Acta Neurochir (Wien) 110: 57–64

Acta Neurochirurgica

Neurosurgical Intensive Care Improves Outcome After Severe Head Injury

P.-E. Wärme[1], **R. Bergström**[2], and **L. Persson**[1]

Departments of [1] Neurosurgery and [2] Statistics, Uppsala University, Uppsala, Sweden

Summary

The present study compares the clinical outcome, as expressed by the Glasgow outcome scale, of two groups of severely head injured patients treated before (49 patients) and after (72 patients) the establishment of a neurosurgical intensive care (NIC) unit at the department of neurosurgery, Uppsala University Hospital. The number of "good recoveries" increased significantly after the establishment of the NIC. This was confirmed by univariate analysis ($p < 0.05$) and by multivariate analysis using the logistic regression model to adjust for differences between the two groups of patients ($p < 0.05$, $p < 0.005$). The most striking improvement was found in patients with a Glasgow coma motor score (GCS M) $\geqslant 4$ on admission. In this subgroup of patients the "good recoveries" increased from 15% to 52%. The object of NIC is basically to prevent or minimize secondary brain damage, and it seems logical that the effect of such care is most obvious in GCS M $\geqslant 4$ patients in whom a good outcome can be anticipated if secondary damage can be prevented or minimized.

In conclusion, the present study shows that improved clinical outcome after severe head injury can be achieved by organizing an NIC unit with a well trained staff capable of providing this care 24 hours a day using established methods of surveillance and treatment.

Keywords: Head injury; neurosurgical intensive care; clinical outcome.

Introduction

During recent decades neurosurgical intensive care (NIC) has developed into a subspeciality of neurosurgery for managing acute cerebral conditions such as head injury, cerebrovascular states, and complicated postoperative care, and many NIC units have been established. Clinical and experimental studies have made important contributions to the development of NIC, and head injury care can actually be considered as the embryo from which NIC has emerged.

Studies on management of head injury have shown the importance of careful neurological surveillance, urgent surgical removal of expansive haematomas, continuous monitoring of intracranial pressure (ICP), and treatment of raised ICP using controlled hyperventilation, osmotherapy, and deep barbiturate coma[1, 2, 4, 13, 15, 16, 19, 25]. The identification of complications that aggravate brain damage, such as hypotension, hypoxaemia, hyperthermia, and epileptic seizures, have also been significant for the development of NIC[23, 24].

Like other forms of intensive care NIC is costly. It is associated with complications, including those related to the prolonged use of intraventricular catheters, endotracheal tubes, multiple intravenous and intra-arterial lines, and the use of potentially harmful drugs. In individual patients such complications may even counteract the beneficial effects of the treatment. Most studies on head injuries have been focused on specific aspects of diagnosis and/or treatment rather than on the care as a whole. Studies devoted to the evaluation of NIC of patients with head injury have reached conflicting conclusions regarding the value of the "aggressive" management included in the concept of NIC[1, 3, 4, 5, 8, 11, 12, 17, 18, 22].

An NIC unit has recently been established at this department of neurosurgery. The resulting change in the management of severe head injury has enabled us to compare the clinical results of NIC with those of previous, more conventional care; this was the main object of the present study. Further, we wished to analyse in particular the effects on clinical outcome of so-called "avoidable factors"[24] appearing during the first week after injury.

Material and Methods

Patients

The present investigation is based on an analysis of the records of 358 patients with head injury. 121 patients had severe head injury defined as set out by Jennett *et al.*[10]. 49 of these patients were treated before (1980–81; Group I) and 72 after (1987–88; Group II) the

