Research Report

Effects of Positioning and Exercise on Intracranial Pressure in a Neurosurgical Intensive Care Unit

Background and Purpose. The purpose of the study was to assess the safety of physical therapy by investigating its effects on intracranial pressure (ICP) and cerebral perfusion pressure. **Subjects.** The subjects were 65 patients in a neurosurgical intensive care unit who had normal ICP (<15 mm Hg) or increased ICP (>15 mm Hg). **Methods.** Intraventricular ICP was measured in a 30-degree head-up position (all patients) and in supine and 45-degree head-up positions (patients with normal ICP) during passive range of motion (comatose patients) and exercises involving limb movement (awake patients). **Results.** In patients with normal ICP, passive range of motion decreased mean ICP by 1 mm Hg in the supine position but not in the head-up position. In patients with high ICP, it decreased ICP by 2 mm Hg. Limb exercises left the mean ICP essentially unchanged in both the patients with normal ICP and the patients with high ICP. Isometric hip adduction increased mean ICP by 4 mm Hg in patients with normal ICP. It did not affect ICP in patients with high ICP. Limb movement was associated with suppression of abnormal ICP waves and improvement of consciousness in 13 patients. **Conclusion and Discussion.** Physical therapy can be used safely in patients with normal or increased ICP provided that Valsalva-like maneuvers are avoided. [Brimioulle S, Moraine J-J, Norrenberg D, Kahn RJ. Effects of positioning and exercise on intracranial pressure in a neurosurgical intensive care unit. *Phys Ther.* 1997;77:1682–1689.]

Key Words: *Cerebral perfusion pressure, Intracranial hypertension, Intracranial pressure, Neurosurgery, Physical therapy.*

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Intracranial hypertension is commonly observed in persons with serious injuries and diseases of the central nervous system.[1–4] Intracranial hypertension is said to be a good indicator of a bad prognosis in persons with head trauma,[1] subarachnoid hemorrhage,[2] and intracerebral hemorrhage.[3] Monitoring and control of the intracranial pressure (ICP) are therefore recommended,[4] although the benefit on clinical outcome remains controversial. Therapeutic options to decrease ICP include ventricular drainage, controlled hyperventilation, osmotic diuretics, glucosteroids, and high-dose barbiturates.[4,5] To prevent further increases in ICP, the patient's head is often elevated and stimulation of the sympathetic nervous system is avoided.[4,6]

Exercise stimulates the sympathetic nervous system.[7] Physical therapy treatments, therefore, could increase ICP, although such an increase has not been documented. Physical therapy has been reported to precipitate *plateau* waves (ie, ICP waves appearing and ending suddenly, reaching 25–60 mm Hg, and sustained for 1–10 minutes) in patients with brain injury.[8] Plateau waves may result in neurological worsening and sometimes even in brain death.[8] The incidence and severity of adverse effects of exercise in patients with intracranial hypertension thus are not known. To our knowledge, the effects of exercise on ICP have never been addressed specifically.

We, therefore, investigated, in patients with normal and increased ICP in a neurosurgical ICU, whether some physical therapy procedures caused deleterious effects on ICP and cerebral perfusion pressure (CPP). Both passive range of motion (PROM) and exercises were investigated because they are applied to different groups of patients, may cause a different degree of stimulation, and thus may affect the ICP differently. Patients with normal ICP and patients with high ICP were studied separately, with different interventions used, because clinical deterioration could have occurred with some procedures in patients with intracranial hypertension.[4] Because position influences the ICP and thus may interfere with the effects of some physical therapy procedures, patients with normal ICP were studied in several positions. Patients with high ICP were studied only in the most recommended position (ie, 30° head-up position).

Method

Subjects

Sixty-five patients were studied (Tab. 1). Criteria for inclusion were presence in the neurosurgical ICU, avail-

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This study was conducted in accordance with the Declaration of Helsinki of the World Medical Assembly and was approved by the Erasme University Hospital Ethical Committee.

