Acta Neurochir Suppl (2008) 102: 93–97

Decompressive craniotomy: durotomy instead of duroplasty to reduce prolonged ICP elevation

Ralf Burger · David Duncker · Naureen Uzma · Veit Rohde

Abstract
Background Usually, decompressive craniectomy (DC) in patients with increased intracranial pressure (ICP) is combined with resection of the dura and large-scale duroplasty. However, duroplasty is cumbersome, lengthens operation time and requires heterologous or autologous material. In addition, the swelling brain could herniate into the duroplasty with kinking of the superficial veins at the sharp cutting edges and subsequent ICP exacerbation. Several longitudinal durotomies avoid these limitations, but it remains a matter of discussion if durotomies reduce ICP sufficiently.
Methods DC was performed in ten patients (mean age 45 years) with increased ICP after head trauma or subarachnoid hemorrhage. After craniectomy, the dura was opened by three to four durotomies from midline to the temporal base. Duration of surgical procedure and ICP during each surgical step and postoperatively were recorded.
Findings Mean duration of surgery was 90±10 min. ICP prior to skin incision was 39±12 mmHg and dropped to 22±9 mmHg after craniectomy. During durotomy ICP decreased stepwise and reached stable values of 12±6 mmHg at the end of surgery. On days 1–10 after surgery, ICP values ranged between 12–17 mmHg.
Conclusion This study showed that durotomy is a fast and easy, but likewise effective method to lower ICP further after craniectomy.

Keywords Intracranial pressure · Decompressive craniectomy · Traumatic brain injury · Durotomy

R. Burger (✉) · D. Duncker · N. Uzma · V. Rohde
Department of Neurosurgery, Georg-August University,
Robert–Koch Str. 40,
37075 Goettingen, Germany
e-mail: ralf.burger@med.uni-goettingen.de

D. Duncker
e-mail: David.Duncker@stud.uni-goettingen.de

N. Uzma
e-mail: uzma@med.uni-goettingen.de

V. Rohde
e-mail: veit.rohde@med.uni-goettingen.de

Introduction

Initially, decompressive craniectomy (DC) was introduced to lower the intracranial pressure (ICP) in patients with inoperable brain tumors [8]. Since the late sixties DC has been performed in uncontrollable ICP after traumatic brain injury [2, 5]. It was implemented in the Guidelines of the Brain Trauma Foundation [3] as one of the "second tier therapies" of increased ICP when first level options have failed. The European Brain Injury Consortium considered DC as "ultima ratio" after failure of other treatment options [22]. In the literature a wide variety of surgical techniques could be found either for location and extent of craniectomy, dura opening and duroplasty had been reported. Unilateral or bilateral [6, 7, 10, 11, 18, 20, 21, 24, 27, 31, 32], bifrontal [14, 15, 19, 26, 34, 35], subtemporal [8, 12, 33] or circumferential [4] bony decompressions had been proposed. However, unilateral hemicraniectomies and bifrontal craniectomies have gained the widest acceptance [29]. Dura opening after bone removal is considered to be mandatory [8]. The majority of centers prefer extensive dura resection and subsequent duroplasty. However, duroplasty is cumbersome, lengthens operation time in these critically ill patients and requires heterologous or autologous material. Longitudinal durotomies avoid these limitations. However, it is a matter of discussion if mere durotomy indeed lowers the ICP over time. Thus, it was the aim of the present study to investigate the effect of simple longitudinal durotomies on intra- and postoperative ICP.

Materials and methods

DC was performed in ten patients (traumatic brain injury [TBI] n=8; subarachnoid hemorrhage [SAH], n=2; six males, four females; mean age 45±5 yrs.) with ICP>30 mmHg for 30 min or longer despite ventricular drainage. Glasgow coma scale score at admission [34], TBI classification [3], Marshall computed tomography (CT) grade [23], Hunt and Hess grade [13] and Fisher CT classification [9] in SAH patients, pre- peri- and postoperative ICP and Glasgow outcome scale (GOS) scale were assessed [17], (Table 1).

All patients were fixed in a Mayfield clamp. A question mark shaped skin incision from the preauricular to the frontal region was performed. Galea, periostium, and temporal muscle were mobilised from the skull. A bone flap of a size of 10×12 cm was removed, bone resection was extended to the temporal base. The dura was opened by straight incisions (n=4; lenght 6–8 cm) from parasagitally to the lower inferior temporal gyrus (Fig. 1).

