

Acta Neurochirurgica

Craniectomy size for subdural haematomas and the impact on brain shift and outcomes

--Manuscript Draft--

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Full Title:	Craniectomy size for subdural haematomas and the impact on brain shift and outcomes
Article Type:	Original Article
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Funding Information:	
Abstract:	<p>Background</p> <p>Midline shift in trauma relates to the severity of head injury. Large craniectomies are thought to help resolve brain shift but can be associated with higher rates of morbidity. This study explores the relationship between craniectomy size and subtemporal decompression for acute subdural haematomas with the resolution of brain compression and outcomes. No systematic study correlating these measures has been reported.</p> <p>Method</p> <p>A retrospective study of all adult cases of acute subdural haematomas that presented to a Major Trauma Centre and underwent a primary decompressive craniectomy between June 2008 and August 2013. Data collection included patient demographics and presentation, imaging findings and outcomes. All imaging metrics were measured by two independent trained assessors. Compression was measured as midline shift, brainstem shift and cisternal effacement.</p> <p>Results</p> <p>36 patients with mean age was 36.1 +/- 12.5 (range 16-62) were included, with a median follow-up of 23.5 months (range 2.2-109.6). The median craniectomy size was 88.7cm² and the median subtemporal decompression was 15.0mm. There was significant post-operative resolution of shift as measured by midline shift, brainstem shift and cisternal effacement score (all p<.00001). There was no mortality, and the majority of patients made a good recovery with 82.8% having a Modified Rankin Score of 2 or less. There was no association between craniectomy size or subtemporal decompression and any markers of brain shift or outcome (all R² < 0.05).</p>

Conclusions

This study suggests that there is no clear relationship between craniectomy size or extent of subtemporal decompression and resolution of brain shift or outcome. Further studies are needed to assess the relative efficacy of large craniectomies and the role of subtemporal decompression.

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4th March 2020

Dear T. Mathiesen,
Editor of Acta Neurochirurgica

We would be grateful if you would consider our manuscript "**Craniectomy size for subdural haematomas and the impact on brain shift and outcomes**" for publication in your journal. We believe that our paper will be a valuable addition to the literature and will be highly cited, being the first study that explores the relationship between craniectomy size and degree of subtemporal decompression and resolution of compression and outcomes.

Background: Head injury is a leading cause of morbidity and mortality in people aged between one and forty years. Primary decompressive craniectomy attempts to reduce global ICP, focal compression and subsequent herniation with the aim to increase survival and reduce morbidity. Compression is assessed by radiological midline shift at the level of the lateral ventricles and by brainstem compression inferred as the presence or absence of cisternal effacement. Although it has not been formally demonstrated it is intuitive that resolution of compression would occur with decompression, and correlate with improved outcome.

Aims: Our primary aims were (i) does the size of the craniectomy relate to the degree of midline shift, brainstem shift, or cisternal effacement resolution? (ii) does the extent of subtemporal decompression relate to the degree of midline shift, brainstem shift, or cisternal effacement resolution? The secondary aim was to look at the long-term patient outcomes.

Cohort: 36 patients who underwent a primary decompressive craniectomy for an acute subdural haematoma between June 2008 and August 2013 and fulfilled our inclusion criteria were included, and followed-up for 23.5months.

Our findings: The median craniectomy size was 88.7cm³ and the median subtemporal decompression was 15.0mm. There was significant post-operative resolution of shift as measured by midline shift, brainstem shift and cisternal effacement score (all $p < 0.0001$). There was no mortality, and the majority of patients made a good recovery with 82.8% having a Modified Rankin Score of 2 or less. There was no association between craniectomy size or subtemporal decompression and any markers of brain shift or outcome (all $R^2 < 0.05$).

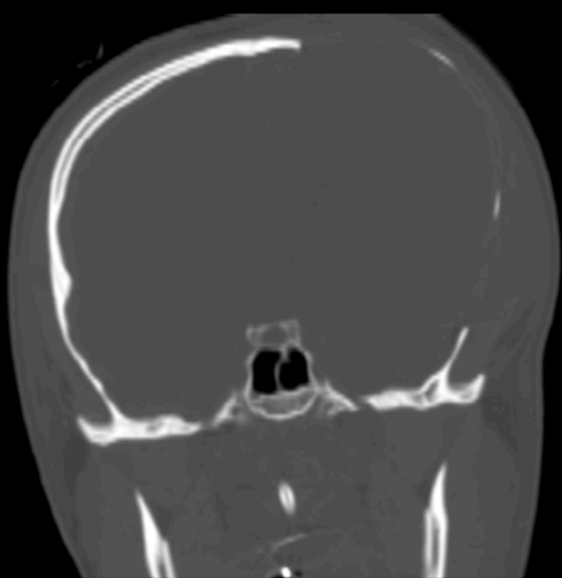
Impact: This study suggests that there is no clear relationship between craniectomy size or extent of subtemporal decompression and resolution of brain shift or outcome. Despite our manuscript having certain limitations, our publication is likely to be highly cited and to be used by health care institutions as part of their craniectomy guidelines. Further studies are needed to assess the relative efficacy of large craniectomies and the role of subtemporal decompression

Yours sincerely,

Lauren Harris







Checklist for authors 27th October 2016

The journal is interested in original papers which are novel and carry important scientific information in the submitted journal field.

Format is important for the journal. We believe that format benefits the quality of science and we are convinced that a good format will enable reviewers and readers to grasp the intellectual contents better. The instructions for authors must be followed.

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We recommend authors refer to the EQUATOR Network website (<http://www.equator-network.org>) for further information on the available reporting guidelines for health research, and the MIBBI Portal for prescriptive checklists for reporting biological and biomedical research where applicable. Authors are requested to make use of these when drafting their manuscript and peer reviewers will also be asked to refer to these checklists when evaluating these studies.

