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OTOLOGY

The evaluation of vestibular compensation by vestibular rehabilitation and prehabilitation in short-term postsurgical period in patients following surgical treatment of vestibular schwannoma

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Abstract

Purpose Vestibular schwannoma removal causes unilateral vestibular deafferentation, which results in dizziness and postural unsteadiness. Vertigo and balance problems together are among the most important aspects affecting quality of life. Intensive vestibular rehabilitation, which starts before surgery, with following postsurgical supervised rehabilitation, using visual biofeedback propose an instrument to accelerate a recovery process. Another option how to accelerate the vestibular compensation, is employment of presurgical gentamicin ablation together with vestibular rehabilitation (prehabilitation) of vestibular function. Purpose of present study was to examine the dynamics of vestibular compensation process using supervised intensive vestibular rehabilitation with visual biofeedback in the short-term postsurgical period. The second aim was to compare both studied groups mainly to evaluate if prehabilitation has potential to accelerate the compensation process in the early postoperative course.

Methods The study included 52 patients who underwent the retrosigmoid vestibular schwannoma removal. They were divided into two groups. The first group was prehabilitated with intratympanic application of gentamicin before surgery to cause unilateral vestibular loss (14 patients), the second group (38 patients) was treated in standard protocol without prehabilitation. All patients underwent at home vestibular training before surgery to learn new movement patterns. Following the surgery supervised intensive vestibular rehabilitation including visual biofeedback was employed daily in both groups between the 5th and 14th postoperative day. Outcome measurements included an evaluation of subjective visual vertical (SVV), posturography and the Activities—Specific Balance Confidence Scale (ABC). ANOVA for repeated measurements was used for statistical analysis.

Results We observed significant improvement in SVV ($p < 0.05$), posturography parameters ($p < 0.05$) and ABC scores ($p < 0.05$) with postoperative rehabilitation program following surgery in both groups. There was no statistically significant difference between group treated by prehabilitation and group without prehabilitation.

Conclusions Results of this study showed that intensive postsurgical rehabilitation represents key factor in compensation process following retrosigmoid vestibular schwannoma surgery. Prehabilitation did not speed up recovery process.

Keywords Vestibular schwannoma · Compensation · Rehabilitation · Prehabilitation · Posturography · Subjective visual vertical

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Introduction

Vestibular schwannomas are slow-growing benign tumours of the temporal bone and cerebellopontine angle that arise from schwann cells of either inferior or superior vestibular portion of the 8th cranial nerve [1]. Tumour growth leads to sensorineural hearing loss, tinnitus, dizziness and unsteadiness. An intracranial hypertension and dysfunction of other cranial nerves are related to giant tumours. Management options include observation, stereoradiosurgery and microsurgical removal depending on several factors, such as tumour size, growth rate or severity of neuro-otological symptoms [2].

Despite significant progress in diagnostics and therapy disease and its active treatment lead to severe functional deficits with significant impact on quality of life. Disturbed postural stability and related balance difficulties represent one of the leading handicaps [3]. Tumour growth results in a gradual vestibular problem both because of 8th cranial nerve/inner ear and cerebellar/brainstem dysfunction. Microsurgical tumour removal by vestibular neurectomy and eventual labyrinthectomy causes acute unilateral vestibular loss, although the vestibular compensation is already in progress by establishment of the central adaptive mechanisms. Post-surgically vast majority of patients suffer from severe dizziness, postural instability and fatigue [4]. Alleviation of the symptoms usually lasts from weeks to months. In cases where there is no restitution of function, certain deficits remain. Elderly patients or patients with additional central nervous disorders often face problems compensating the vestibular loss. In cases of simultaneous acute vestibular loss and cerebellar lesions (e.g., due to the surgery), the compensatory process may be prolonged or incomplete [5]. Resulting balance problems represent difficulties in daily activities affecting the quality of life.