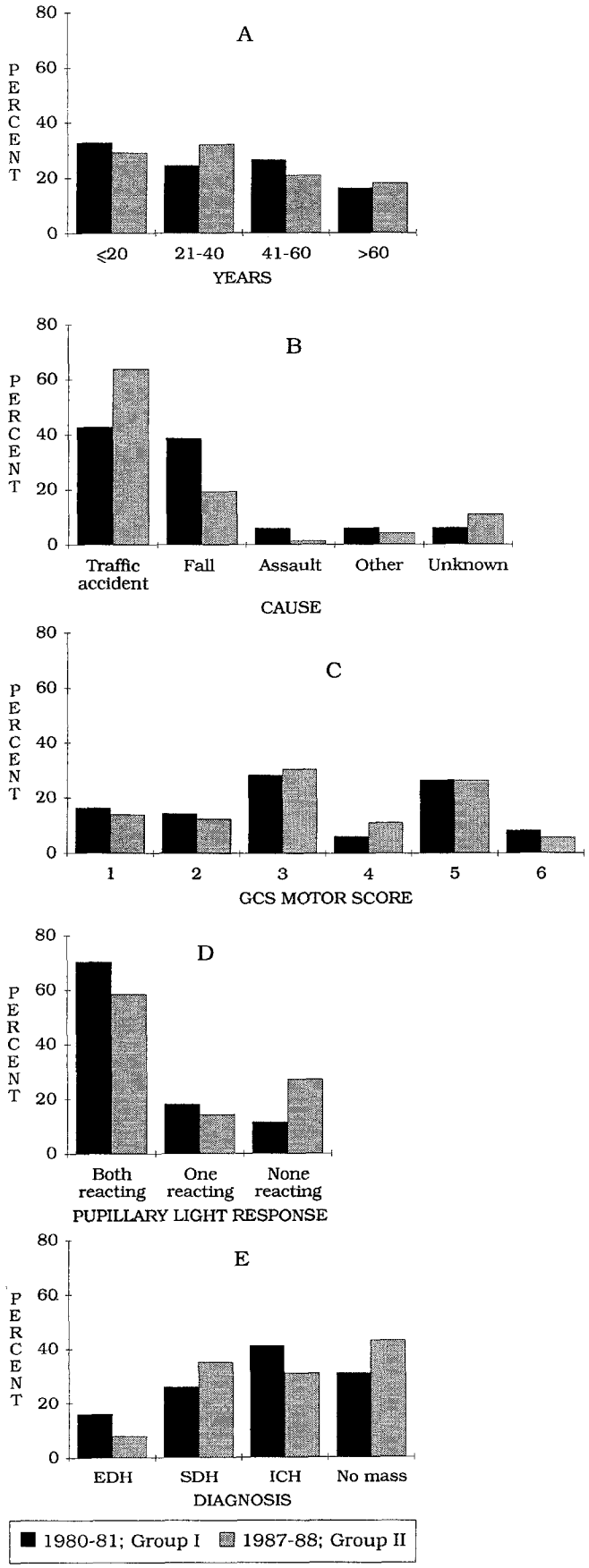

Fig. 1 A–E. A) Age distribution in the two series. B) Causes of the head injuries. C) Glasgow Coma Scale Motor score (GCS M) at the time of admission. D) Pupillary light response at the time of admission. E) CT diagnoses

establishment of the NIC unit. Patients undergoing surgery were included only if they remained in coma for more than 6 hours after operation. Patients dying within 6 hours of injury, and patients with penetrating head injuries were excluded. In 1980–81 28% and in 1987–88 39% of all head injured patients admitted were included in the study.

The mean age of the two groups was 37 and 36 years, respectively (Fig. 1 A). Traffic accidents were the predominant cause of injury, accounting for 43% and 64%, respectively (Fig. 1 B). Multiple injury, defined as associated chest injury, abdominal injury requiring surgical intervention, major fracture of one or more extremities, or spinal injury was present in 9 patients (18%) in Group I and in 13 patients (18%) in Group II. The extracranial injury was given priority in the initial management of 2 patients in Group I and 3 in Group II. The clinical state on admission was graded according to the Glasgow Coma Scale motor score (GCS M). The distribution of the GCS M score on admission was nearly identical in the two groups (Fig. 1 C). The few patients with a GCS M score of $\geqslant 5$ on admission deteriorated later to be classified as severe injury (Fig. 1 C). In Group I 59% and in Group II 57% of the patients had an abnormal reaction to pain stimulation (abnormal flexion, extension, or no reaction) on admission. The pupillary light responses differed somewhat (Fig. 1 D): a larger proportion of patients had bilaterally reactive pupils in Group I (70%) than in Group II (59%).

In both groups the diagnosis of the intracranial lesion was almost always based on computerized tomography (CT). The CT findings were categorized as epidural haematoma (EDH), acute subdural haematoma (SDH), intracerebral haematoma/expansive contusion (ICH), or "no-mass-lesion" (defined as normal CT, CT with signs of diffuse swelling, and/or with small, often scattered contusions; Fig. 1 E). In Group I 31% and in Group II 43% of cases were classified as "no-mass lesions".

Management

In Group I 76% of the patients and in Group II 65% were first admitted to one of the 22 hospitals in the region, and most were initially managed in telephone cooperation with the neurosurgical department before referral. Patients directly admitted to the university hospital unit were initially treated by a general surgeon and an anaesthesiologist. The initial resuscitation, including intubation of most unconscious patients, emergency care, and ambulance transport system were similar during the two periods.