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Table 1.
Description of Patients at Time of the Study[a]

	Passive Range of Motion		Exercise	
	Normal ICP	High ICP	Normal ICP	High ICP
No. of patients	30	12	15	8
Age (y)	41 (3–78)	44 (8–68)	56 (26–75)	51 (36–85)
Length of stay in ICU (d)	2 (1–13)	2 (1–11)	2 (1–6)	2 (1–7)
Glasgow Coma Scale score	6 (3–15)	5 (3–11)	14 (11–15)	13 (11–15)
Gender (M:F)	22:8	6:6	6:9	5:3
Surgery	16	5	10	7
IPPV	23	10	2	
Trauma	15	7	2	
ICH	10		5	
SAH	5	3	3	7
Miscellaneous		2	5	1

[a] Age, length of stay in intensive care unit (ICU), and Glasgow Coma Scale score expressed as median and range (in parentheses). ICP=intracranial pressure, IPPV=intermittent positive pressure ventilation, ICH=intracerebral hemorrhage, SAH=subarachnoid hemorrhage.

ability of ICP monitoring, and ICP stability allowing a correct interpretation of the ICP changes during the study. Patients with continuous intraventricular cerebrospinal fluid drainage or fluctuations in ICP that led to frequent fluid drainage were not accepted. Persons with abnormal ICP waves were accepted if the waves were regular in frequency and amplitude and did not meet the criteria for A waves (plateau waves) or B waves (cyclic waves occurring one to two times a minute and reaching 20 mm Hg).[8] Intracranial pressure monitoring had been started in these patients because of their neurological status (Glasgow Coma Scale score of less than 8 out of 15) or because of surgery for a ruptured intracranial aneurysm.[8] At the time of the study, each patient's neurological status was stable, as assessed by the clinical examination and by the Glasgow Coma Scale score.[8] Patients with intracranial hypertension were being treated according to standard recommendations,[4–8] including cerebrospinal fluid drainage (which could be interrupted for the duration of the study without deleterious effect) and high-dose barbiturates (3–7 mg per kilogram of body weight per hour) in the most severe cases.

Patients were divided into two groups according to their level of consciousness. Patients who were comatose or stuporous and therefore unable to collaborate formed the group that received PROM. Patients with a level of consciousness sufficient to allow active participation formed the group that received limb exercise. Both groups were subdivided into a group with normal ICP values and a group with high ICP values, according to each patient's ICP value at the beginning of the study. "Normal ICP" refers to values less than 15 mm Hg and "high ICP" refers to values greater than 15 mm Hg when the subject is at rest in the 30-degree head-up position.[8] "Head-up position" refers to trunk and head elevation from the horizontal, with the head remaining in neutral position with respect to the trunk. For each group of patients, Table 1 summarizes the gender and age, the length of stay in the ICU, the neurological status as assessed by the Glasgow Coma Scale score at time of the study, the incidence of surgery and of mechanical ventilation, and the main neurological diagnosis.

Measurements

Intracranial pressure was monitored through a catheter inserted into one of the lateral cerebral ventricles. The zero pressure reference was set at mid-distance between the lateral canthus and the tragus (level of foramen of Monro). Intracranial pressure was recorded continuously during the study, using a Statham P23 or P50 pressure transducer,* a Sirecust 404 signal processor,† and an HP7404A multichannel recorder.‡ Electrocardiographic activity and systemic arterial pressure (SAP) were recorded simultaneously when continuous monitoring was available (39 out of 65 patients). Cerebral perfusion pressure was computed as (SAP − ICP), with SAP being referenced at the same zero level as ICP. All pressures were expressed as mean pressure and were averaged over the last 30 seconds of each observation period (rest or exercise). The pressure monitoring system was verified using an electronic pressure generator,§ which was calibrated once a week against a mercury

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manometer. The permeability of the ventricular catheter and the time response of the measurement system were verified—by the absence of wave damping during quick pressure changes—at the beginning of the study and after each change in patient position. The study was done during the day, during either a regular physical therapy session or an additional session at the end of the afternoon.

Passive Range of Motion

The 30-degree head-up position, which is generally recommended to minimize ICP in neurosurgical ICUs, was selected as reference position.[4] In patients with normal ICP, a set of measurements was obtained, in a random sequence, in a supine position and in 30- and 45-degree head-up positions. Patients with high ICP were studied only in the 30-degree head-up position. In each position, measurements were done at rest, during the therapist's movement of the upper and lower limbs in a random order, and again at rest. Passive range of motion consisted of moving one upper limb and one lower limb over the greatest available range of motion, which we expected would generate the most important stimuli. Upper-extremity PROM was shoulder flexion to 150 to 180 degrees from the rest position while the forearm and hand were maintained in a neutral position. Lower-limb PROM was hip flexion to 90 to 150 degrees from the horizontal while the leg was maintained horizontal and the foot remained in a neutral position. Each movement was repeated passively about 10 times a minute for 2 minutes. Passive range of motion in each position was delayed until at least 5 minutes after stabilization of the heart rate, SAP, and ICP. Passive range of motion was delivered to either the right limb or the left limb, depending on the presence or absence of injuries in the limbs.