Please follow the checklist and check the following points:

y_____ The Title should be objective, short and concise, include a keyword in the title. Avoid using the words: Novel, Unique, First

y_____ Abbreviations and acronyms: Please include a list and place after the Title Page. Please use only accepted acronyms and abbreviations and avoid introducing new unless necessary for improved comprehension or "readability".

y_____ The abstract should be divided as follows:

Background – Why was the study carried out/Why is this case report so special

Methods – What did the research group do?

Results – What did the research group find?

Conclusions- What might this research mean?

Number the page-the abstract page will be page#2

Introduction:

If possible try to keep the introduction short, while mentioning the following points:

y _____ Introduce the topic and give an objective review of the background

y _____ Identify an explicit gap of knowledge; the reason why the study is needed

y _____ Please write down the gap of knowledge briefly:

No study correlates the relationship between craniectomy size and degree of subtemporal decompression with the resolution of compression and outcomes.

y _____ Define an aim based on the gap of knowledge

y _____ Please write down the aim briefly:

The primary aims were (i) does the size of the craniectomy relate to the degree of midline shift, brainstem shift, or cisternal effacement resolution? (ii) does the extent of subtemporal decompression relate to the degree of midline shift, brainstem shift, or cisternal effacement resolution? The secondary aim was to look at the long-term patient outcomes.

.....

y _____ The material and methods-section should contain information that allows reproduction of your study (in principle) and allows tracing of your results.

y _____ This is the section where statistics should be placed.

y _____ Do not forget that for chemicals or equipment the name and location should be given in parentheses.

y _____ Describe how the participants /cells in your study were selected and excluded.

Do not describe standard methods in detail – use references

Results:

The best way to write a good result section is to follow the four golden rules:

Keep it relevant

Let the text tell the story

Let the tables give the evidence

Let the figures/Video highlight and illustrate the novel information described in the paper

y_____ Results of all analyses should be included, and all results that are noted in the Discussion need to be shown here

Discussion:

Please discuss in your own words the following:

y_____ State and discuss the principal finding. This finding should be a result of the aim.

y_____ Discuss the strengths and weakness of the study comparing it with other studies with different results. Are the findings reliable and generalizable?

y_____ Discuss the possible impact of the study and implications

y_____ Discuss the unanswered questions and the possibility of future research with explicit recommendations of what is a “next step”.

Conclusion:

y_____ This should be a brief summary of your principal finding and what it means.

y_____ Please state the conclusion briefly:

This study suggests that there is no clear relationship between craniectomy size or extent of subtemporal decompression and resolution of brain shift or outcome.

New Springer Guidelines:

Please place the following headings prior to the reference section.

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Acknowledgements:

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An individual who helped with editing/proofreading/ writing

A department chair who provided only general support.

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Category of disclosure	Description of interest/Arrangement

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Manuscript No. (if you know it) _____

Author name CATHERIN SCOTT HILL

Are you the corresponding author? Yes No

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The corresponding author should be prepared to send potential conflict of interest disclosure form if requested during peer review or after publication on behalf of all authors (if applicable).

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Category of disclosure	Description of interest/Arrangement

Article title CRANIECTOMY SIZE FOR SUBDURAL HAEMATOMAS and IMPACT ON BRAIN SHIFT + OUTCOMES

Manuscript No. (if you know it) _____

Author name LAUREN HARRIS

Are you the corresponding author? Yes No

Herewith I confirm that the information provided is accurate.

Author signature Lauren Harris Date 4/13/2020

Author response to reviewers' comments

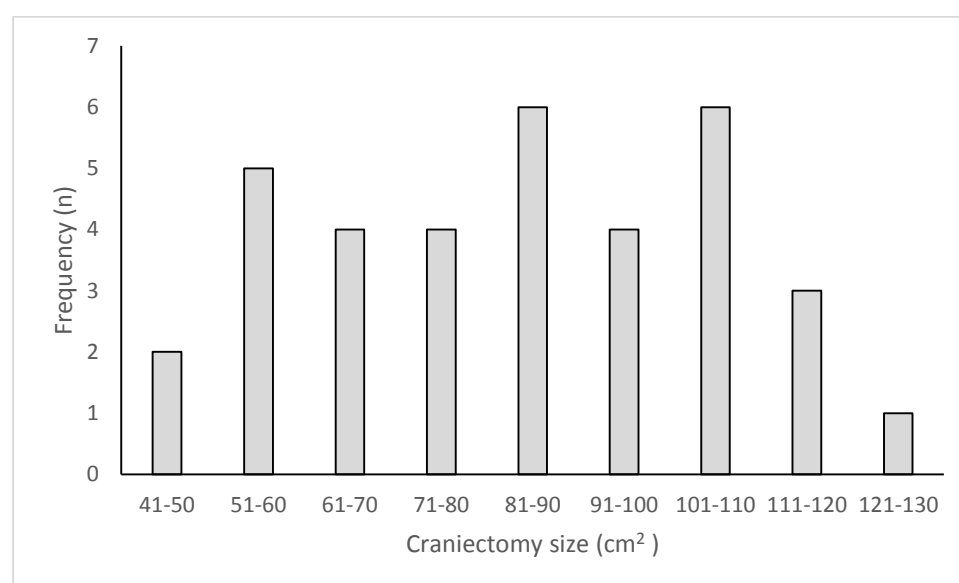
Thank you for taking the time to review our manuscript. We appreciate your advice and have made the appropriate changes below. We hope it is now of the standard expected for publication in *Acta Neurochirurgica*. We have answered each of your questions in bold below and have highlighted the changes in red in the text.