Urgent evacuation of expansive intracranial haematomas was performed similarly during both periods, but the subsequent neurosurgical management differed in several respects. The major principles of management are shown in Table 1. One important difference was that on the NIC unit patients were treated by specially trained staff, and all aspects of the care were related to the underlying brain injury. Further, the neurological state was continuously assessed by doctors and trained NIC nurses and the parameters of the GCS, focal neurological signs and pupillary size and reactivity were noted on a bed-side observation chart, and the ECG, intra-arterial blood pressure, central venous pressure, cerebral perfusion pressure, arterial oxygen saturation, were continuously monitored. Factors known to aggravate ischaemic brain injury such as systemic hypo-

Table 1. *The Major Components of the Regimen Protocols Used in 1980–81 and in 1987–88*

"Conventional" neurosurgical care (1980–81)	Neuro-intensive care (1987–88)
Diagnostic methods	
* no neurological observation chart	* beside neurological observation chart
* CT scan on admission and in cases of deterioration 1.5 CT scans during the first week (mean value)	* repeated CT scan controls 2.3 CT scans during the first week (mean value)
* no ICP monitoring	* ICP monitoring in 46% of patients
Surgical management	
* expansive intracranial haematomas urgently evacuated	* expansive intracranial haematomas urgently evacuated
* lobe resection performed in 8% of patients in all cases combined with the evacuation of an intracranial focal mass	* lobe resection performed in 21% of patients one third of these performed in the absence of an intracranial focal mass
Non-surgical management	
General ICU if prolonged hyperventilation, respiratory complications, or multiple injuries present	General ICU only in severe multiple injuries
Respiratory care	
* 7.5 days of hyperventilation (mean value of survivors)	* 10.8 days of hyerventilation (mean value of survivors)
* 1.2 arterial blood gas analyses/day (first week)	* vigorous respiratory care 3.8 blood gas analyses/day (first week) and continuous monitoring of end-tidal carbon dioxide and in some cases pulsoximetry
* short period of weaning before extubation	* slow and controlled weaning with ICP-monitoring tracheostomy often used
Circulation	
* arterial line for continuous blood pressure in some cases	* arterial line for continuous blood pressure hypotension vigorously treated
* slight dehydration	* normovolaemia clear fluid for 1–2 days followed by total parenteral or enteral nutrition
Metabolism	
* no standardized treatment of hyperthermia	* standardized treatment of hyperthermia (> 38 °C) continuous body temperature control in selected cases
Steroids	
* steroids administered to 96% of patients	* steroids administered to 25% of patients
Mannitol	
* mannitol administered to 65% of patients	* mannitol administered to 76% of patients
High-dose barbiturates	
* high-dose thiopenhtone infusion (without ICP-monitoring) in 4% of patients	* high-dose thiopentone infusion in 14% of patients in all cases guided by ICP-monitoring and EEG

tension, hypoxaemia, hyperthermia, hyperglycaemia, and epileptic seizures were carefully watched for and treated throughout the period of NIC. In the 1987–88 period CT was used more frequently and was often repeated after 24 to 48 h.

In most severely injured patients with diffuse brain injury or intracranial haematomas not improving significantly after surgery the ICP was continuously monitored via an intraventricular catheter or an epidural pressure transducer (Honeywell). Rise in ICP was

treated when the baseline ICP exceeded 20–25 mmHg. Some patients with a lower baseline ICP but with frequent, high, plateau-like waves lasting for 5 min or more, often elicited by tracheal suction, were also considered to have an ICP increase requiring treatment. Controlled mild hyperventilation (PCO_2 3.5–4.5 kPa) was used in almost all cases in both groups of patients. During the 1987–88 period hyperventilation was generally used for longer periods, usually until the patient regained consciousness (obeying commands) or for about 14 days after injury, and weaning from the ventilator was slow and carefully checked clinically and in many cases with ICP monitoring. Further, in the 1987–88 period CSF drainage was sometimes done, but this was not regularly used to control ICP.

Osmotherapy was used similarly in both groups in emergency situations. In 1987–88, however, subsequent mannitol treatment was in most instances guided by ICP monitoring.

High-dose thiopentone infusion was used to treat elevated intracranial pressure in 4% of the Group I patients. In Group II 14% of the patients were thus treated, but under ICP-monitoring; this treatment was largely used in cases of raised ICP due to diffuse cerebral swelling.