Central compensation of sudden unilateral vestibular loss can be promoted and improved by specific rehabilitation programs [6]. These consist of specific therapy that improve the active readjustment of vestibular function, including gaze stabilisation exercises and balance training [6, 7]. It was shown that vestibular rehabilitation can be further supplemented by employment of visual biofeedback [8].

Another way to improve the compensation process is vestibular prehabilitation [9]. This approach encompasses first vestibular exercises to induce motor training and to optimize the function of vestibular and postural reflexes. Subsequently remaining vestibular function on the side of disease is ablated with intratympanic gentamicin treatment while rehabilitation program continues. Surgery is performed when total or near total loss of vestibular function and a compensated vestibulo-ocular reflex are achieved [10]. According to current trends prehabilitation is supported to allow rapid postsurgical recovery [11]. Aim of present study was to examine the dynamics of vestibular compensation process using intensive vestibular rehabilitation with visual biofeedback in the short-term postsurgical period. The second aim was to compare both studied groups mainly to evaluate if prehabilitation has potential to accelerate the compensation process in the early postoperative course.

Patients and methods

There were 52 patients who enrolled in the prospective longitudinal study. This number consists of patients who underwent complete battery of measurement. The group of 35 patients could not be counted because they lacked some of the measurements in specific period of time due to postsurgical complications, withdrawal of the study after surgery and unexpected discharge. In all cases retrosigmoid-transmeatal approach was employed to remove vestibular schwannomas at the Department of Otorinolaryngology and Head and Neck Surgery, University Hospital Motol, 1st Faculty of Medicine, Charles University, Prague in the period between January 2015 and January 2018. Our group of patients included 31 women and 21 men at the age from 20 to 73 years. There were only tumours grade 2 to grade 4 according the Koos classification with average extrameatal dimension of 22.1 ± 10.6 mm. Detailed patient and tumour characteristics are reviewed in Tables 1, 2 and 3. Residual vestibular function on the side of tumour was confirmed with caloric stimulation in all cases before surgery.

Prior the surgery participants were divided into two groups. The prehabilitated group included 16 patients. All patients in this group had presurgical intratympanic application of gentamicin. This procedure produces unilateral vestibular deafferentation on the side of the tumour was employed only in patients with non-serviceable hearing. We used Gardner-Robertson hearing scale to classify serviceable hearing preservation [12]. The grade of hearing disability is counted by pure tone audiometry and speech discrimination score. Non-serviceable hearing is classified by Gardner-Robertson grade III, IV and V. Patients received three intratympanic injections of approximately 0.3–0.6 ml of 40 mg/ml nonbuffered gentamicin at each application during 1 day (minimum of 2 h between each instillation). Sufficient dose of gentamicin application to cause vestibular ablation was controlled by clinical examination with newly developed spontaneous nystagmus and positive head impulse test. More than three doses of gentamicin application had to be administered to reach efficient vestibular lesion in several cases in prehabilitated group (maximum 6 doses). The second group of 36 patients were managed without preoperative gentamicin application. It consists of patients with serviceable hearing (Gardner-Robertson grade I and II), bilateral

Table 1 Patients and tumour characteristics of two different groups of patients. The first group is prehabilitated with gentamicin administered intratympanically and the second one is without gentamicin application

	Total	Prehabilitated group	Group without gentamicin	*P* values
Number of patients	52	16	36	
Age	47.9 ± 13.2	49.1 ± 14.4	47.3 ± 12.8	0.64
Tumour size (mm)	22.1 ± 10.6	17.2 ± 7.1	24.4 ± 11.1	0.14
Evolution (years)		2.0 (0.5–6.0)	2.0 (0.5–7.0)	0.41
Caloric test before surgery		26.7 ± 15.2	28.9 ± 23.1	0.73
Sex				
Men	21	10	11	
Women	31	6	25	

Table 2 Characteristics of patients in prehabilitated group with intratympanic gentamicin application