Duration of surgical procedure, mean arterial blood pressure (MABP), endexpiratory etpCO_2 and ICP were recorded during each surgical step with possible effect on ICP (beginning of surgery, during burrhole placement, removal of the bone flap, each durotomy and skin closure). In the postoperative period, ICP was recorded until day 10. ICP, MABP, etpCO_2, and duration of surgery are presented as absolute values with mean and standard deviation. One-Way Repeated Measures Analysis of Variance was employed to compare intracranial pressure, MABP and

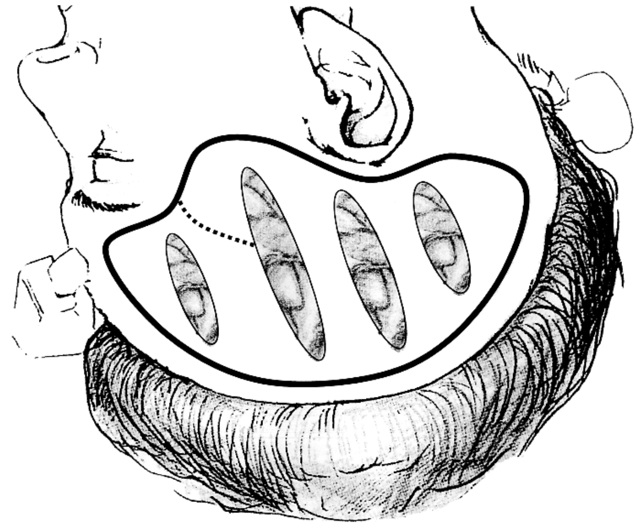

Fig. 1 Schematic illustration of bone flap size (*bold line*) and contour of sylvian fissure (*scattered line*). After decompressive craniectomy intracranial pressure was significantly decreased by widening of durotomies without bulging of edemateous brain (modified illustration from Yarsagil M.G., Microneurosurgery Part I, Thieme Verlag, Stuttgart, New York, 1984)

Table 1 Demographic data of study patients

	Impact	TBI grading	H & H scale	GCS	Marshall CT grading	CT Fisher scale	Level of ICP [indication for DC] (mmHg)	Surgery (DC) [days after impact]	GOS [3 months]	Comments
TBI	fall from stairway	III		4	DI 3		~50	8	4	
TBI	fall from stairway	III		4	DI 3		~35	2	3	
TBI	car accident	III		3	DI 4		~35	1	2	Anisocoria before DC
TBI	public bus accident	III		3	DI 4		~58	1	3	
TBI	bicycle accident	III		4	DI 3		~70	0	2	Anisocoria before DC
TBI	fall from stairway	III		3	DI 3		~21	3	3	Early DC due to CAT scan
TBI	fall from scaffolding	III		3	DI 3		~42	0	1	
TBI	car accident	III		4	DI 3		~25	4	3	
SAH	ICA–aneurysm		IV	3		IV	~38	3	3	No ischemia, massive brain edema
SAH	PCA–aneurysm		IV	3		III	~41	5	3	PCA infarction, brain edema

TBI Traumatic brain injury, *GCS* Glasgow coma scale [34], *DC* decompressive craniectomy, *DI* diffuse injury, *H & H* Hunt and Hess grading [13], *GOS* Glasgow outcome scale [17]

TBI grading by Bullock et al. [3]; Fisher grading I–IV post SAH [9]; Marshall CT grading after TBI [23].

$etpCO_2$ values over time in the study group. The Kolmogorov–Smirnov test (with Lilliefors' correction) was used to test data for normality. The significance level was $p < 0.05$. Statistical analysis was performed with SigmaStat 2.0 (Jandel Scientific®, SPSS Inc., Chicago, IL, USA).

Results

Before surgery, the mean ICP was 42±16 mmHg with a range between 21–70 mmHg. Baseline ICP immediately prior to skin incision was 39±12 mmHg. ICP showed high or sometimes slightly increased values during burrhole placement and dropped significantly for the first time after removal of the bone flap to 22±9 mmHg ($p<0.001$). The first durotomy reduced the mean ICP to 16±6 mmHg ($p=0.018$). After the third durotomy, an ICP of 10±3 mmHg ($p=0.003$) was reached and remained stable until skin closure (mean value of 12±6 mmHg ($p>0.05$). Mean duration of operative procedure was 90±10 min. Mean arterial blood pressure was 80±18 mmHg and the mean endexpiratory pCO_2 was 34±4 mmHg. During surgery, these values did not show statistically significant differences. In the postoperative period (days 1 to 10 after DC) ICP values ranged between 12±9 and 17±5 mmHg ($p=0.031$).

