**
Alimohamad Asghari, MD, Otorhinolaryngology Head and Neck Surgery, Skull Base Research Center, The Five Senses Institute, Iran University of Medical Sciences, Hazrat Rasoul Akram Hospital, Niayesh Street, Sattar khan Avenue, Tehran, Iran.
Email: dramasghari@gmail.com

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## Abstract

**Introduction:** Patients with sensorineural hearing loss suffer concomitant vestibular dysfunction that is more prevalent in patients with inner ear anomaly and could be aggravated with cochlear implantation. To assess the vestibular dysfunction in patients with cochlear implantation, we compared their results with those of patients with and without inner ear anomaly.

**Materials and methods:** This is a historical cohort study lasting for 20 years on 50 patients with cochlear implantation. All patients underwent dynamic posturography and Bruininks-Oseretsky Test.

**Results:** Twenty-two (44%) of the participants showed some types of inner ear anomaly. The frequency of abnormal Bruininks-Oseretsky Test was 45.5% and 10.7% ($P$ = .005, odds ratio [OR] = 6.9). Abnormal composite was seen in 77.3% and 21.4%, respectively ($P$ < .001; OR = 12.5). The mean strategy score in the fifth condition of the sensory organization test was 25.0 ± 20.4 in patients with inner ear anomaly, whereas it was 44.1 ± 18.9 in those without it ($P$ = .001).

**Conclusion:** Balance capability in cochlear implantation patients with inner ear anomaly compared to those without inner ear anomaly was worse. More vestibular rehabilitation treatment plans are suggested for these patients.

KEYWORDS
Bruininks-Oseretsky Test, cochlear implantation, inner ear anomaly, posturography, vestibular function tests

## 1 | INTRODUCTION

From the embryological development perspective, sensorineural hearing loss (SNHL) is closely related to vestibular dysfunction, which is one of the main reasons of balance disturbance.[1] Balance is the result of coordination between input signals from the visual, vestibular, and proprioceptive systems and results in normal motor performance by setting both static and dynamic posture.[1,2]

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Cochlear implantation (CI) has been used to regain hearing ability in patients with profound bilateral SNHL. Significant advances were observed in the auditory system of patients with profound SNHL who received CI in both groups with normal temporal bone and those with inner ear anomalies (IEAs).[3]

However, some believe that CI is associated with the risk of surgically induced vestibular dysfunction due to the device insertion, resulting in inflammation; improvement of balance function was reported by Rumalla et al via direct stimulation of the vestibular nerves.[4,5]

Computerized dynamic posturography (CDP), also called test of balance, is a noninvasive test which can be used in patients with balance problems that have not been diagnosed by other conventional vestibular tests. In fact, it could be considered as a supplementary vestibular function assessment test besides the conventional tests.

CDP analyzes visual, proprioceptive and vestibular information, motor system, central responses of the lower limbs, and body movements assessed in different situations. Three tests consider the body balance in patients in the orthostatic position: sensory organization test (SOT), motor control test, and adaptation test which evaluate the functional abilities of the patients.[6]

The Bruininks-Oseretsky Test (BOT) of motor proficiency was first introduced in 1978 and modified to BOT-2 in 2005. The BOT-2 is an individually administered test of fine and gross motor skills. It is intended to be used by practitioners for evaluation of motor performance, specifically in the areas of fine manual control, manual coordination, body coordination, strength, and agility to assess the overall balance function.[7]

Evaluation and management of vestibular functions in patients with SNHL associated with developmental IEAs become more prominent due to the prevalence of vestibular dysfunctions in patients with IEAs. Currently, some severe forms of IEAs are considered as contraindication for CI, whereas mild and moderate cases could be candidates for CI.[8]

Therefore, patients with SNHL associated with IEAs who are candidates for CI are at the risk of vestibular dysfunction for the following three reasons: SNHL itself, IEA, and CI. To date, to the best of our knowledge, there is no study on the vestibular system in patients with CI and IEAs. Therefore, we aimed to assess and compare the vestibular dysfunction in cochlear implanted patients who had some kinds of IEAs, as documented by temporal bone high-resolution computed tomography (HRCT) and patients with normal anatomy of the inner ear. The vestibular function was assessed and characterized by CDP and BOT-2.