Exercise

All measurements were taken with the patient in the 30-degree head-up position. The exercises consisted of (1) shoulder flexion from the rest position up to 150 to 180 degrees while the forearm and hand were maintained in a neutral position, (2) maximal flexion of the hip, knee, and foot (dorsiflexion), (3) knee extension from 120 to 180 degrees while the thigh was maintained at 30 degrees from the horizontal by the physical therapist, and (4) hip flexion from 0 to 30 degrees from the horizontal while the knee remained extended. All exercises were repeated actively about 10 times a minute for 2 minutes. The fifth exercise used isometric contractions and consisted of contraction of the adductor muscles of the hip. The patient was told to "compress the hand" of the physical therapist while the therapist's hand was inserted between the patient's knees, with the knees flexed to 90 degrees and the feet resting on the bed. Adduction was sustained for at least 5 seconds and was repeated 5 to 10 times according to the patient's capability. Measurements were taken with the patient at rest, during the different exercises done in a random sequence, and again at rest. Exercises did not start until at least 5 minutes after stabilization of the heart rate, SAP, and ICP (no change on monitor display or paper recording). Exercises were done with either the right limb or the left limb, depending on the presence or absence of injuries in the limbs.

Data Analysis

Results are reported as mean values (± standard error). Statistical analysis consisted of an analysis of variance for repeated measures.[9,10] Changes due to treatment were analyzed with either one factor (motion type) or two factors (position and motion type). When factors showed a significant effect or interaction, hypotheses comparing specific observation periods were analyzed using the contrasts method.[9,10]

Results

Body Position

Data for the effects of body position on heart rate, SAP, ICP, and CPP are shown in Table 2. Body position, studied only in patients with normal ICP, did not affect heart rate. At rest, changing from the 30-degree head-up position to the supine position decreased SAP by 2±1 mm Hg ($P<.05$). At rest, compared with the reference 30-degree head-up position, the supine position increased ICP by 6±1 mm Hg ($P<.01$) and increased CPP by 3±1 mm Hg ($P<.05$). At rest, further head elevation from 30 to 45 degrees did not affect ICP but decreased CPP by 6±1 mm Hg ($P<.001$).

Passive Range of Motion

Data for the effects of PROM on heart rate, SAP, ICP, and CPP are shown in Table 2. No differences were observed for any variable between rest periods before and after limb movement or between motions of the upper and lower limbs. Data for the rest periods and motion periods were thus grouped for further analysis. Passive range of motion slightly increased heart rate and did not affect SAP. In patients with normal ICP, an interaction was observed between the effects of position and those of motion ($P<.01$) (Figs. 1 and 2). Motion did not affect ICP or CPP in the 30- and 45-degree head-up positions, but it decreased ICP by 1±1 mm Hg ($P<.05$) and increased CPP by 3±1 mm Hg ($P<.05$) in the supine position. In patients with high ICP, PROM decreased ICP by 2±1 mm Hg ($P<.01$) and increased CPP by 7±2 mm Hg ($P<.02$). In four patients with normal ICP and in four patients with high ICP, PROM was associated with a suppression of abnormal ICP waves (recorded on the ICP tracing) and with an improvement in consciousness (reported by the physical therapist).

Table 2.
Effects of Body Position and Passive Range of Motion in Patients With Normal ICP (<15 mm Hg, n=30) and in Patients With High ICP (>15 mm Hg, n=12)[a]

	HR (bpm)		SAP (mm Hg)		ICP (mm Hg)		CPP (mm Hg)	
	X̄	SE	X̄	SE	X̄	SE	X̄	SE
Patients with normal ICP								
30°, rest	94	4	106	4	9	1	86	4
30°, motion	97	4[b]	107	4	8	1	87	4
45°, rest	95	5	107	4	8	1	80	4[c]
45°, motion	98	4[b]	107	4	8	1	80	4
0°, rest	94	5	104	4[c]	15	1[c]	89	4[c]
0°, motion	96	5[b]	106	4	14	1[b]	92	4[b]
Patients with high ICP								
30°, rest	97	5	120	8	21	1	88	6
30°, motion	103	5[b]	124	8	19	1[b]	95	7[b]

[a] HR=heart rate, SAP=systemic arterial pressure, ICP=intracranial pressure, CPP=cerebral perfusion pressure.
[b] $P \leq .05$, motion versus rest in the same position.
[c] $P \leq .05$, 45° versus 30° or 0° versus 30° while at rest.