The outcome 3 months after admission was assessed by the GOS scale. One patient made a good recovery (GOS 4), 6 patients remained moderately disabled (GOS 3), one patient remained in a vegetative status (GOS 2) and one patient died 10 days after DC due to sepsis and multiorgan failure (GOS 1).

Discussion

Decompressive craniectomy is considered as a second tier therapy in the Guidelines of the Brain Trauma Foundation [3] and as last tier therapy in the European Brain Injury Consortium [22]. A well-defined ICP trigger for DC does not exist. ICP thresholds between 20 mmHg [26, 32] and 40 mmHg [31] were reported. However, many authors propose to perform DC in patients with medically uncontrollable ICP of 30 mmHg and higher or with a cerebral perfusion pressure below 70 mmHg with further neurological detoriation [7, 20, 21]. In accordance with these data, we proceed to DC in medically refractory ICP of 30 mmHg and higher. In selected patients with acute subdural hematoma, massive brain swelling and signs of herniation, we performed DC even if the registered ICP did not reach 30 mmHg.

The technical details of DC are not well defined. Uni- and bilateral, subtemporal, bifrontal and circumferential craniectomies had been performed. However, unilateral and bilateral hemicraniectomies [6, 7, 10, 11, 18, 20–22, 27, 31, 32] as well as bifrontal craniectomies [14, 15, 19, 26, 35, 36] have gained the broadest acceptance. Several studies have indicated that opening of the dura is crucial for effective ICP reduction but again, a variety of methods had been described, Stellate-, X-, Z -, question mark- or fishmouth-shaped dura openings [1, 21, 24–27, 30, 36] had been proposed followed by large-scale duraplasty with heterologous or autologous material [1, 6, 10, 20, 21, 24–27, 30, 35, 36]. Duroplasty has some major disadvantages: (1) prolongation of the operative procedure, which might have a negative effect on the outcome in a severely ill patient; (2) use of heterologous or autologous material; (3) herniation of the edematous brain into the duroplasty with kinking of brain arteries and veins at the sharp cutting edges of the resected dura which might result in ischemia or venous congestion, thereby further contributing to brain swelling. Therefore some authors [7] recommended to create a vascular channel with small pillars on each side of crossing vessels at the dural margin made of absorbable gelatin (hemostatic sponge) combined with polyglycol acid (absorbable suture); (4) Dura resection and duroplasty is a cumbersome procedure for the neurosurgeon.

The present study shows that mere durotomy by dural incisions avoids the disadvantages of dural resection and duroplasty without having a diminished effect on ICP control. ICP dropped by 44% after bone flap removal and by another 26% after durotomy. This observation is in line with other studies which monitored ICP during DC. In these studies, ICP prior to surgery ranged between 29.2–40.4 mmHg [20, 25, 30, 31, 35, 36] and dropped to values below 20 mmHg [1, 20, 25, 28, 30, 31, 35, 36] after bone flap removal. Some authors found a clear correlation between the extent of bone removal and decline of ICP [30]. However, a strong focus on the size of the bone flap is not justifed as dura opening after DC likewise has a strong effect on ICP [18]. Authors who monitored ICP and brain $p(ti)O_2$ showed that ICP continuously dropped to low pathological values during DC and duroplasty whereas brain $p(ti)O_2$ tremendeously improved to normal values [16, 27, 32]. Interestingly, brain $p(ti)O_2$ was not related to bone flap removal but to dura opening, which underlines again that dura opening is the crucial factor in DC [27]. Within the next 24–72 h after DC ICP remained stable below 20 mmHg in our and other studies [1, 25, 30, 36]. We measured ICP until day 10 post surgery, and did not see any ICP rebound despite reduction of the sedation and anti-edema drugs.

The lack of any ICP rebound suggests that secondary brain swelling does not play a role in our modification of DC, possibly because the dura stripes between the durotomies avoid extensive brain herniation and, thereby, any kinking of arteries and veins at the sharp cutting edges of the incised dura. It has to be pointed out that this "protective" effect is not guaranteed with too many dura incisions respectively with too small dural openings: In one patient in whom several dural incisions had been performed and who was re-operated due to a subgaleal hematoma, we observed brain herniation between the small dural openings. Thus, we believe that the number of durotomies should be limited to three or four. This is supported by the fact that in our study a further decrease of the elevated ICP was not seen if more than three durotomies had been performed.

In our study mean duration of surgery was 90 min which is very short in comparison to DC surgery with duroplasty, supporting again the concept of the modification of DC presented here.