Lobe resection was performed in 8% of Group I patients and in 21% of Group II patients. The indication was based on clinical deterioration and on CT findings in Group I and in Group II also on ICP-recordings. In some patients both barbiturate treatment and lobe resection were used.

High-dose steroid treatment was used less often in Group II and was in fact not included in the management protocol. In most instances the drug had been instituted before referral, and was withdrawn at the NIC unit.

Complications, that is, systemic hypotension, hypoxaemia, hyperthermia, and epileptic seizures, were systematically searched for in the medical records. The following definitions were used; systemic hypotension, systolic blood pressure < 90 mmHg on any occasion; hypoxaemia, PO_2 < 10 kPa on any occasion; hyperthermia, rectal temperature exceeding 39 °C on at least 2 separate occasions; the presence of seizures was based on clinical observation. Fewer notes on these parameters were found in the 1980–81 records than in those from 1987–88, and comparison of their true incidence would seem impossible. Available information from all patients of both groups was therefore used to study the relation between these complications and the clinical outcome.

Clinical Outcome

The clinical outcome 6 months after injury was assessed according to the Glasgow Outcome Scale (GOS)[9] as noted in hospital and practitioners records or at interviews.

Statistical Methods

In the univariate analyses of dichotomous variables Fisher's exact test was used to test for differences between groups. For categorial variables with more than two categories a standard chi-square test for homogeneity was employed. Differences between groups in the case of continuous variables were tested by the standard t-test.

In the multivariate analyses the logistic regression model was used. In this model it is assumed that the logarithm of the odds of "good recovery" is a linear function of explanatory variables such as period (1980–81 versus 1987–88), age, GCS M score on admission, pupil reactivity, "mass/no mass" lesion, presence or absence of multiple injury. The model enables estimation of the effects of variables after adjusting for the effects of other variables. From the estimated parameters of the model, the odds ratio (OR) associated with each variable was computed. The OR was used as the basic measure of relative risk in the multivariate analysis. The rather small number of observations meant that in models with many explanatory variables the estimated parameters were somewhat uncertain and the results should be treated with some caution.

Results

The clinical outcome 6 months after injury is shown in Fig. 2 A. In 1980–81 12% of the patients made a good recovery while 31% did so in 1987–88. This difference was significant in the univariate analysis ($p < 0.05$). In a first multivariate analysis only variables

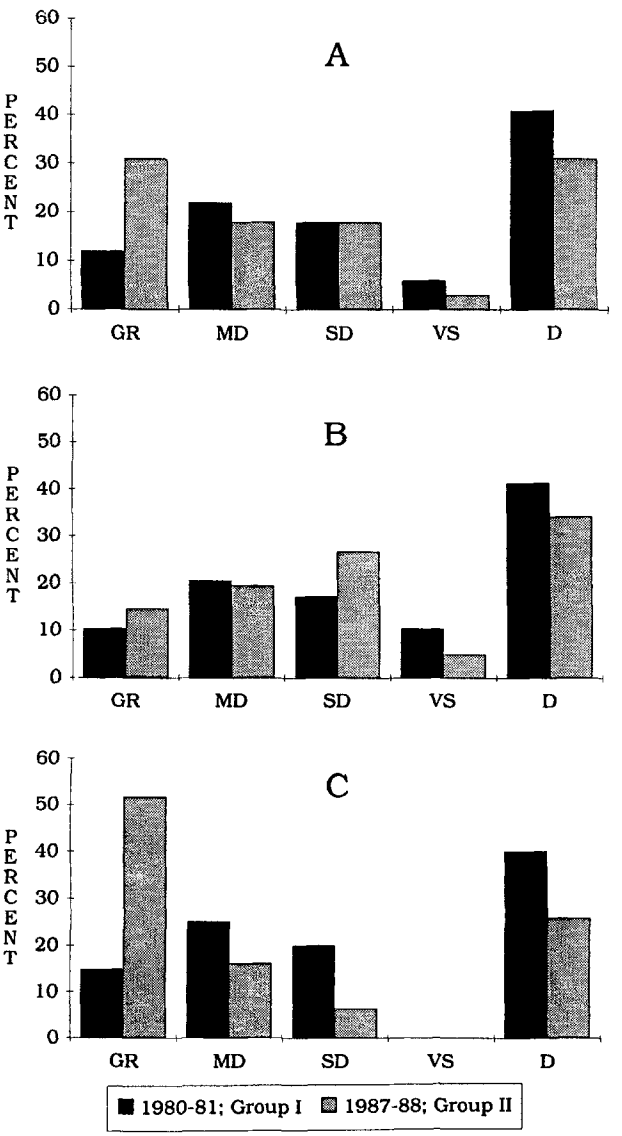

Fig. 2 A–C. A) Clinical outcome according to the Glasgow Outcome Scale (GOS) 6 months after injury. B) Clinical outcome 6 months after injury among patients with a GCS M score of 1–3 at the time of admission. C) Clinical outcome 6 months after injury among patients with a GCS M score of ⩾ 4 at the time of admission