Reviewers' comments:

Reviewer #1: I think the authors need to comment on:

Were all the bone flaps of adequate size - the implication of the paper is that size of bone flap is not important but if all of these are large enough then that may explain the lack of correlation

We have added in Figure 4 to graphically show the size of the craniectomy, and added in an explanation into the discussion (below).



The European Brain Injury Consortium had a mean craniectomy size of 67cm² and determined that less than 30cm² was inadequate.[8] By this definition, all the bone flaps in our study were of adequate size (Figure 4), which may explain the lack of correlation.

Additionally, not all the cases were planned as primary decompressive craniectomies, some were planned as craniotomies, but swelling and intraoperative appearance may have led to the decision to leave the bone out

Figure 4

Histogram of craniectomy size

50% of the patients were mRS of 0 - the implication being that they did not have a particularly severe injury?

On presentation we had over three quarters presenting as a severe TBI, with over half at least one fixed pupil. This is detailed in the results section. We have added in further detail to our discussion to re-iterate this point. We were fortunate to have good outcomes. However, there

may be some selection bias due to our inclusion criteria - patients required a post-operative CT scan - potentially excluding some bad outcomes. This is highlighted in the text.

The outcomes over a median of 23.5 months were very positive. Despite significant TBI, with patients having a median presentation GCS of 5 (three quarters of the cohort presented as a severe TBI and half had at least one fixed pupil), there were no mortalities and the majority of the patients made a good recovery. Our inclusion criteria necessitated a post-operative CT scan, so patients who were too unstable for a post-operative scan, and may have gone on to die, were excluded.

Reviewer #2: This is a retrospective study of 36 patients with acute subdural haematomas to see if there is a relationship between craniectomy size and midline shift, brainstem shift and cisternal effacement. It also addresses if sub temporal decompression relates to: midline shift, brainstem shift and cisternal effacement. It also included data on patient outcomes. The results show there is no relationship.

Introduction

1. The reference from the first sentence of the introduction seems to be from an editorial. Would be better to cite primary research for this.

The additional references have been included (ref 17 /18 /25).

Jennett B, MacMillan R (1981) Epidemiology of head injury. *Br Med J (Clin Res Ed)* 282(6258):101–104

Kay A, Teasdale G (2001) Head injury in the United Kingdom. *World J Surg* 25(9):1210–1220

Teasdale GM (1995) Head injury. *J Neurol Neurosurg Psychiatry* 58(5):526–539

Materials and Methods

1. States 5 year period. Please give time frame or dates of where this 5 year period resides

Apologies – was stated in the abstract only in error, now added into methods.

Between June 2008 and August 2013.

2. One would assume patient's with an acute subdural as their primary pathology but also had other brain injuries (e.g. small contusions) are included in the inclusion criteria? Or would these cohort of patients be under the domain of 'diffuse brain injury' and thus excluded? Please clarify here in methods. The results later on infer these pathologies were also included

Patients who underwent craniectomy for an acute subdural haematoma were included irrespective of presence or absence of additional brain injury including contusions or diffuse injury. Patients who underwent bifrontal or bilateral craniectomies were excluded. Clarified as below.

Inclusion criteria were adult patients who underwent a unilateral decompressive craniectomy with a primary diagnosis of acute subdural causing mass effect, including those with evidence of additional brain injury on computed tomography (CT) scan (including contusions (1cm³ or less), traumatic SAH, extradural haematomas <1cm in thickness). Patients who underwent bifrontal or bilateral craniectomies were excluded. Patients were excluded if they underwent a craniectomy for other causes; including extradural haemorrhage, diffuse brain injury, malignant middle cerebral artery (MCA) infarction, aneurysmal subarachnoid haemorrhage (SAH), or tumour. Other exclusion criteria included patients under the age of 16, and patients in whom there was no

pre-operative imaging within six hours of surgery, or post-operative imaging within seven days. This requirement allowed us to calculate the degree of shift or effacement resolution.

3. Please state how to data was stored

All data was stored in accordance with General Data Protection Regulations and the Data Protection Act 2018. It was kept in encrypted pseudo-anonymised files on a computer in a locked room at the hospital. Access was limited to the clinical research team.

Results

1. 36 primary decompressive craniectomies in a 5 year period in London Trauma Centre seems rather small. It would be useful to give a background of the catchment area that neurosurgery serves and the total number of acute subdurals that were operated on.

This is a small number reflecting our strict inclusion and exclusion criteria including a pre-operative scan within 6 hours, and a post-operative scan within 7 days. This was necessary to allow us to calculate the degree of shift or effacement resolution as related to the acute subdural and mass effect. We have highlighted this in the results and discussion as below.

The study was carried out in the largest of the four MTCs in London, serving a population of over 2.5 million people.

36 patients underwent a primary decompressive craniectomy for an acute subdural haematoma in a 5-year period between June 2008 and August 2013 and fulfilled our strict inclusion and exclusion criteria.

There are several limitations to this study. It was a retrospective, single centre study, with a relatively small sample size, reflecting out strict inclusion and exclusion criteria.

2. It states time taken between admission and operation was 0 days. Would be more useful to give in number of hours if the mean was 0 days.

Many thanks. Corrected.

The time taken between admission and operation was a median of 4.2 hours (interquartile range 1.8 hours – 1 day).

3. Is there any ICP measurement data available? If so, would be useful to include to see if pre and post op ICP data and compare that with craniectomy size.

Unfortunately, we do not have adequate ICP data available for meaningful inclusion. Records were paper during the study period and we have been unable to retrospectively collect this for the included patients. We have added this into a limitation in the manuscript.

ICP data was unavailable, so we were unable to compare pre and post-operative data and compare it to craniectomy size, or stratify it with pathology. However, brain herniation through the defect acted as a crude surrogate. We hope to assess this in future work.