## 2 | METHODS

This is a historical cohort study in which patients (50 individuals) who had undergone CI at Rasool-e-Akram Hospital during a 20-year period from 1997 to 2017 were enrolled. All patients were selected for CI because of bilateral profound SNHL. Patients without HRCT before implantation who did not complete vestibular and equilibrium tests were excluded from the study. The other exclusion criteria were history of meningitis, cochlear ossification, unilateral IEAs, Michel's aplasia, history of cerebellar disorders documented both clinically and by brain imaging, history of diseases involving the equilibrium system (CNS and spinal disorders), any kind of visual problem not been corrected with glass, and blindness.

All patients were informed that their data might be used in future research projects and they signed an informed consent to allow using their anonymous data in future studies. The approval of ethics committee for this study was obtained from Research Ethics Committee of Iran University of Medical Sciences (IR.IUMS.FMD.REC.1397.167).

All the patients received similar surgical procedures. The implanted devices were cochlear in 33 (75%) and MED-EL in 11 patients (25%). All patients underwent HRCT for evaluating the temporal bone abnormalities and the IEAs. These abnormalities were incomplete partition (IP), common cavity, enlarged vestibular aqueduct, and hypoplastic cochlea. All CT scans were assessed by a radiologist experienced in the field of head and neck imaging and an experienced otologist, and positive findings were documented by consensus.

All patients were evaluated, using equilibrium tests 9.7 ± 5.1 years after the CI with a mean of 9.23 ± 4.3 in the normal group and 10.29 ± 5.8 in the group with IEA. These tests included BOT-2 and posturography including somatosensory, visual, vestibular, and peripheral parts integrated as composite result. At the end, the results of BOT and posturography were compared between patients with and without IEA. All statistical analyses were performed using SPSS version 18. For continuous data, normality was checked by Kolmogorov-Smirnov test and if the data were normal, *t* test was used for comparing between patients with and without IEA. If the data were not normal or if the variable had an ordinal scale, the Mann-Whitney *U* test was used for the comparison. In addition, chi-square test was used for comparing nominal variables between the two groups. To adjust the potential role of other variables on the results of BOT and posturography, we used multivariate logistic regression models. For this purpose, we categorized all these vestibular tests into dichotomous variables. A *P*-value lower than 0.05 was considered as statistically significant.

## 3 | RESULTS

A total of 50 cochlear implanted patients were enrolled in the study. The mean age of the patients was 16.8 ± 7.4 years with a range of 3 to 48 years; during CI, it was 5.9 ± 4.8 years (range: 2-25). Half (25) of the patients were female. Implantation device was inserted in the right ear in 41 patients (82%) and in the left one in 9 patients (18%).

Among all patients, 22 (44%) showed some types of IEA in CT imaging, all being bilateral. The most common abnormality was IP in 12 patients (54.5%), followed by enlarged vestibular aqueduct in

5 patients (22.7%), common cavity in 4 patients (18.2%), and hypoplastic cochlea in 1 patient (4.5%). IP was moderate in 6 patients and mild or severe in 4 patients each (Table 1).

Eight patients (16%) showed CSF leak. Internal auditory canal abnormalities were seen in six patients (12%); among them, two were wide, and four were narrow. SNHL was congenital in 40 (80%) and progressive in 10 patients (20%).

Mean BOT score among the patients was 24.3 ± 5.1 (12-34). Mean BOT in patients with and without IEA was 23.5 ± 6.5 and 25 ± 3.7, respectively (*P* = .35). Thirty-seven patients (74%) showed BOT score of at least 20 (normal BOT). Among 22 patients with IEA, 10 (45.5%) showed abnormal BOT, whereas among 28 patients without IEA, 3 (10.7%) showed abnormal BOT (*P* = .005, OR = 6.9, 95% confidence interval = 1.6-30).