Table 2. *The Two Multivariate Analyses with "Good Recovery" (GOS) as the Dependant Variable*

	First multivariate analysis			Second multivariate analysis		
	$\hat{\beta}$	SE($\hat{\beta}$)	p	$\hat{\beta}$	SE($\hat{\beta}$)	p
Time period (1980–81 versus 1987–88)	1.28*	0.65	0.048	4.33**	1.35	0.0014
Variables present on admission						
GCS motor score	0.58	0.19	0.0025	0.47	0.37	0.20
Age	−0.043	0.016	0.0065	−0.107	0.035	0.0020
Presence of "mass" lesion	0.36	0.68	0.60	0.25	1.11	0.82
Cause of injury						
fall versus traffic accident	−0.01	0.80	0.99	1.34	1.41	0.34
other causes versus traffic accident	−0.40	0.91	0.66	1.85	1.37	0.18
Presence of multiple injury	−1.47	0.86	0.09	−0.50	1.28	0.69
Pupillary light respone						
one versus neither reacting				0.03	1.72	0.99
two versus neither reacting				1.38	1.37	0.31
Variables present during the first week of NIC						
Number of CT scans	−0.02	0.71	0.98	−0.39	1.12	0.73
Epilepsy				−2.71	1.30	0.037
Systemic hypotension				−3.73	1.30	0.0042
Duration of hyperventilation				−3.53	1.09	0.0012

* OR = 3.59.
** OR = 75.6.

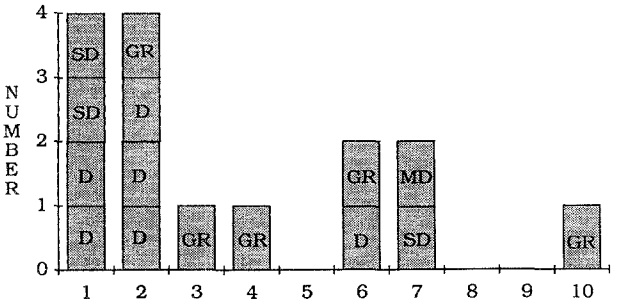

Fig. 3. The day of surgery in relation to the head injury and to the clinical outcome (GOS) in 15 lobe-resected patients

with few missing observations, important in the univariate analysis, were included (119 observations). In a second multivariate analysis with a small number of further variables added, the number of available observations was reduced to 101. Both the multivariate analyses showed that the GOS GR group had increased significantly in 1987–88 ($p < 0.05$ and $p < 0.005$, respectively). Consequently this improvement was not due to other interfering variables such as differences between the two populations of patients regarding GCS M scores, pupil reactivity, age, multiple injury, or "mass/no-mass" lesions (Table 2). Multivariate analysis further confirmed the well known relation between poor clinical outcome and increasing age and low GCS M score on admission (Table 2). The mortality was not particularly studied, but decreased from 41% in 1980–81 to 31% in 1987–88.

We categorized the two populations of the patients in accordance with the GCS M score on admission into two subgroups, those with a GCS M score of 1–3 (no reaction to pain, extension, or abnormal flexion; 70 patients) and those with a GCS M score of $\geqslant 4$ (51 patients) and compared their clinical outcome. In the GCS M 1–3 subgroup a slight reduction in VS and D and a comparable increase of GR and SD patients was found (Fig. 2 B). The differences were not confirmed statistically. In the GCS M $\geqslant 4$ subgroup, the poportion of patients making a good recovery increased from 15% to 52%, and there was a corresponding decrease in all other outcome groups ($p = 0.016$, Fisher's exact test; Fig. 2 C).