Table 3.
Effects of Exercise in Patients With Normal ICP (<15 mm Hg, n=15) and in Patients With High ICP (>15 mm Hg, n=8)[a]

	HR (bpm)		SAP (mm Hg)		ICP (mm Hg)		CPP (mm Hg)	
	X̄	SE	X̄	SE	X̄	SE	X̄	SE
Patients with normal ICP								
Rest	79	4	110	3	9	1	89	4
UL motion	85	4[b]	110	2	9	1	90	2
LL motion	88	5[b]	113	2[b]	10	1	92	2[b]
Knee adduction	92	5[b]	119	3[b]	13	1[b]	96	3[b]
Patients with high ICP								
Rest	74	5	116	5	18	1	87	6
UL motion	83	4[b]	116	3	15	1[b]	90	4
LL motion	84	4[b]	118	3	17	1	89	4
Knee adduction	89	4[b]	119	3	18	2	90	4

[a] HR=heart rate, SAP=systemic arterial pressure, ICP=intracranial pressure, CPP=cerebral perfusion pressure, UL=upper limb, LL=lower limb (grouping of three exercises).
[b] $P<.05$, motion or adduction versus rest.

Both changes usually disappeared soon after discontinuation of limb movement.

Exercise

Data for the effects of exercise on heart rate, SAP, ICP, and CPP are shown in Table 3. No differences were observed between rest periods before and after limb movement or between the three exercises involving movement of the lower limbs. Data for the rest periods and lower-limb exercise periods were thus pooled for further analysis. In patients with normal ICP, exercises increased heart rate ($P<.001$), slightly increased SAP and CPP ($P<.05$) during lower-limb motion, and did not affect ICP. In patients with high ICP, exercises increased heart rate ($P<.001$), did not affect SAP and CPP, and decreased ICP ($P<.05$) during upper-limb movements. Isometric contraction of the adductors had different effects in the two groups. In patients with normal ICP, it increased heart rate, SAP, ICP, and CPP when compared with rest ($P<.001$) or with exercises with movement ($P<.001$). Intracranial pressure increased above 30 mm Hg in some patients (Fig. 3), and headache occurred in 8 of the 15 patients. These effects were transient, and variables usually returned to baseline within 1 minute after the end of the exercise. Systemic arterial pressure, ICP, and CPP were comparable at rest, during exercises with movement, and during the isometric contractions in patients with high ICP. In 1 patient with a normal ICP and in 4 patients with high ICP, exercises with movement resulted in the suppression of abnormal ICP waves and in an improvement of consciousness. Both changes usually disappeared soon after discontinuation of the exercises.

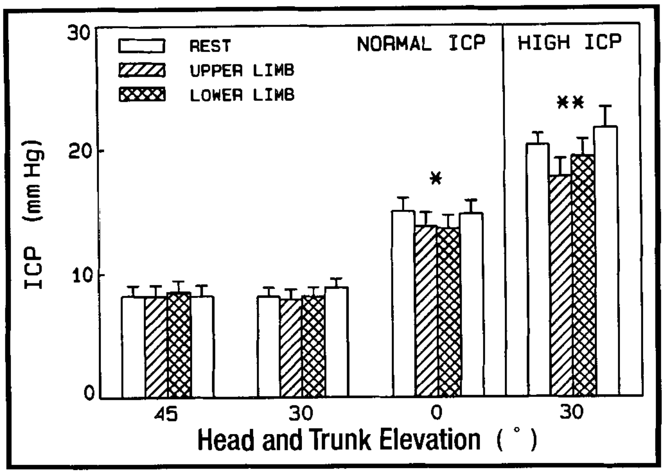

Figure 1.
Effects of passive ronge of motion on intracranial pressure (ICP)) ($\bar{X}\pm$SE) in patients with normal ICP (<15 mm Hg, n=30) and in patients with high ICP (>15 mm Hg, n=12). Asterisk (*) denotes P=.026, double asterisk (**) denotes P=.003 (rest versus limb movements in the same position), by contrast analysis.