4. How many patients had a cranioplasty during the follow up?

100% of patients had a cranioplasty at a median of 9.3 months (range 1.6 – 53.1 months).

Ethical approval

1. Please state if this project was registered as a service evaluation for data collection to commence. Please also state if patient consent was required/obtained to include their radiological imaging.

This study was registered locally with the Clinical Effectiveness Unit as a Service Evaluation prior to data collection. Data was fully anonymised so formal consent was not required.

Tables

1. Table 1. Total number of patients adds up to 35 not 36. 1 patient is missing (results state 36 patients)

Apologies – one fall from standing patient was missed from the patients (not the percentage) when erroneously transcribing results from excel. Thank you for highlighting this omission and giving us the opportunity to correct it.

Mechanism	Patients (n)	Percentage (%)
Fall from height	10	25.0
Assault	9	27.8
Pedestrian versus vehicle	6	11.1
Other road traffic accident	4	16.7
Fall from standing	5	13.9
Pre-eclampsia	1	2.8
Unknown mechanism	1	2.8

2. Table 4. Total number is again 35 patients in this table not 36. 1 patient is missing from the table.

One patient was lost to follow up. This has been made clear in the text and in the description of the table.

Long term follow-up was available in 97.2% of cases (35/36)

Table 4: Patient outcomes on the Modified Rankin Scale. Data is given as raw numbers and percent. One patient was lost to follow up.

Editors comment: Please add data on criteria (inclusion/exclusion) to make a DC and please provide data/discussion to allow stratification for icp/degree of brain swelling and pathology.

Thank you, we have added in the below to reflect your comments.

Methods:

The decision to undergo a decompressive craniectomy was made by the on-call consultant Neurosurgeon in charge of the patient's care, based on the patient's demographics, clinical status, imaging findings and neurotrauma experience.

Results:

In 17 patients (47.2%) there was an element of brain herniation through the craniectomy defect on post-operative imaging, as reported by a consultant Neuroradiologist. There was no relationship between brain herniation through the craniectomy defect and pre-operative midline shift ($p = 0.679$), brainstem shift ($p = 0.642$), or craniectomy size ($p = 0.595$) on a two-tailed t-test.

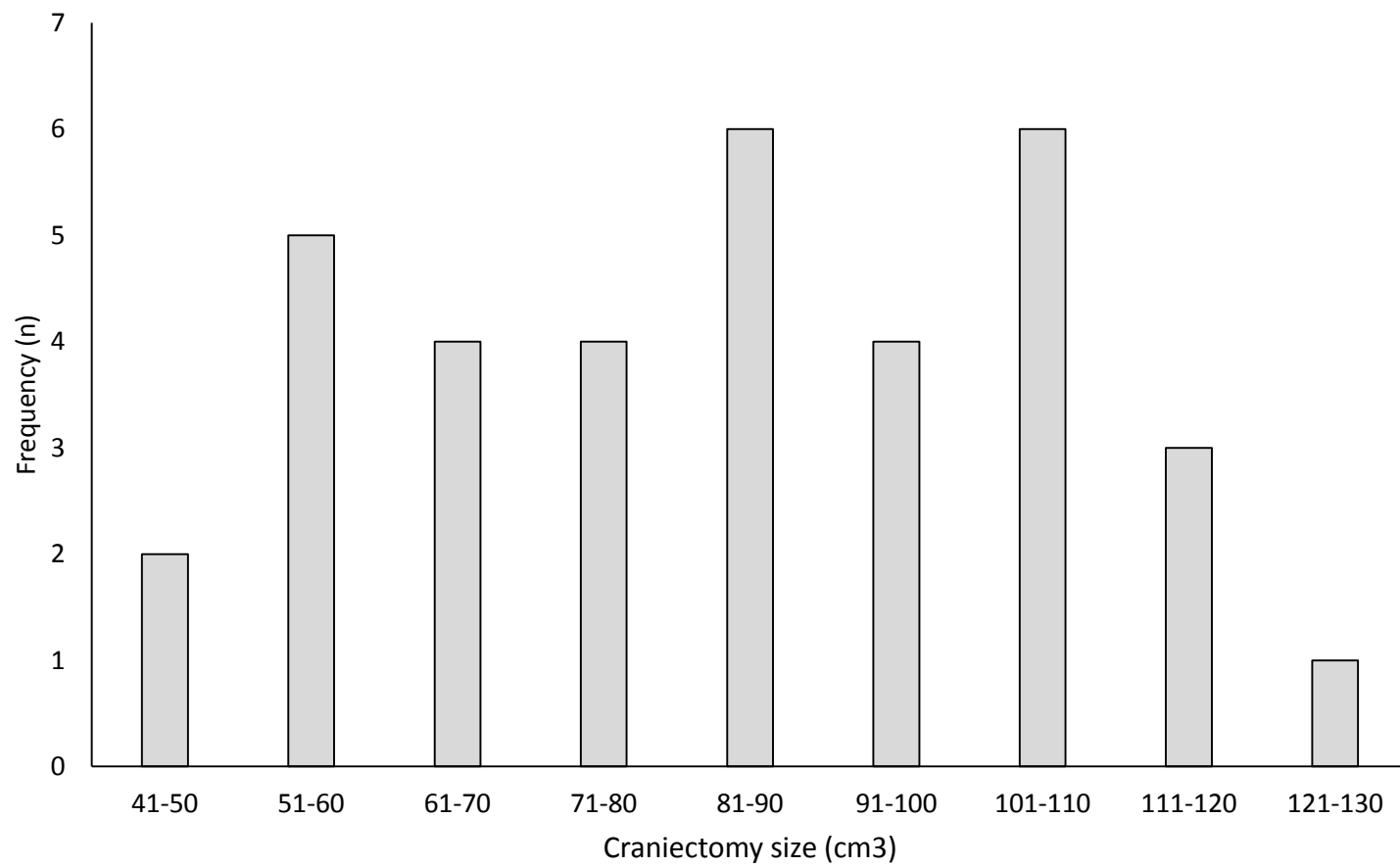
33 patients (91.7%) had a post prognostication Magnetic Resonance Imaging (MRI) scan post-operatively. 20 (60.6%) had no evidence of DAI on imaging, and 6 (18.2%), 5 (15.2%), and 2 (6.1%) had evidence of grade 1, 2, and 3 DAI respectively.