There was a significant increase in the number of lobe resections performed in 1987–88. The outcome for these 15 patients is shown in Fig. 3. In 10 the resected lobe harboured a focal lesion (haematoma and/or focal oedema), while 5 had diffuse brain swelling only. Of the 5 patients with diffuse injury 2 made a good recovery, 1 was severely disabled, and 2 died; in 3 of these patients lobe resection was undertaken when high-dose barbiturate treatment had failed to control ICP. The interval between injury and lobe resection is also shown in Fig. 3. It should be noted that all lobe

Table 3. *The Proportion (%) of Patients with a Complication (Hypotension, Hypoxemia, Hyperthermia, Epilepsy) Grouped According to GCS M Score and GOS*

	Hypotension			Hypoxaemia			Hyperthermia			Epilepsy		
GCS M score	all	1–3	⩾4	all	1–3	⩾4	all	1–3	⩾4	all	1–3	⩾4
GOS: GR, MD (%)	33	38	29	55	45	60	10	15	7	16	23	10
GOS: SD, VS, D (%)	54	59	45	69	72	60	21	18	27	27	24	32

resections, including those carried out several days after injury, were performed urgently to control rapidly progressive signs of herniation and/or ICP rise.

We found an association between a poor clinical outcome (GOS: SD, VS, D) and the presence of certain complications during the entire first week after injury (Table 3). For this analysis, available information from all 121 patients was used, except for studies on hypoxaemia, where information from 1987–88 only was used, because in 1980–81 the number of blood gases was too low to allow reliable analysis. Systemic hypotension was present in 54% of all patients with a poor outcome, and in 33% of those with a favourable outcome. This difference was more pronounced among patients with GCS M scores of 1–3. Hypoxaemia, hyperthermia, and epilepsy were also commoner in the patients with a poor outcome; a conspicuous finding was that hyperthermia and epilepsy occurred more commonly in patients graded as GCS M ⩾ 4 and with a poor outcome (Table 3). The multivariate analysis also showed that the presence of epilepsy or systemic hypotension at any time during the first week of NIC was associated with a poor outcome (Table 2). Hypoxaemia and hyperthermia were omitted from the multivariate analysis because of many missing observations.

Discussion

There are several hazards inherent in retrospective clinical studies, and such studies do not generally yield strong evidence concerning the efficacy of certain modes of treatment. However, the main object of the present study was not to study specific components of head-injury care but to compare the results of two different management regimens as a whole, employed in the same department. The issue is important for many reasons, not least from a practical point of view, because the establishment of an NIC unit is a major and costly commitment for most neurosurgical units and the benefits must overweight the costs.

The comparison of two groups which have not been obtained by randomization must be carried through in a careful way. A simple univariate analysis can give misleading results as there is no guarantee that the groups are comparable with regard to important confounding variables. Therefore a multivariate analysis is essential. The logistic regression analyses performed imply that adjustments have been made for the variables included in these analyses. However, we can of course not be certain that other variables not considered may not distort the results.

The clinical outcome after severe head injury improved significantly after the establishment of an NIC unit and the concomitant introduction of more aggressive neurosurgical care. This improvement does not seem to be due to differences between the compared patient populations, because both multivariate and univariate analysis gave statistical support to the conclusion that the NIC did indeed increase the number of "good recoveries" and reduced the number of MD, VS and D outcome groups, whereas the number of SD was unchanged. It is important to note that the reduction in mortality did not as a whole result in an increased number of surviving but severely disabled or vegetative patients. Similar results have been reported in other studies on "aggressive" neurosurgical care[1, 2, 22].

The clinical outcome improved strikingly among patients with a GCS M score of ⩾ 4 on admission, the proportion making a good recovery increasing from 15% to 52% between the two periods. In contrast, the improvement in clinical outcome among patients graded GCS M 1–3 was much smaller and not statistically significant. There are probably several reasons for this difference. It is well established that the clinical outcome after severe head injury depends on the severity of both the primary brain injury and of any secondary brain injury. It seems reasonable to suppose that the brain injury was less severe among patients graded GCS M ⩾ 4 on admission than in the GCS M 1–3 group, which would be consistent with a better

chance of good recovery unless secondary damage developed. On the other hand, patients graded GCS M 1–3 apparently had a severer brain injury on admission, which would presage a poorer outcome whether or not secondary brain damage developed subsequently. The object of NIC is basically to prevent or minimize secondary brain damage, and it seems logical that the effect of such care is most obvious in GCS M $\geqslant 4$ patients in whom a good outcome can thus be anticipated if secondary damage can be prevented or minimized. The clinical results in this group of patients with "moderately" severe head injuries would appear to be a good indicator of the quality of head-injury care.