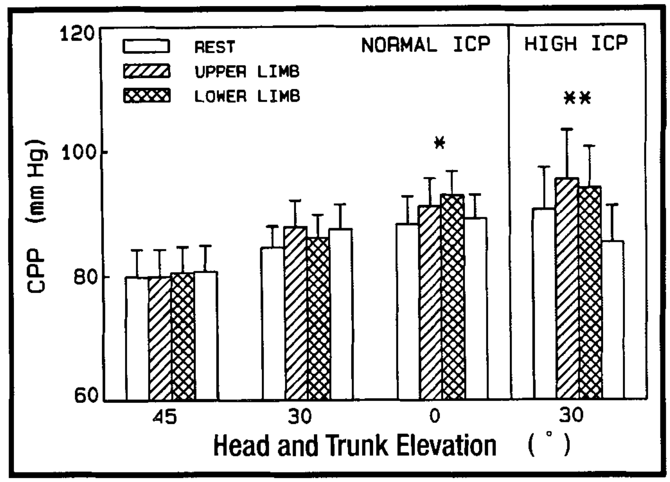

Figure 2.
Effects of passive range of motion on cerebral perfusion pressure (CPP) ($\bar{X}\pm$SE) in patients with normal ICP (<15 mm Hg, n=18) and in patients with high ICP (>15 mm Hg, n=8). Asterisk (*) denotes P=.049, double asterisk (**) denotes P=.011 (rest versus limb movements in the same position), by contrast analysis.

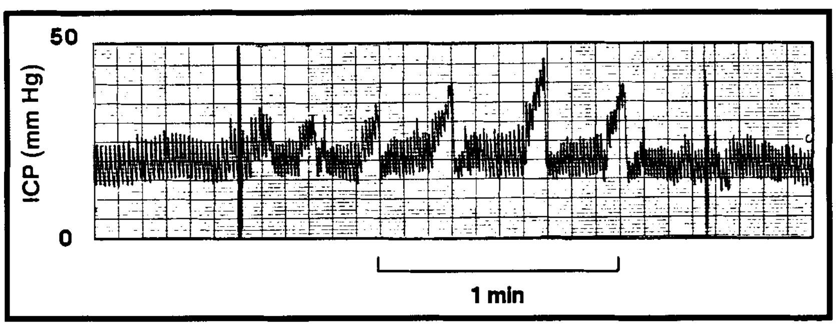

Figure 3.
Typical intracranial pressure (ICP) recording during hip adduction. Intracranial pressure increased and decreased immediately after initiation and discontinuation of the exercise, respectively, in most patients who performed the exercises adequately. In several patients, ICP increased above 30 mm Hg at the end of the Valsalva-like maneuver.

Discussion

Body Position

Standard recommendations for control of intracranial hypertension include elevation of the patient's trunk and head to 30 degrees from the horizontal.[4] This position has been selected in our department for patients with brain injury and was therefore used during our study of patients with high ICP. Supine and 45-degree head-up positions are also commonly used during physical therapy and respiratory therapy sessions for patients with critical illness. We, therefore, studied the use of these positions by patients with normal ICP to assess whether the effects of physical therapy on ICP would be affected by body position. For ethical reasons, patients with high ICP were excluded from this part of the study.

Recent studies[11,12] have demonstrated that progressive head elevation from 0 to 50 degrees decreases CPP as well as ICP. The investigators in these studies concluded that a supine position would be more appropriate to maintain CPP in patients with intracranial hypertension. In our patients with normal ICP, the same trend in CPP was found between 0 and 45 degrees. The benefit of the supine position over the 30-degree head-up position (3 mm Hg), however, is of doubtful clinical importance and is associated with a substantial increase in ICP (6 mm Hg). Use of a prolonged supine position also can lead to deterioration in respiratory function and gas exchange, increase arterial partial pressure of carbon dioxide, and decrease arterial partial pressure of oxygen, and thereby contribute to further increases in ICP over time.[13] We, therefore, suggest that, as long as CPP is maintained above the critical value of 60 to 70 mm Hg, the respiratory benefit of head elevation be accepted to outweigh the moderate CPP reduction. When CPP decreases below this critical value, the supine position could be tested in an effort to restore CPP. Close monitoring of ICP and CPP would be required, however, because hemodynamic responses to changes in body position can be different from patient to patient, depending on the patient's hydration status and cardiovascular status, especially during positive pressure ventilation.