Among all patients, abnormal somatosensory, visual, vestibular, and preferential assessments were seen in 5 (10%), 9 (18%), 19 (38%), and 12 (24%) patients, respectively. In addition, abnormal composite was seen in 23 patients (46%). Distribution of abnormal somatosensory, visual, vestibular, and preferential parts of posturography as well as the whole composite was compared between patients with and without IEA. Overall, 68.2% (15/22) of patients with IEA showed abnormal vestibular part of SOT, whereas in patients without IEA this ratio was 14.3% (4/28) (*P* < .001; OR = 12.9, 95% confidence interval = 3.2-51.5). In addition, 77.3% (17/22) of patients with IEA showed abnormal whole composite of SOT, whereas in those without IEA this ratio was 21.4% (6/28) (*P* < .001; OR = 12.5, 95% confidence interval = 3.2-47.9). Other parts of SOT did not show statistically significant differences among patients with and without IEA (Table 2).

We performed these analyses in two strata of patients with congenital (*N* = 40) and progressive (*N* = 10) SNHL separately. Similar patterns of statistically significant differences between patients with and without IEA were observed in both strata; the rate of abnormal vestibular and composite scores was statistically higher in patients with IEA compared to those without IEA, both in congenital and progressive cases (Table 3).

The frequency of abnormal visual, somatosensory and preferential scores did not show a statistically significant difference in patients with and without IEA, in both congenital and progressive cases. Among 12 patients with IP, 7 (58.3%) showed abnormal vestibular test in SOT, whereas among 10 patients with other forms of IEA, 8 (80%) showed abnormal vestibular test (*P* = .38). For composite results, these percentages were 75% and 80%, respectively (*P* > .9).

In addition, the mean strategy scores of patients in each of six SOT conditions in three different trials were calculated and compared between patients with and without IEA. The mean score of condition 5 was 25.0 ± 20.4 in IEA patients and 44.1 ± 18.9 in those without IEA (*P* = .001). In addition, the mean score of condition 4 was 64.7 ± 20.2 in IEA patients and 74.0 ± 6.6 in those without IEA

**TABLE 1** Distribution and subtypes of inner ear anomalies (N = 50)

| Type of abnormality | No. | % among all patients | % among all abnormalities | % among all IPs |
|---|---|---|---|---|
| No abnormality | 28 | 56.0 | — | — |
| All abnormalities | 22 | 44.0 | 100 | — |
| Incomplete partition (IP) | 12 | 24.0 | 54.5 | 100 |
| Mild IP | 4 | 8.0 | 18.2 | 33.3 |
| Moderate IP | 6 | 12.0 | 27.3 | 50.0 |
| Severe IP | 2 | 4.0 | 9.1 | 16.7 |
| Enlarged vestibular aqueduct | 5 | 10.0 | 22.7 | — |
| Common cavity | 4 | 8.0 | 18.2 | — |
| Hypoplastic cochlea | 1 | 2.0 | 4.5 | — |

**TABLE 2** Comparison of different constituents and composite between patients with and without inner ear anomaly (IEA)

| | Group (IEA = 22, no IEA = 28) | Abnormal test no. (%) | *P* value | Odds ratio (95% confidence interval) |
|---|---|---|---|---|
| Somatosensory system | IEA present | 1 (4.5) | .37 | 0.29 (0.03-2.8) |
| | IEA absent | 4 (14.3) | | |
| Visual system | IEA present | 6 (27.3) | .16 | 3.1 (0.7-14.3) |
| | IEA absent | 3 (10.7) | | |
| Vestibular system | IEA present | 15 (68.2) | <.001 | 12.9 (3.2-51.5) |
| | IEA absent | 4 (14.3) | | |
| Preferential system | IEA present | 5 (22.7) | .85 | 0.9 (0.2-3.3) |
| | IEA absent | 7 (25.0) | | |
| Composite | IEA present | 17 (77.3) | <.001 | 12.5 (3.2-47.9) |
| | IEA absent | 6 (21.4) | | |

**TABLE 3** Comparison of abnormal vestibular and composite scores among patients with and without IEA in terms of SNHL type (congenital vs progressive)

| | SNHL type | Group | Abnormal test (%) | P value | Odds ratio (95% confidence interval) |
|---|---|---|---|---|---|
| Vestibular system | Congenital | IEA present | 66.7 (12/18) | .002 | 9 (2.1-38.8) |
| | | IEA absent | 18.2 (4/22) | | |
| | Progressive | IEA present | 75 (1/4) | .033 | 4 (0.7-21.8) |
| | | IEA absent | 0 (0/6) | | |
| Composite | Congenital | IEA present | 72.2 (13/18) | .002 | 8.8 (2.1-37.1) |
| | | IEA absent | 22.7 (5/22) | | |
| | Progressive | IEA present | 100 (4/4) | .048 | 6 (1.0-35.7) |
| | | IEA absent | 16.7 (1/6) | | |

Abbreviations: IEA, inner ear anomaly; SNHL, sensory neural hearing loss.