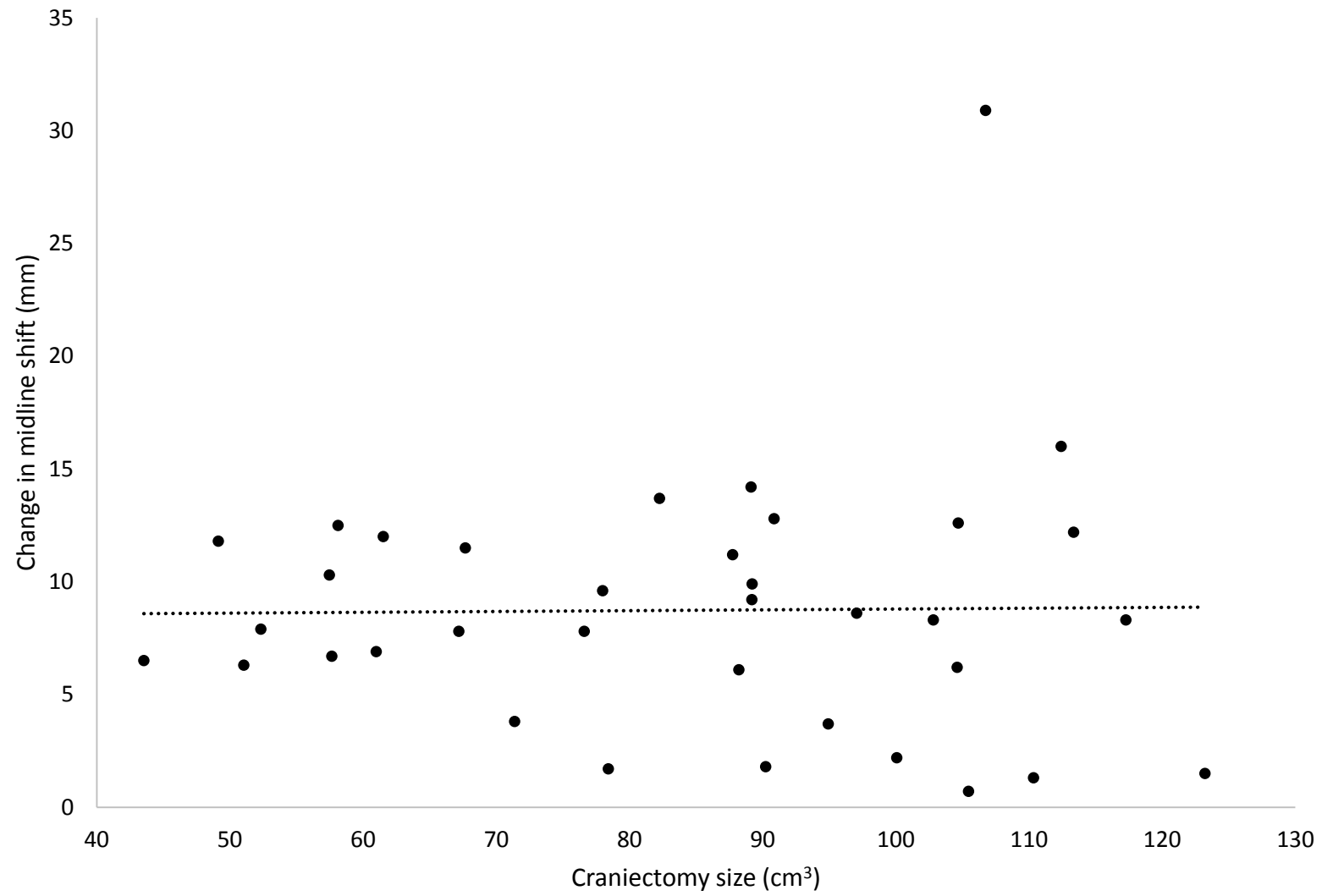
Discussion:

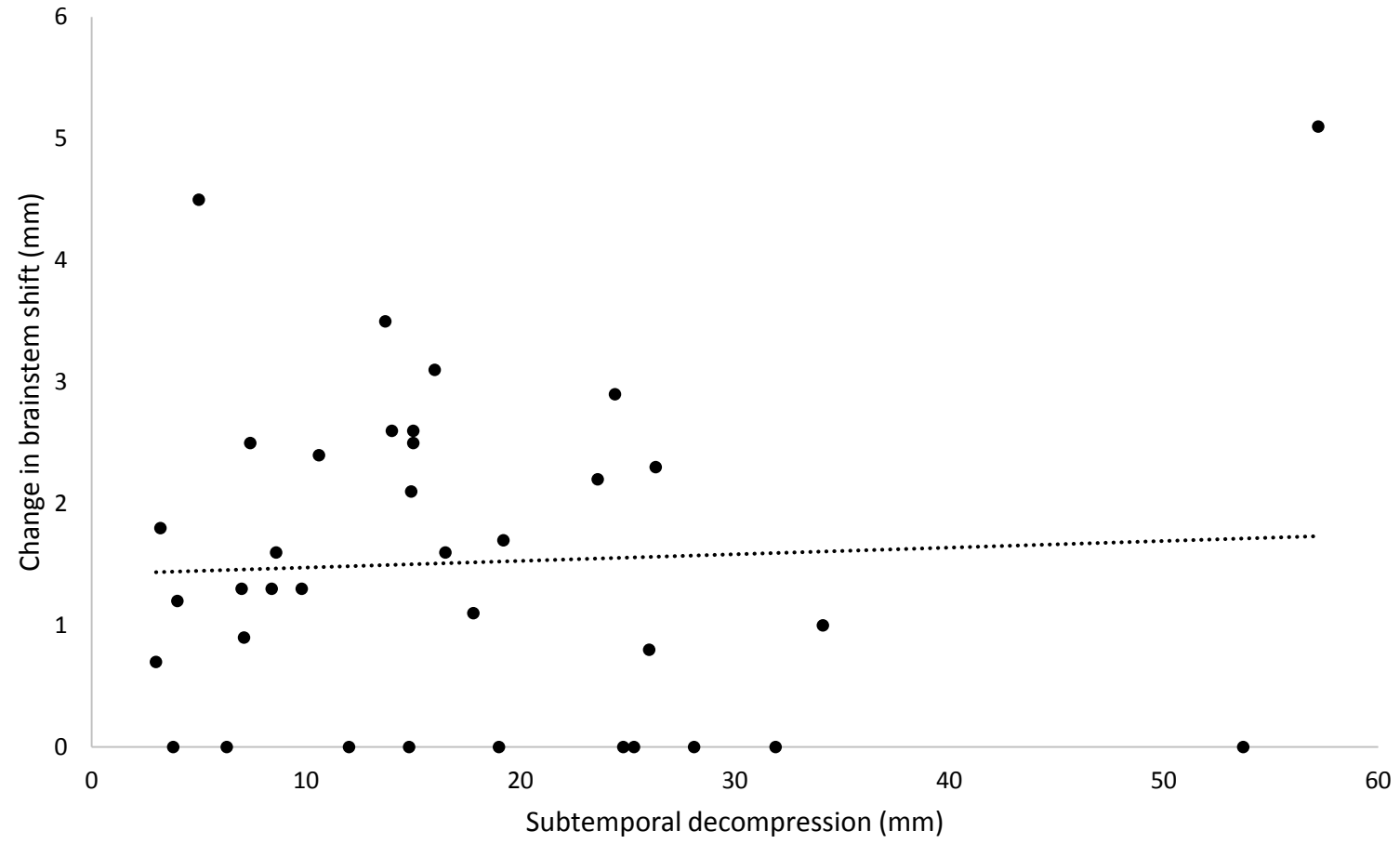
In 47% of cases there was herniation of brain through the craniectomy defect on post-operative imaging, suggesting a degree of brain swelling post-operatively. This showed no association with pre-operative shift or craniectomy size.

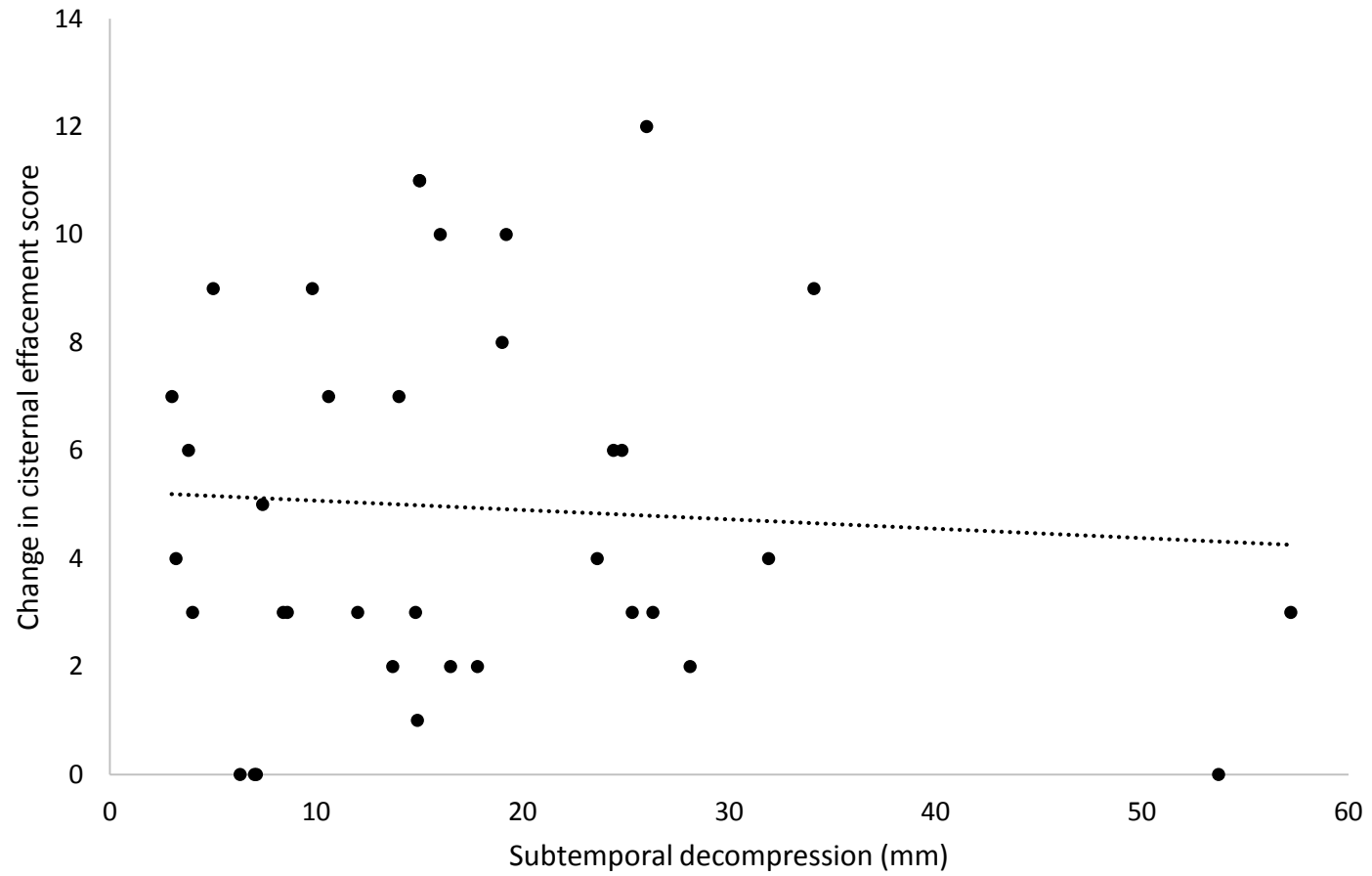
ICP data was unavailable, so we were unable to compare pre and post-operative data and compare it to craniectomy size, or stratify it with pathology. However, brain herniation through the defect acted as a crude surrogate. We hope to assess this in future work.