Patient	Age	Side (L-left, R-right)	Tumour size (mm)—the longest size	Koss grade	Hearing disability (Gardner-Robertson grade)	Canal paresis—SD (%)	Evaluation (years)
1	37	L	15	2	3	37	1
2	44	R	12	2	2	21	0.5
3	47	R	13	2	5	0	1
4	54	L	28	4	2	7	2
5	57	L	26	4	3	52	0.5
6	43	R	21	4	3	76	6
7	58	L	33	4	3	31	0.5
8	35	R	41	4	4	27	1
9	46	R	20	3	3	39	3
10	55	L	16	3	3	2	2
11	43	R	13	3	3	31	0.5
12	31	R	50	4	5	67	4
13	53	R	37	4	4	4	1
14	55	L	20	4	3	30	3
15	37	R	17	3	3	37	3
16	51	L	33	4	4	58	1

peripheral vestibular lesion, high grade of hypofunction of vestibular system on the tumour side or combined vestibular lesion, patients with large tumour size (unsafe to wait several months to surgery) and patients who disagree procedure of intratympanic installing of gentamicin.

All patients in both groups were instructed for home rehabilitation to learn new movement patterns at home. The vestibular training started 3 months before the surgery. More specifically in the prehabilitated group gentamicin application was employed following 2 weeks of at home vestibular training and continued both during the application and subsequently. Effect of gentamicin vestibular ablation was retested 6 weeks following the treatment.

The vestibular function was tested by neurootologic examination of vestibulo-ocular reflex including electronystagmography with caloric stimulation, head impulse test. Inclusion criterion to prehabilitated group was normal vestibular function on the tumour side or mild peripheral vestibular lesion with canal reactivity on the tumour side. Compensation process was evaluated using subjective visual vertical measurement (SVV), and posturography. The validated questionnaire Activities—Specific Balance Confidence Scale (ABC) was employed to evaluate subjective assessment of an impact caused by vestibular dysfunction. All of these examinations were provided before the surgery, in early post-surgery period (5–7th postoperative day) and on the day of discharge (usually 14th postoperative day).

The SVV measurement was performed by the “bucket method” [13]. This examination was repeated three times and average deviation was counted.

To evaluate postural control, we used Synapsys Posturography System (Synapsis S.A., Marseille, France) with a force platform (400 × 400 mm) with three strain-gauge sensors. The body sway was quantified by displacement of

Table 3 Characteristics of patients in group without gentamicin application

Patient	Age	Side (L-left, R-right)	Tumour size (mm)—the longest size	Koss grade	Hearing disability (Gardner-Robertson grade)	Canal paresis—SD (%)	Evaluation (years)
1	29	R	28	4	3	32	1
2	48	L	15	2	2	25	2
3	48	R	20	3	2	20	1
4	63	R	10	2	3	26	2
5	41	L	31	4	5	59	0.5
6	73	R	20	4	3	45	6
7	57	R	11	4	4	35	1
8	61	L	14	2	4	23	2
9	28	R	13	2	3	50	1
10	39	L	15	3	2	9	2
11	56	R	10	2	2	21	2
12	46	L	13	2	1	10	3
13	50	L	18	3	2	34	0.5
14	29	R	30	4	2	78	2.5
15	37	L	17	3	3	60	5
16	64	R	36	4	4	6	5
17	66	R	15	3	2	2	4
18	56	R	16	2	2	17	0.5
19	46	L	16	2	1	1	4
20	30	L	47	4	5	35	1
21	21	R	42	4	5	39	2
22	59	R	13	2	3	21	2
23	33	R	17	2	4	16	4
24	63	L	23	3	2	30	0.75
25	34	L	16	3	1	25	0.5
26	36	L	11	2	2	1	3
27	38	R	34	4	3	22	6
28	64	R	14	2	2	30	7
29	68	R	21	3	3	13	4
30	38	L	47	4	5	17	3
31	49	L	19	4	3	4	1
32	61	R	14	2	1	18	1
33	51	L	17	3	5	30	4
34	25	L	24	4	2	12	1
35	64	R	20	4	3	26	4
36	54	L	25	4	3	17	3