**TABLE 4** Comparison of mean strategy scores and abnormally located COG in each six different conditions of SOT between patients with and without IEA

| | Strategy scores | | | | Abnormal (out of border) COG | | | |
|---|---|---|---|---|---|---|---|---|
| SOT condition | Group | N | Mean | P value | Group | N | No. (%) | P value |
| 1 | IEA present | 22 | 98.3 ± 0.4 | .07 | IEA present | 22 | 7 (31.8) | .98 |
| | IEA absent | 28 | 98.1 ± 0.3 | | IEA absent | 28 | 9 (32.1) | |
| 2 | IEA present | 22 | 96.9 ± 6.3 | .45 | IEA present | 22 | 7 (31.8) | .77 |
| | IEA absent | 28 | 98.0 ± 0.7 | | IEA absent | 28 | 10 (35.7) | |
| 3 | IEA present | 22 | 97.8 ± 1.4 | .52 | IEA present | 22 | 5 (22.7) | .67 |
| | IEA absent | 28 | 97.8 ± 0.9 | | IEA absent | 28 | 5 (17.9) | |
| 4 | IEA present | 22 | 64.7 ± 20.2 | .048 | IEA present | 22 | 8 (36.4) | .38 |
| | IEA absent | 28 | 74.0 ± 6.6 | | IEA absent | 28 | 7 (25.0) | |
| 5 | IEA present | 21 | 25.0 ± 20.4 | .001 | IEA present | 22 | 9 (40.9) | .36 |
| | IEA absent | 28 | 44.1 ± 18.9 | | IEA absent | 28 | 8 (28.6) | |
| 6 | IEA present | 13 | 20.2 ± 21.8 | .13 | IEA present | 14 | 5 (35.7) | .93 |
| | IEA absent | 26 | 32.0 ± 22.8 | | IEA absent | 27 | 10 (37.0) | |

Abbreviations: COG, center of gravity; IEA, inner ear anomaly; SOT, sensory organization test.

**TABLE 5** Multivariate logistic regression models for predicting abnormal BOT, posturography, and its different components based on relevant parameters

| Variable | Cox and Snell $R^2$ | Hosmer and Lemeshow test, P value | Significant or borderline variables in model | Odds ratio (95% confidence interval) | P value |
|---|---|---|---|---|---|
| BOT | 0.38 | .51 | IEA | 3.1 (1.2-8.2) | .02 |
| Somatosensory component | 0.19 | .98 | — | — | — |
| Visual component | 0.28 | .004 | Age | 0.81 (0.66-1) | .054 |
| | | | Gusher | 0.016 (0.001-0.6) | .026 |
| Vestibular component | 0.33 | .80 | IEA | 2.3 (1.3-4.2) | .005 |
| Preferential component | 0.08 | .34 | — | — | — |
| Composite | 0.38 | .75 | IEA | 2.3 (1.3-4.2) | .005 |

Abbreviations: BOT, Bruininks-Oseretsky Test; IEA, inner ear anomaly.

(*P* = .048) (Table 3). Regarding the center of gravity (COG), we compared this assessment between two groups of patients with and without IEA. For this purpose, we compared patients with three COG measures in normal area as the first group vs other patients with at least one measure of out-of-border COG. Comparison between these two groups did not show any significant statistical difference between patients with and without IEA in six different conditions of SOT (Table 4).

We assessed the association of important independent variables on our different equilibrium tests. For this purpose, we considered gender, age, age at CI, presence of gusher, internal auditory canal abnormality, type of SNHL, type of CI device, and IEA as independent variables and posturography outputs as dependent variables. The associations were assessed by multivariate logistic regression models. The results are presented in Table 5. As we can see, IEA was a significant predictor of performance in BOT, vestibular component, and whole composite test abnormality.