The improved outcome after the introduction of an NIC unit can probably be attributed to several factors, both diagnostic and therapeutic. The improved diagnosis of impending secondary brain damage relied in essence on 3 factors: (i) careful continuous neurological surveillance of all patients, using a special bed-side chart throughout the period of NIC, to detect any neurological deterioration or absence of improvement, and to identify and treat medical complications (this was accomplished by training the whole staff, including nurses and assistant nurses, to achieve team-work to avoid the "avoidable factors"); (ii) repeated CT in patients not improving significantly within the first 24–48 hours; and (iii) continuous monitoring to disclose ICP changes. Decisions about the management of the individual patient were essentially based on an interplay between these three factors; none of them alone seemed to provide sufficient information. This interplay is difficult to describe or measure in a scientific sense, which may explain why continuous ICP monitoring has not yet been generally adopted routinely in the neurosurgical handling of head-injured patients even though it was evaluated clinically more than 30 years ago[14].

We believe that intensified diagnosis and surveillance lead to faster institution and probably more exact use of the therapeutic armamentarium. Few basic changes took place between the two periods, and no entirely new mode of therapy was used in 1987–88. However, controlled hyperventilation was used over a longer period in 1987–88. Weaning from the ventilator was slow and carefully controlled by neurological examinations and often also by ICP monitoring. Thus late deterioration and/or ICP elevation could be detected. The value of prolonged controlled hyperventilation has been questioned ever since it was introduced to counter elevated ICP[15]. In the present series moderate hyperventilation was used (PCO_2 3.5–4.5 kPa). This method is widely accepted and is based on the observation that head-injured patients usually hyperventilate spontaneously; the use of the ventilator cuts the energy expenditure due to respiratory work[7, 20]. Recently Muizelaar *et al.*[21] showed in rabbits that the effect of hyperventilation, *i.e.* vasoconstriction, was brief and that the vessel diameter returned to normal during continuous hyperventilation; return to normoventilation was followed by vasodilation. They concluded that in situations with low brain compliance short periods of normoventilation may elicit dramatic ICP elevation. Their experiments underline the importance of careful surveillance of artificially ventilated patients by frequent blood-gas checks and end-tidal CO_2 monitoring, and further that discontinuation of hyperventilation and especially weaning should be carefully monitored and should not be attempted too early.

The increased use of barbiturates has probably played a role in controlling elevated ICP, but it is beyond the scope of the present study to evaluate this treatment. The use of lobe resection to achieve internal decompression was often successful when the clinical course, ICP elevation, and/or CT findings indicated impending death. The fact that lobe resection was performed as late as 10 days after injury underlines the fact that NIC should be continued for a considerable time.

The identification of "avoidable factors" by Rose *et al.*[24] clearly improved head-injury care. Hypotension, hypoxaemia, hyperthermia, and epileptic seizures may aggravate brain damage. We found a relation between the occurrence of these complications at any time during the first week and poor outcome. Concerning hypotension, this relation was pronounced in patients graded GCS M 1–3 on admission, whereas hyperthermia, and epileptic seizures occurred more frequently in patients graded GCS M $\geqslant 4$ on admission and with a poor outcome. The negative effect of these complications are probably more obvious in GCS M $\geqslant 4$ patients because, the underlying brain injury is consistent with a favourable outcome unless such complications develop. These findings are interesting for several reasons. Modern intensive care, including NIC, involves several iatrogenic risks owing to prolonged use of invasive equipment for monitoring and treatment and the administration of many potentially harmful drugs. These risks are especially troublesome in head-injured patients because the injured brain is particularly vulnerable. The clinical results of NIC will thus always greatly depend on the ability to limit the complications of intensive care.

The present study shows that improved clinical outcome after severe head injury (*i.e.* an increased number of GR and a reduced number of disabled or dead patients) can be achieved by organizing an NIC unit with well trained staff capable of providing this care 24 hours a day using established methods of surveillance and treatment.

Acknowledgements

This study was supported by the Swedish Medical Research Council (Project no. 7888), the Laerdal Foundation for Acute Medicine, and Tore Nilssons stiftelse. We wish to thank Professor Urban Pontén for his invaluable and constructive criticism and support throughout this study.