the Centre of foot Pressure (CoP) in the Anterior–posterior (AP) and medio-lateral (ML) directions. Each assessment included four tests—the stance on the firm surface with eyes open, the stance on the firm surface with eyes closed, the stance on the foam surface with eyes open and the stance on the foam surface with eyes closed. Each test took 50 s. The CoP parameters were calculated: the velocity of CoP in AP and ML directions, amplitudes of CoP in AP and ML directions, line integral, root mean square and total area [8]. Software MATLAB was used to calculate these parameters.

For subjective assessment of the impact of the postural problems caused by unilateral vestibular loss after the surgery we used the validated questionnaire Activities—Specific Balance Confidence Scale (ABC). It contains 16 questions concerning daily routine activities. Patients express perceptually their assurance of the postural control during the activities [14].

Very soon after surgery all patients underwent intensive supervised vestibular rehabilitation programme. Subjects received exercises designed to improve gaze stability, habituation and balance. The physiotherapist designed the specific exercises for the concrete individual in order to treat their particular symptoms. Vestibular adaptation exercises were used for treating impairments in gaze stability. Habituation exercises were used for treating subjective dizziness during specific position changes. Exercises that manipulate balance sensory modalities were used to improve postural stability, this part of exercises used visual biofeedback. Patients trained on force platform and they were instructed to move their CoP represented by a cursor on a tablet connected to the platform [8]. Various balance exercises were used to target different aspects of balance function, namely steadiness, symmetry and dynamic stability (e.g., a patient stood with feet shoulder-width apart with eyes open, looking at a monitor screen and shifting the body weight to place the cursor into targets marked on the monitor). The rehabilitation programme was provided by at the Department of Rehabilitation and Exercise Medicine, 2nd Faculty of Medicine, University Hospital Motol, Charles University, Prague.

Numeric normally distributed (parametric) data are presented as mean ± SD, other numeric data as median (range). Parametric data were statistically analysed using repeated measures ANOVA with Fisher post-hoc test or Student's *t* test. Non-parametric data were analysed using Mann–Whitney test. Analysis was performed using STATISTICA v13.3 (TIBCO, US). Level of statistical significance was set at $p < 0.05$.

Results

We had two different groups in our study with dissimilar number of subjects. Mean of total age was 47.9 ± 13.2 standard deviation, in prehabilitated group 49.1 ± 14.4, in group without gentamicin 47.3 ± 12.8. We did not notice difference with level of statistical significance at $p < 0.05$ between the groups. We also did not remark difference with level of statistical significance at $p < 0.05$ between the groups in tumour size. Mean in total was 22.1 ± 10.6 mm, in prehabilitated group 17.2 ± 7.1 mm and in group without gentamicin 24.4 ± 11.1 mm. There was no difference with level of statistical significance at $p < 0.05$ in years of evaluation of patient's problems to indication to surgery. The median in prehabilitated group was 2.0 years with range 0.5–6.0, in group without gentamicin was 2.0 years with range 0.5–7.0. We did caloric test in time of surgery indication, before gentamicin application and surgery. Patients included in prehabilitated group have mean canal paresis with side difference 26.7 ± 15.2, the group without gentamicin has mean canal paresis with side difference 28.9 ± 23.1. We did not notice difference with level of statistical significance at $p < 0.05$ between the groups (Table 1).