Furthermore, we constructed different univariate logistic regression models considering the composite as dependent variable and each of four sensory parts of SOT (including somatosensory, visual, vestibular, and preferential) as independent variables. We showed that the vestibular results had the strongest association with the composite (odds ratio [OR] = 35.4; 95% confidence interval = 6.4-196.8; $P < .001$). The association of somatosensory and preferential parts was not statistically significant, and the association of the visual part was in the borderline.

## 4 | DISCUSSION

Development and maintenance of body balance in all body positions is a complex process that needs appropriate integration of sensory and motor systems.[9] Correct vestibular function stabilizes the position of the eyes, head, and body in the space and contributes to upright standing. This system is composed of two parts of vestibular-ocular (for visual stabilization during the head movement) and vestibular-spinal (for maintaining orientation of the body and postural body tone) that are necessary for motor developmental milestones.[9]

In maintaining balance, young children are more dependent on the visual system. In older ages, they use vestibular and somatosensory systems and full maturity occurs by the age of 10 and motor coordination and adult-like gait pattern matures by 7 to 10 years of age.[9] Thus, early detection of vestibular dysfunction and identifying patients at higher risk of vestibular defects are important for earlier therapeutic and rehabilitative measurements that ameliorate functional impairments of these patients in future and improve their quality of life.

Vestibular pathologies result in static and dynamic balance abnormalities and neuro-motor skills, so they present frequently with abnormal related symptoms and signs such as dizziness, vertigo, imbalance, gait disorders, and falls. This may negatively affect their age-matched skills such as bicycle riding.[2] In addition, they could impair psychological behavior, communication skills, and school performance in children. In adults, balance impairment can affect the quality of life and professional and social performance.[4]

Assessment of problems related to balance and functional ability has become more complete with CDP, especially in patients in whom the conventional tests are not diagnostic. CDP could make an appropriate differential diagnosis in patients with imbalance and help determine whether the abnormality is related to a problem in the afferent or sensory organs and their integrations, motor response, or both. In addition, it can determine the risk of falling in patients and provide an objective and quantitative measure of the efficacy of treatment plans and understanding the pathophysiology of imbalance that would be useful in preventive strategies for falling. This makes the CDP a unique diagnostic tool that could not be replaced by other tests. In fact, it could be considered as a good complement for other diagnostic tests. In addition, the SOT part of CDP is the only quantitative test for assessment of three sensory systems affecting balance.[4]

SOT analysis of CDP can determine the type of sensory abnormality responsible for balance impairment and provide a quantitative assessment of three sensory systems affecting balance. This would be very important in selecting the treatment strategy as well as providing a good quantitative measure for monitoring the improvement of the patient's condition during treatment.[4]

As mentioned before, in patients with SNHL who have certain types of IEA and have undergone CI, three factors increase the probability of vestibular impairments: SNHL itself, IEA, and CI.[2,10,11]

Vestibular deterioration after CI is attributed to different factors including electrical stimulation by the implant, direct trauma to the adjacent vestibular part and scala tympani during electrode insertion, acute serous labyrinthitis due to cochleostomy, intraoperative perilymph loss, foreign body reaction and labyrinthitis, and endolymphatic hydrops.[12,13]

In this study, we assessed a group of patients who underwent CI and evaluated their balance using BOT and SOT posturography tests. Furthermore, we compared the performance of these tests between patients with and without IEA. As shown, in assessment of different sensory systems of SOT and whole composite, the difference between the two groups of patients with and without IEA was statistically significant for the vestibular system and whole composite (both ORs greater than 12). Higher abnormality in the vestibular system in patients with IEA is an expected finding as the patients with IEA are at risk of higher vestibular system dysfunction. In addition, abnormal composite score was higher in patients with IEA (this is mainly associated with abnormal vestibular system results). The interesting point is that the rate of abnormal vestibular and composite assessment (that indicates a problem in balance control) in patients with IEA is about 50% higher than those without IEA (68% vs 14% in vestibular assessment and 77% vs 21% in whole composite). In fact, there is considerable deterioration of vestibular function and equilibrium performance when the patient has a baseline anatomical inner ear anomaly. Worse vestibular and composite scoring of SOT in CDP in patients with IEA is expected and in fact vestibular defects are the main reason for composite abnormal findings (compared to visual and proprioceptive impairments). This is obviously due to the damaged vestibular system secondary to abnormal vestibular anatomy and its impaired function. It is also interesting to point out the share of three factors of SNHL, CI, and IEA in vestibular and composite impairments. As mentioned, patients without IEA showed abnormal vestibular and composite results in 14% and 21%, respectively, whereas in IEA patients this percentage rose more than 50% in both. This shows a more powerful share for IEA compared to CI and SNHL in balance deterioration and risk of falls. It would be interesting if we had the CDP results before surgery to compare it with the postsurgery findings. Comparison of the values before and after surgery could determine whether there is a positive interaction among IEA, SNHL, and CI or not (in vestibular and composite abnormal results). Unfortunately, we do not have the data of patients before surgery. This point could be important in developing treatment plans of imbalance in patients with IEA who are candidates for CI.