References

1. Becker DP, Miller JD, Ward JD, Greenberg RP, Young JD, Sakalas R (1977) The outcome from severe head injury with early diagnosis and intensive management. J Neurosurg 47: 491–502
2. Bowers SA, Marshall LF (1980) Outcome in 200 consecutive cases of severe head injury treated in San Diego County: a prospective analysis. Neurosurgery 6: 237–242
3. Colohan AR, Alves WM, Gross CR, Torner JC, Metha VS, Tandon PN, Jane JA (1989) Head injury mortality in two centers with different emergency medical services and intensive care. J Neurosurg 71: 202–207
4. Eisenberg HM, Frankowski RF, Contant CF, Marshall LF, Walker MD (1988) High-dose barbiturate control of elevated intracranial pressure in patients with severe head injury. J Neurosurg 69: 15–23
5. Gelpke GJ, Braakman R, Habbema Dik J, Hilden J (1983) Comparison of outcome in two series of patients with severe head injuries. J Neurosurg 59: 745–750
6. Gennarelli TA, Spielman GM, Langfitt TW, Gildenberg PL, Harrington T, Jane J, Marshall LF, Miller JD, Pitts LH (1982) Influence of the type of intracranial lesion on outcome from severe head injury. A multicenter study using a new classification system. J Neurosurg 56: 26–32
7. Gordon E, Pontén U (1976) The non-operative treatment of severe head injuries. In: Vinken PJ, Bruyn GW (eds) Handbook of clinical neurology, vol 24. North Holland Publ Co, Amsterdam, pp 599–626
8. Heiden JS, Weiss MH (1978) Head injury management, letter to the editor. J Neurosurg 48: 491
9. Jennett B, Bond M (1975) Assessment of outcome after severe brain damage. A practical scale. Lancet 1: 480–484
10. Jennett B, Teasdale G, Galbraith S, Pickard J, Grant H, Braakman R, Avezaat C, Maas A, Minderhoud J, Vecht CJ, Heiden J, Small R, Caton W, Kurze T (1977) Severe head injuries in three countries. J Neurol Neurosurg Psychiatry 40: 291–298
11. Jennett B, Teasdale G, Fry J, Braakman R, Minderhoud J, Heiden J, Kurze T (1980) Treatment for severe head injury. J Neurol Neurosurg Psychiatry 43: 289–295
12. Kalbag RM (1978) Head injury management, letter to the editor. J Neurosurg 48: 489–490
13. Langfitt TW, Gennarelli TA (1982) Can the outcome from head injury be improved? J Neurosurg 56: 19–25
14. Lundberg N (1960) Continuous recording and control of ventricular fluid pressure in neurosurgical practice. Acta Psych Scand [Suppl] 149: 36
15. Lundberg N, Kjällquist Å, Bien CH (1959) Reduction of increased intracranial pressure by hyperventilation. Acta Psych Scand 34 [Suppl] 139
16. Lundberg N, Troupp H, Lorin H (1965) Continuous recording of the ventricular-fluid pressure in patients with severe acute traumatic injury: a preliminary report. J Neurosurg 22: 581–590
17. Marshall LF, Smith RW, Shapiro HM (1979 a) The outcome with aggressive treatment in severe head injuries. Part 1: The significance of intracranial pressure monitoring. J Neurosurg 50: 20–25
18. Marshall LF, Smith RW, Shapiro HM (1979 b) The outcome with aggressive treatment in severe head injuries. Part II: Acute and chronic barbiturate administration in the management of head injury. J Neurosurg 50: 26–30
19. Mendelow AD, Karmi MZ, Paul KS, *et al* (1979) Extradural haematoma: effect of delayed treatment. Br Med J 1: 1240–1242
20. Miller JD (1989) Measuring ICP in patients – its value now and in the future. In: Hoff JT, Betz AL (eds) Intracranial pressure VII. Springer, Berlin Heidelberg New York Tokyo, pp 5–15
21. Muizelaar JP, Van Der Poel HG, Zhongchao L, Kontos H, Levasseur JE (1988) Pial arteriolar vessel diameter and CO_2 reactivity during prolonged hyperventilation in the rabbit. J Neurosurg 69: 923–927
22. Nordström C-H, Sundberg G, Messeter K, Schalén W (1989) Severe traumatic brain lesions in Sweden. Part 2: Impact of aggressive neurosurgical intensive care. Brain Injury 3: 267–281
23. Reilly PL, Adams JH, Graham DI, Jennett B (1975) Patients with head injury who talk and die. Lancet 2: 375–377
24. Rose J, Valtonen S, Jennett B (1977) Avoidable factors contributing to death after head injury. Br Med J 2: 615–618
25. Seelig JM, Becker DP, Miller JD, Greenberg RP, Ward JD, Choi SL (1981) Traumatic acute subdural haematoma: Major mortality reduction in comatose patients treated within four hours. N Engl J Med 304: 1511–1518

Correspondence and Reprints: Dr. Lennart Persson, Department of Neurosurgery, University Hospital, S-751 85 Uppsala, Sweden.