In conclusion, these preliminary results clearly indicate, that unilateral craniectomy with durotomy has the potential to overcome the disadvantages of craniectomy and duroplasty: (1) the operation is shorter and less cumbersome than conventional DC which might have a positive effect on the outcome of the patient with increased ICP after brain injury and subarachnoid haemorrhage; (2) heterologous or autologous material for duroplasty after dura resection is not required; (3) it is assumed that brain herniation with vessel kinking and secondary brain swelling is avoided by the dura stripes between the durotomies. However, these positive preliminary results have to be further evaluated in a larger series which is currently under way in our institution.

Conflict of interest statement We declare that we have no conflict of interest.

References

1. Aarabi B, Hesdorffer DC, Ahn ES, Aresco C, Scalea TM, Eisenberg HM (2006) Outcome following decompressive craniectomy for malignant swelling due to severe head injury. J Neurosurg 104(4):469–479
2. Britt RH, Hamilton RD (1978) Large decompressive craniectomy in the treatment of acute subdural hematoma. Neurosurgery 2 (3):195–200
3. Bullock R, Chesnut RM, Clifton G, Ghajar J, Marion DW, Narayan RK et al (2000) Management and prognosis of severe traumatic brain injury. Part 1: Guidelines for the management of severe traumatic brain injury. Part 2: Early indicators of prognosis in severe traumatic brain injury. J Neurotrauma 17(6–7):451–627
4. Clark K, Nash TM, Hutchison GC (1968) The failure of circumferential craniotomy in acute traumatic cerebral swelling. J Neurosurg 29(4):367–371
5. Cooper PR, Rovit RL, Ransohoff J (1976) Hemicraniectomy in the treatment of acute subdural hematoma: a re-appraisal. Surgical Neurol 5:25–28
6. Coplin WM, Cullen NK, Policherla PN, Vinas FC, Wilseck JM, Zafonte RD, Rengachary SS (2001) Safety and feasibility of craniectomy with duraplasty as the initial surgical intervention for severe traumatic brain injury. J Trauma 50(6):1050–1059
7. Csokay A, Egyud L, Nagy L, Pataki G (2002) Vascular tunnel creation to improve the efficacy of decompressive craniotomy in post-traumatic cerebral edema and ischemic stroke. Surg Neurol 57(2):126–129
8. Cushing H (1905) The establishment of cerebral hernia as a decompressive measure for inaccessible brain tumors; with the description of intramuscular methods making the bone defect in temporal and occipital regions. Surg Gyn Obstet 1:297–314
9. Fisher CM, Kistler JP, Davis JM (1980) Relation of cerebral vasospasm to subarachnoid hemorrhage visualized by computerized tomographic scanning. Neurosurgery 6(1):1–9
10. Gaab MR, Rittierodt M, Lorenz M, Heissler HE (1990) Traumatic brain swelling and operative decompression: a progressive investigation. Acta Neurochir [Suppl.] 51:326–328
11. Gerl A, Tavan S (1980) Bilateral craniectomy in the treatment of severe traumatic brain edema. Zentralbl Neurochir 41(2):125–138
12. Gower DJ, Lee KS, McWhorter JM (1988) Role of subtemporal decompression in severe closed head injury. Neurosurgery 23 (4):417–422
13. Hunt WE, Hess RM (1968) Surgical risk as related to time of intervention in the repair of intracranial aneurysms. J Neurosurg 28(1):14–20
14. Hutchinson PJ, Kirkpatrick PJ (2004) Decompressive craniectomy in head injury. Curr Opin Crit Care 10(2):101–104
15. Hutchinson PJ, Corteen E, Czosnyka M, Mendelow AD, Menon DK, Mitchell P, Murray G, Pickard JD, Rickels E, Sahuquillo J, Servadei F, Teasdale GM, Timofeev I, Unterberg A, Kirkpatrick PJ (2006) Decompressive craniectomy in traumatic brain injury: the randomized multicenter RESCUEicp study (www.RESCUEicp.com). Acta Neurochir Suppl 96:17–20
16. Jaeger M, Soehle M, Meixensberger J (2003) Effects of decompressive craniectomy on brain tissue oxygen in patients with intracranial hypertension. J Neurol Neurosurg Psychiatry 74 (4):513–515
17. Jennett B, Bond M (1975) Assessment of outcome after severe brain damage. Lancet 1(7905):480–484
18. Jourdan C, Convert J, Mottolese C, Bachour E, Gharbi S, Artru F (1993) Evaluation of the clinical benefit of decompression hemicraniectomy in intracranial hypertension not controlled by medical treatment. Neurochirurgie 39(5):304–310
19. Kjellberg RN, Prieto A Jr (1971) Bifrontal decompressive craniotomy for massive cerebral edema. J Neurosurg 34(4):488–493
20. Kontopoulos V, Foroglou N, Patsalas J, Magras J, Foroglou G, Yiannakou-Pephtoulidou M, Sofianos E, Anastassiou H, Tsaoussi G (2002) Decompressive craniectomy for the management of patients with refractory hypertension: should it be reconsidered? Acta Neurochir (Wien) 144(8):791–796
21. Kunze E, Meixensberger J, Janka M, Sorensen N, Roosen K (1998) Decompressive craniectomy in patients with uncontrollable intracranial hypertension. Acta Neurochir Suppl 71:16–18
22. Maas AI, Dearden M, Teasdale GM, Braakman R, Cohadon F, Iannotti F, Karimi A, Lapierre F, Murray G, Ohman J, Persson L, Servadei F, Stocchetti N, Unterberg A (1997) EBIC-guidelines for management of severe head injury in adults. European Brain Injury Consortium. Acta Neurochir (Wien) 139(4):286–294
23. Marshall LF, Marshall SB, Klauber MR, Van Berkum Clark M, Eisenberg H, Jane JA, Luerssen TG, Marmarou A, Foulkes MA (1992) The diagnosis of head injury requires a classification based on computed axial tomography. J Neurotrauma 9(Suppl 1):287–292
24. Munch E, Horn P, Schurer L, Piepgras A, Paul T, Schmiedek P (2000) Management of severe traumatic brain injury by decompressive craniectomy. Neurosurgery 47(2):315–322