In searching the literature, we did not find similar studies on patients with both IEA and CI. Schwab et al assessed the balance function by dynamic posturography and identified SOT conditions of 5 and 6 as the lowest score conditions among 6 different conditions of SOT. In addition, their assessments showed that the vestibular subitem of SOT was the worse sensory organ in SOT performance.[14] These are consistent with our results.

Unlike the VEMP and caloric tests that are evaluated each ear separately (and thus are lateralized), CDP is not a lateralized assessment and represents a complete assessment of the vestibular system. In addition, the vestibular system is composed of three semicircular canals and two otolith organs (the utricle and saccule). Vestibular system is responsible for coordination of eye movements based on the body movements (via vestibule-ocular reflex), preserving body stability and balance based on body movements (vestibule-spinal reflex). The pathology of each part of the vestibular system could affect one specific function. For example, saccular destruction could make abnormal VEMP that mainly assesses the function of the saccule and relates to horizontal acceleration, whereas the horizontal semicircular canal is responsible for sensing the head rotation around a vertical axis. In CDP, we assess the whole vestibular system. It is interesting that we know which parts of the vestibular system are more assessed in vestibular part assessment of SOT. As the sway of vision is in the anterior posterior direction, it may interfere mainly with the function of the vertical semicircular canals. In this case, patients with specific disturbance in the saccule may show better performance in the vestibular part of SOT. Since most parts of the vestibular system are affected in the IEA, the whole test in SOT will be abnormal. We showed a dramatic increase in vestibular dysfunction in patients with IEA compared to others. It would be interesting to show which IEA is more closely associated with vestibular dysfunction in SOT (we could not show this difference mainly due to the small sample size in different types of IEA); it is probable that the vestibular part of SOT is more sensitive to a specific anatomical pathology, for example, in otoliths or in the semicircular canals. Assessment of SOT patterns in different subtypes of IEA would be interesting as different subtypes of IEA affect the vestibular system with different severities, and involvement of vestibular anatomical parts is not similar in this spectrum.

## 5 | CONCLUSIONS

Maintaining balance in CI patients with IEA compared to those without it was worse, as shown by lower strategy scores in the fifth condition of SOT and higher abnormal vestibular and composite results of SOT part of dynamic posturography. This is due to profound structural and functional defects in the vestibular system of patients with IEA and necessitates vestibular system evaluation before and even after CI surgery considering more vestibular rehabilitation treatment plans in these patients.


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### CONFLICT OF INTEREST

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### AUTHOR CONTRIBUTIONS

Farideh Hosseinzadeh and Alimohamad Asghari had full access to all the study data; took responsibility for the integrity of the study and the accuracy of data analysis; and conceived and designed the study. Alimohamad Asghari took responsibility for funding and supervising the study. Farideh Hosseinzadeh, Alimohamad Asghari, Maziar Moradi-Lakeh, Mohammad Farhadi, Ahmad Daneshi, Mohammad Mohseni, and S.Saeed Mohammadi interpreted the data. Farideh Hosseinzadeh and S.Saeed Mohammadi analyzed the data. Farideh Hosseinzadeh was responsible for the study coordination and recruitment. Farideh Hosseinzadeh drafted the manuscript. All authors critically revised the manuscript for important intellectual content and approved the final manuscript.

### ORCID


*Farideh Hosseinzadeh* https://orcid.org/0000-0003-1555-4711
*Alimohamad Asghari* https://orcid.org/0000-0002-9107-4309


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