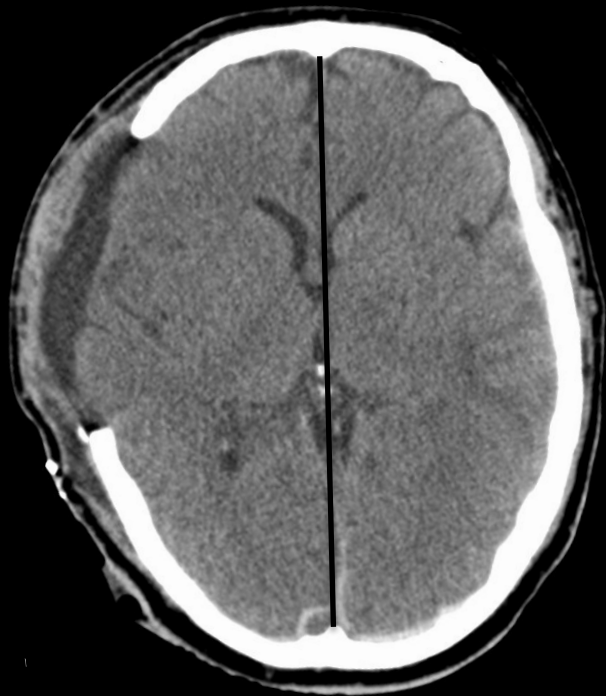
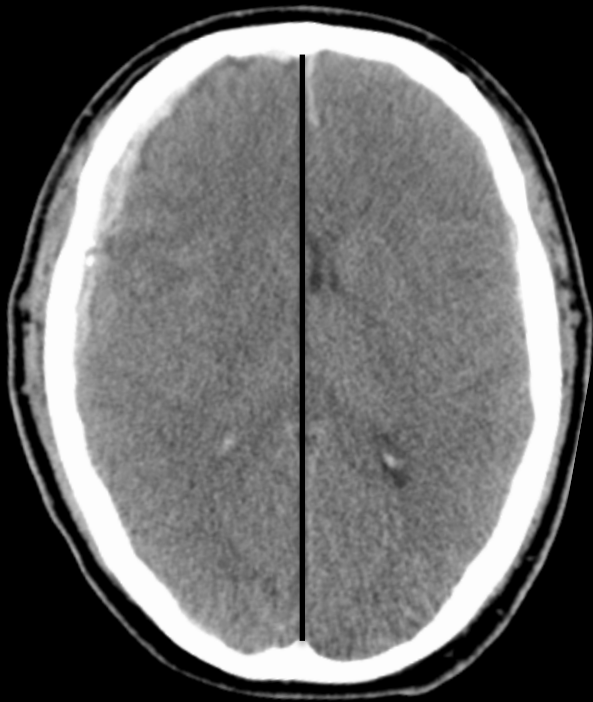
Figure 4-7











[Click here to view linked References](#)

Title page

Craniectomy size for subdural haematomas and the impact on brain shift and outcomes

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Abbreviations and acronyms

ICP = intracranial pressure

MCA = middle cerebral artery

SAH = subarachnoid haemorrhage

GCS = Glasgow coma scale

PACS = picture archiving and communication software

CT = computed tomography

TBI = traumatic brain injury

MRI = magnetic resonance injury

DAI = diffuse axonal injury

1 **Abstract**

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4 **Background**

5 Midline shift in trauma relates to the severity of head injury. Large craniectomies are thought to help
6 resolve brain shift but can be associated with higher rates of morbidity. This study explores the
7 relationship between craniectomy size and subtemporal decompression for acute subdural haematomas
8 with the resolution of brain compression and outcomes. No systematic study correlating these measures
9 has been reported.

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15 **Method**

16 A retrospective study of all adult cases of acute subdural haematomas that presented to a Major Trauma
17 Centre and underwent a primary decompressive craniectomy between June 2008 and August 2013. Data
18 collection included patient demographics and presentation, imaging findings and outcomes. All imaging
19 metrics were measured by two independent trained assessors. Compression was measured as midline
20 shift, brainstem shift and cisternal effacement.

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25 **Results**

26 36 patients with mean age was 36.1 +/- 12.5 (range 16-62) were included, with a median follow-up of
27 23.5 months (range 2.2-109.6). The median craniectomy size was 88.7cm² and the median subtemporal
28 decompression was 15.0mm. There was significant post-operative resolution of shift as measured by
29 midline shift, brainstem shift and cisternal effacement score (all p<.00001). There was no mortality, and
30 the majority of patients made a good recovery with 82.8% having a Modified Rankin Score of 2 or less.
31 There was no association between craniectomy size or subtemporal decompression and any markers of
32 brain shift or outcome (all R² < 0.05).