Standard CoP parameters were evaluated during the course of postoperative treatment [15]. Because of very similar results in each type of measurement we focused on evaluation of total area, tested on the foam surface with eyes closed (Fig. 1). The analysis of total area demonstrated significant difference between particular time

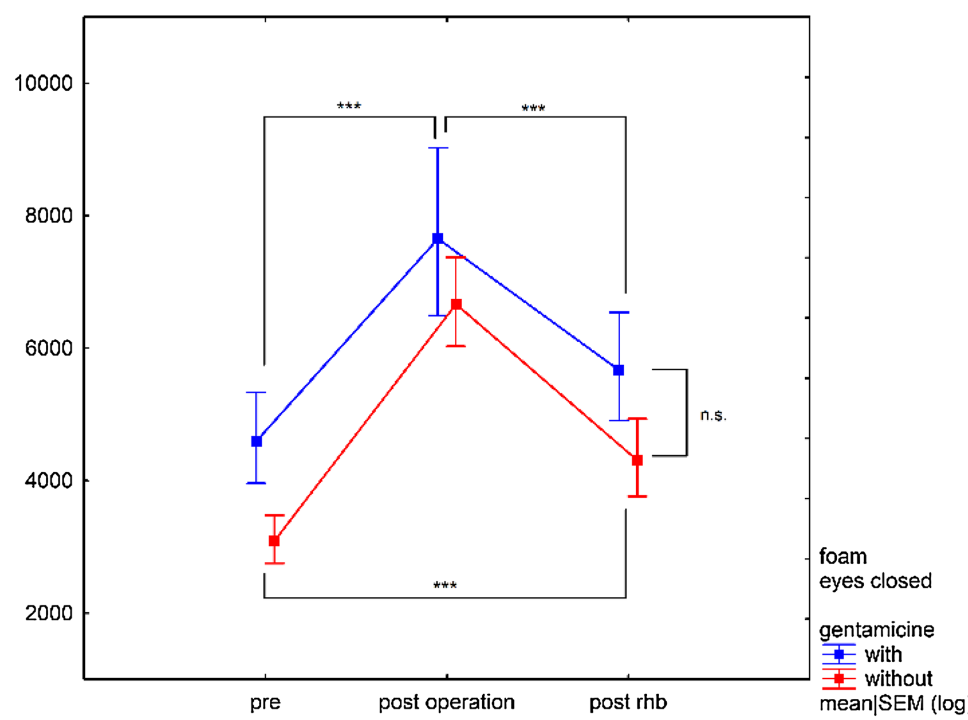

Fig. 1 Comparison of the group prehabilitated with gentamicin and the group without gentamicin in total area parameter in posturographic measurement tested on the foam surface with eyes closed before the surgery, in early post-surgery period and on the day of discharge after vestibular rehabilitation

period of measurement. Mean total area of CoP before surgery was 4592 mm^2 in prehabilitated group and 3090 mm^2 in group without gentamicin. Mean total area of CoP in early post-operative period was 7656 mm^2 in prehabilitated group and 6668 mm^2 in group without gentamicin. Mean total area of CoP in period after rehabilitation was 5662 mm^2 in prehabilitated group and 4305 mm^2 in group without gentamicin. We did not notice difference with level of statistical significance at $p < 0.05$ between the groups. We can see positive trend in group without gentamicin in compare of prehabilitated group.

The analysis of subjective visual vertical deviation demonstrated significant difference between particular time period of measurement. Mean SVV deviation before surgery was 2.3° in prehabilitated group and 0.7° in group without gentamicin. Mean SVV deviation in early post-operative period was 4.6° in prehabilitated group and 4.7° in group without gentamicin. Mean SVV deviation in period after rehabilitation was 3° in prehabilitated group and 3.3° in group without gentamicin. Although the SVV deviation was more significant in prehabilitated group, we noticed similar result in already 2 weeks after vestibular rehabilitation. Whether these trends there was no difference between groups with level of statistical significance at $p < 0.05$ (Fig. 2).