Passive Range of Motion

Passive range of motion slightly increased heart rate and tended to increase SAP, presumably due to stimulation of the sympathetic nervous system. Despite the likely increased sympathetic activity, PROM did not worsen ICP or CPP. Moreover, it appeared to contribute to decreased ICP and increased CPP in the supine position and in patients with intracranial hypertension (ie, in conditions of higher ICP). This finding seems to contradict a previous study in which no change in ICP was noted during passive arm extension and hip flexion (some head elevation being mentioned but not quantified in the article).[14] In that study, however, the investigators agreed that the method used to measure ICP did not allow them to detect small changes. The manometer was monitored visually, and the circuit between the patient and the manometer was maintained open to allow fluid drainage during the study, which certainly had a damping effect on the ICP changes. Our study shows that PROM can be used safely in patients with normal and high ICP and that it even tends to improve ICP and CPP in conditions of higher ICP.

The increase in CPP is due to both an increase in SAP and a decrease in ICP. The mechanism of this ICP reduction is not obvious. Some of the patients appeared to synchronize their ventilatory rate with the limb movements, which could increase ventilation. No change in end-tidal carbon dioxide, however, was observed in the 5 patients in whom capnographic monitoring was available. Moreover, no change in ventilation was observed in the patients treated with positive pressure ventilation (33 out of 42 patients), which makes a large change in arterial carbon dioxide tension unlikely. More interestingly, PROM was associated, mainly in patients with high ICP, with a transient suppression of abnormal ICP waves and an improvement in consciousness. These changes were probably related to the patient stimulation. Intracranial pressure reductions have been observed in other studies during painful and sensory stimulation and during touching and talking to children.[15–17] Stimulation inhibits rapid eye movement (REM) sleep, which has been reported to increase ICP.[18,19] Reversing REM sleep or altered consciousness could thus possibly decrease ICP. Altogether, these observations are consistent with the hypothesis that, in our patients, the ICP reduction resulted from the stimulation occurring during PROM.

Exercise

Exercise had different effects on ICP and CPP, according to the type of exercises and the initial ICP. During exercises with movement, ICP and CPP remained essentially unchanged. During the isometric contractions, ICP and CPP increased in the patients with normal ICP but remained unchanged in the patients with high ICP. Visual observation of the patients during the exercises provided an explanation for the discrepancy between the patients with normal ICP and the patients with high ICP. In all patients (mainly the patients with normal ICP) who were able to perform the exercises adequately, hip adduction was associated with a sustained interruption of ventilation comparable to a Valsalva maneuver. Such a maneuver is expected to increase the intraabdominal and intrathoracic pressure and thus probably contributed to increases in ICP.[20] Patients with high ICP usually were unable to perform the exercises adequately (meaning that muscle contraction was absent or minimal), which explains the unchanged ICP and CPP in this group. The increase in ICP was associated with an increase in CPP and did not result in deterioration of the clinical neurological status. Exercise was instead associated with an improvement of consciousness in some patients, as was PROM. Thus, exercise can be used safely in patients with normal or high ICP. Isometric exercises, however, should be avoided or limited to prevent Valsalva-like maneuvers that lead to an increase in ICP or induce headache.

Our results should be extended with caution to patients with severe intracranial hypertension, because only few patients with an ICP above 30 mm Hg met the criteria for inclusion in the study. Due to their altered consciousness, however, these patients are usually unable to efficiently perform exercises. With regard to PROM, even if beneficial effects on ICP and CPP are recorded in patients with higher ICP, continuous monitoring of ICP and CPP remain warranted during stimulation of patients with severe intracranial hypertension.

Summary and Conclusions

We investigated the effects of position and the effects of PROM and exercise in patients with normal and high ICP in a neurosurgical intensive care unit. In comparison with the reference 30-degree head-up position, the supine position increased ICP and should be avoided in patients with intracranial hypertension. Passive range of motion did not increase ICP and even tended to decrease ICP in patients with intracranial hypertension. Exercise similarly tended to decrease ICP in patients with intracranial hypertension. In contrast, isometric contraction of the hip adductors transiently increased ICP in patients who did the exercises adequately, likely due to a Valsalva maneuver. We conclude that physical therapy procedures can be performed without deleterious effects by patients in a neurosurgical ICU. The supine position and Valsalva maneuvers, however, should be avoided, and ICP should be monitored closely in patients with severe intracranial hypertension.

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