25. Olivecrona M, Rodling-Wahlstrom M, Naredi S, Koskinen LO (2007) Effective ICP reduction by decompressive craniectomy in patients with severe traumatic brain injury treated by an ICP-targeted therapy. J Neurotrauma 24(6):927–935
26. Polin RS, Shaffrey ME, Bogaev CA, Tisdale N, Germanson T, Bocchicchio B, Jane JA (1997) Decompressive bifrontal craniectomy in the treatment of severe refractory posttraumatic cerebral edema. Neurosurgery 41:84–92
27. Reithmeier T, Lohr M, Pakos P, Ketter G, Ernestus RI (2005) Relevance of ICP and p(ti)O_2 for indication and timing of decompressive craniectomy in patients with malignant brain edema. Acta Neurochir (Wien) 147(9):947–952
28. Rutigliano D, Egnor MR, Priebe CJ, McCormack JE, Strong N, Scriven RJ, Lee TK (2006) Decompressive craniectomy in pediatric patients with traumatic brain injury with intractable elevated intracranial pressure. J Pediatr Surg 41(1):83–87
29. Sahuquillo J, Arikan F (2006) Decompressive craniectomy for the treatment of refractory high intracranial pressure in traumatic brain injury. Cochrane Database Syst Rev 25(1): CD003983
30. Skoglund TS, Eriksson-Ritzen C, Jensen C, Rydenhag B (2006) Aspects on decompressive craniectomy in patients with traumatic head injuries. J Neurotrauma 23(10):1502–1509
31. Schneider GH, Bardt T, Lanksch WR, Unterberg A (2002) Decompressive craniectomy following traumatic brain injury: ICP, CPP and neurological outcome. Acta Neurochir Suppl 81:77–79
32. Stiefel MF, Heuer GG, Smith MJ, Bloom S, Maloney-Wilensky E, Gracias VH, Grady MS, LeRoux PD (2004) Cerebral oxygenation following decompressive hemicraniectomy for the treatment of refractory intracranial hypertension. J Neurosurg 101(2):241–247
33. Taylor A, Butt W, Rosenfeld J, Shann F, Ditchfield M, Lewis E, Klug G, Wallace D, Henning R, Tibballs J (2001) A randomized trial of very early decompressive craniectomy in children with traumatic brain injury and sustained intracranial hypertension. Childs Nerv Syst 17(3):154–162
34. Teasdale G, Jennett B (1976) Assessment and prognosis of coma after head injury. Acta Neurochir (Wien) 34(1–4):45–55
35. Whitfield PC, Patel H, Hutchinson PJ, Czosnyka M, Parry D, Menon D, Pickard JD, Kirkpatrick PJ (2001) Bifrontal decompressive craniectomy in the management of posttraumatic intracranial hypertension. Br J Neurosurg 15(6):500–507
36. Yoo DS, Kim DS, Cho KS, Huh PW, Park CK, Kang JK (1999) Ventricular pressure monitoring during bilateral decompression with dural expansion. J. Neurosurg. 91(6):953–959