Mean ABC score before surgery was 91 points in prehabilitated group and 92 points in group without gentamicin. Mean ABC score in early post-operative period was 63 points in prehabilitated group and 60 points in group without gentamicin. Mean ABC score in period after rehabilitation was 81 points in prehabilitated group and 80 points in group without gentamicin. There was no difference between the groups, but a significant difference between measurements before and after surgery and after rehabilitation. These results confirm our data of objective methods (Fig. 3).

Discussion

Surgical removal of vestibular schwannoma leads to sudden unilateral deafferentation of vestibular function [3, 16]. That is why most patients report vertigo and disturbed postural control during immediate postsurgical period. Our department is a centre of microsurgical treatment of pontine angle tumours in our country. We try to manage new treatment protocol to improve quality of life in our patients. We have decided to add protocol with vestibular prehabilitation. The idea of chemical presurgical ablation of vestibular function on the side of the tumour with paralleled rehabilitation helps to separate two traumas of vestibular schwannoma surgery (surgical procedure with traumatisation of cerebellum and brainstem and acute vestibular loss) [11]. The possibility, how to achieve this separation, is chemical ablation of vestibular system with ototoxic antibiotic gentamicin installed intratympanically. It causes a reduction or even an ablation of vestibular function on the side of the lesion [11]. We administered three intratympanic injections of nonbuffered gentamicin at each application during one day (minimum of 2 h between each administers) with patients included to

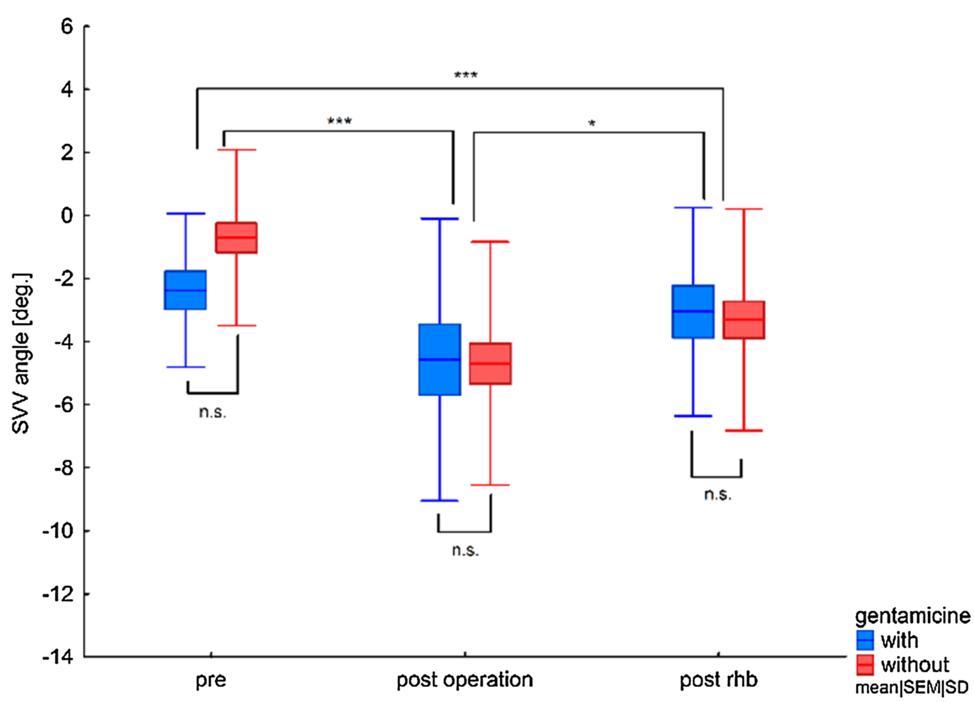

Fig. 2 Comparison of the group prehabilitated with gentamicin and the group without gentamicin in subjective visual vertical (SVV) measurement before the surgery, in early post-surgery period and on the day of discharge after vestibular rehabilitation

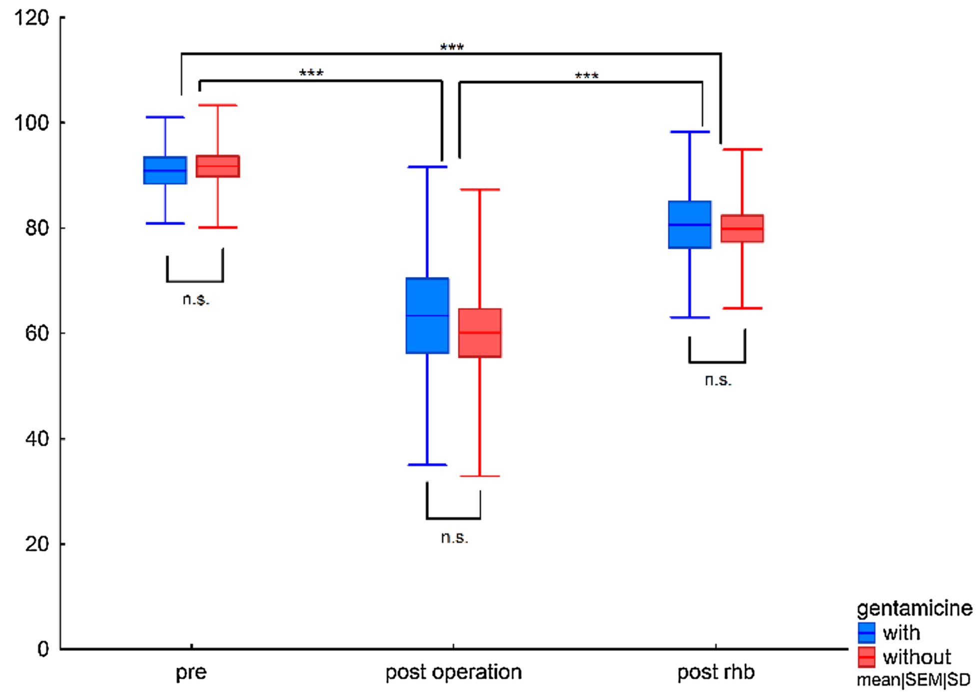

Fig. 3 ABC score filled by patients before the surgery, in early post-surgery period and on the day of discharge after vestibular prehabilitation. Patients were divided in the group prehabilitated with gentamicin and the group without gentamicin

prehabilitated group. Sufficient dose of gentamicin application to cause vestibular ablation was controlled by clinical examination with newly formed spontaneous nystagmus and positive head impulse test. In several cases this treatment was not efficient and we had to add next applications of gentamicin. The maximum number was six doses in all. It has been shown that with ablation the compensatory process is accelerated and patients feel reduction of vestibular symptoms [10, 11, 16]. After 6 weeks of vestibular rehabilitation there was compensated unilateral vestibular lesion, without spontaneous nystagmus and with positive head impulse test. We did caloric stimulation after gentamicin installation in case of disputable results of vestibular ablation by clinic tests. It is not certain if this procedure can be employed generally in each patient who is planned for surgery and has some vestibular function preserved. There is some risk of preoperative hearing deterioration with intratympanic gentamicin treatment. That is why we generally did not suggest prehabilitation in patients with potential for serviceable hearing preservation. This is one of the reasons, why we have a smaller number of patients in the group with prehabilitation. Another reason for the difference in the amounts of subjects in the groups is that large tumour with high risk to morbidity of surgical delay and a patient's disagreement to intratympanic administering of gentamicin.

Another option, how to speed up the compensatory process, is employment of intensive vestibular rehabilitation, which is focused on improving the ability to stabilize the retinal image during movement and also the postural stability [7, 16]. But several publications reported no positive influence of intensive rehabilitation program after surgery [17, 18]. We decided to include intensive vestibular rehabilitation to our postsurgical treatment in each patient. This procedure should be provided with the highest frequency as possible according to patient's health status. The rehabilitation should be used as soon as possible after surgery [16]. Assistance of supervising physiotherapist during the rehabilitation following the surgery to avoid injuries and learning incorrect movements during exercising is advantageous. Incorporation of visual biofeedback into the rehabilitation program speeds up improvement of postural instability as well [8]. The visual biofeedback is user friendly and constructed for at home rehabilitation as well. Finally, it makes the rehabilitation more entertaining for patients.

First aim of our study was to determine if employment of prehabilitation speeds up the recovery process following retroisigmoid vestibular schwannoma surgery. We got the idea from publications by Magnusson's group [10, 11, 19]. We divide our patients into two defined groups. We administered gentamicin intratympanically before surgery with equal dose in majority of our patients. We used similar rehabilitation protocol in prehabilitated group. On the other hand, we used different values to measurement—subjective visual vertical measurement, posturography system without vibrotactil stimulation, we compared our objective results with subjective assessment by questionnaire. We had similar, but not equal battery of measurement of vestibular function. In our study we used clinic neurootologic examination of vestibulo-ocular reflex with head impulse test, objective measurement included electronystagmography with caloric stimulation, subjective visual vertical measurement, static posturography and ABC questionnaire. If we compare our results with results of Magnusson's group, our results do not correspond with theirs. Our results show the non-significant difference between prehabilitated group and group without gentamicin in all studied parts of measurement—posturography, SVV deviation and ABC score during short-term period after surgery. But it cannot be compared literally, because these studies are not conducted by the same protocol of measurements.

There are several reasons, why we have different conclusions by our methods. Firstly, we used mostly the retrosigmoid approach during surgery unlike using the translabyrintal approach [10, 11]. There is destruction of receptor organ of vestibular system without affecting the cerebellum in translabyrintal approach, so it is less invasive surgical method in indicated cases [20]. There is manipulation of cerebellum during the surgery by the retrosigmoid approach. It often causes combined vestibular loss after surgery. Patients with combined vestibular loss have slower compensatory process than patients with peripheral unilateral vestibular loss independently in application prehabilitation. It can be one of the reasons, why we have similar conclusions between groups. Secondly, the prehabilitation with gentamicin mostly leads to reduction of vestibular system on the side, not complete ablation in our patients. Maximal side difference was 92% in our patients with maximum administering gentamicin intratympanically with six doses in all, in contrast of 100% side difference in most patients in study of Magnusson's group [21, 11]. There is a reason, why our patients have vestibular symptoms after vestibular schwannoma surgery despite the pre-surgical prehabilitation with compensation of the lesion. Thirdly, several patients in group without gentamicin with large tumours growing for years had compensated unilateral vestibular loss because of central compensation process proceeding by period of growing time.

The second aim of our study is to describe if the postoperative rehabilitation with visual biofeedback can accelerate compensation process in short-time postsurgical period. Some studies reported, that there is no significant positive influence of intensive rehabilitation after vestibular schwannoma surgery in acute postoperative period [17, 18]. According to our results, we noticed a significant difference during the time periods—presurgical, postsurgical and after intensive rehabilitation even in short-time period after surgery in both groups. We have a comparison of subjective assessment by validated questionnaire ABC with objective methods including deviation of SVV and parameters in static posturography. The main difference is shown in the total area parameter in posturography measurement, tested on the foam surface with eyes closed.

Conclusion

Vestibular prehabilitation with preoperative chemical ablation of vestibular function does not significantly accelerate vestibular compensation after surgical vestibular schwannoma removal in our set of patients during the short-term postsurgical period. However, the intensive rehabilitation program is the crucial part of treatment, which supports vestibular compensation after unilateral vestibular deafferentation even only after few days following surgical removal of vestibular schwannoma.

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Compliance with ethical standards

Conflict of interest Authors have no competing interests to declare.

Ethical approval The study protocol was approved by the local ethical committee.

Informed consent All participants gave their oral informed consent documented in the medical records.

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