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39 **Conclusions**

40 This study suggests that there is no clear relationship between craniectomy size or extent of subtemporal
41 decompression and resolution of brain shift or outcome. Further studies are needed to assess the relative
42 efficacy of large craniectomies and the role of subtemporal decompression.

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45
46 **Keywords:** Craniectomy, Decompression, Subdural Hematoma, Shift, Herniation, Brainstem
47 Compression
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Introduction

Head injury is the leading cause of morbidity and mortality in people aged between one and forty years in the United Kingdom, severely disabling 150-200 people per million annually.[12, 17, 18, 25] Elevated intracranial pressure (ICP) within the fixed-volume skull is one of the most important causes of death and disability, and the management remains a challenge.[4, 26] Primary decompressive craniectomy, when a craniectomy is performed at the time of mass lesion evacuation, may be planned pre- or intra-operatively depending on the degree of brain swelling and ICP. Surgery attempts to reduce global ICP, focal compression and subsequent herniation with the aim to increase survival and reduce morbidity.

Compression is assessed by radiological midline shift at the level of the lateral ventricles and by brainstem compression inferred as the presence or absence of cisternal effacement. The degree of midline shift relates to the severity of the head injury and has been correlated with outcome.[1, 7, 11, 27, 28] Shift in excess of haematoma depth is an additional poor prognostic factor.[21, 23] Although it has not been formally demonstrated it is intuitive that resolution of compression would occur with decompression, and correlate with improved outcome.

This study investigates the results of primary decompressive craniectomy for acute traumatic subdural haematomas. It explores the relationship between craniectomy size and degree of subtemporal decompression with the resolution of compression and outcomes. No systematic study correlating these measures has been reported. The primary aims were (i) does the size of the craniectomy relate to the degree of midline shift, brainstem shift, or cisternal effacement resolution? (ii) does the extent of subtemporal decompression relate to the degree of midline shift, brainstem shift, or cisternal effacement resolution? The secondary aim was to look at the long-term patient outcomes.

Materials and Methods

A retrospective study of cases of acute subdural haematomas that presented to a Major Trauma Centre (MTC) and underwent a primary decompressive craniectomy in a 5-year period, between June 2008 and August 2013. The study was carried out in the largest of the four MTCs in London, serving a population of over 2.5 million people. Inclusion criteria were adult patients who underwent a unilateral decompressive craniectomy with a primary diagnosis of acute subdural causing mass effect, including those with evidence of additional brain injury on computed tomography (CT) scan (including contusions (1cm^3 or less), traumatic SAH, extradural haematomas $<1\text{cm}$ in thickness). Patients who underwent bifrontal or bilateral craniectomies were excluded. Patients were excluded if they underwent a craniectomy for other causes; including extradural haemorrhage, diffuse brain injury, malignant middle cerebral artery (MCA) infarction, aneurysmal subarachnoid haemorrhage (SAH), or tumour. Other exclusion criteria included patients under the age of 16, and patients in whom there was no pre-operative imaging within six hours of surgery, or post-operative imaging within seven days. This requirement allowed us to calculate the degree of shift or effacement resolution. The decision to undergo a

1 decompressive craniectomy was made by the on-call consultant Neurosurgeon in charge of the patient's
2 care, based on the patient's demographics, clinical status, imaging findings and neurotrauma experience.
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4 Data collection included patient demographics, the nature of trauma, admission Glasgow Coma Score
5 (GCS) and pupils, imaging findings (including location of bleed, size of haematoma, contusions,
6 traumatic SAH, brain shift, brainstem compression, craniectomy size, herniation through the craniectomy
7 defect, diffuse axonal injury (DAI)), and outcomes (Modified Rankin Scale, cranioplasty). All imaging
8 metrics were measured using in-house Citrix picture archiving and communication software (PACS).
9 Measurements were undertaken independently by two trained assessors and the mean was then
10 determined. Pre and post-operative CT scans were used. Where there was more than one post-operative
11 scan only the earliest scan was included.
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17 Midline shift was calculated as the displacement of the septum pellucidum in millimetres in an
18 orthogonal plane from the midline. Brainstem shift was calculated as the displacement of the centre point
19 of the midbrain in millimetres in an orthogonal plane from the midline. The midline was defined as a
20 line drawn from the anterior attachment of the falx cerebri on the frontal bone to its posterior attachment
21 on the occipital bone. The centre point of the midbrain was defined as the midpoint of a line drawn from
22 between the cerebral peduncles to between the superior colliculi. Both determination of the midline and
23 measurement of shift were made on the same axial CT slice, at the rostro-caudal midpoint of the lateral
24 ventricle and at the level of the superior colliculi respectively. Haematoma size was calculated as the
25 maximum diameter on axial imaging. Results were averaged and if the deviation between the two
26 assessors' scores were 3mm or more for midline shift or 1mm or more for brainstem shift then a third
27 assessor took a final measurement. The two measurements that were closest were then retained as an
28 average.
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37 Brainstem compression was assessed using a cisternal effacement score.[3] Measurements were taken at
38 2 cisternal levels, perimesencephalic at the level of dorsum sellae and 10mm above at the level of the
39 quadrigeminal. The perimesencephalic cistern was divided into 4 sections (rhomboid) and the
40 quadrigeminal into 3 (semilunar) (Figure 1 and 2). Each of these 7 segments was scored: 0 = no
41 effacement, 1 = some effacement, 2 = complete effacement. The total score could range from 0 (no
42 effacement) to 14 (complete effacement). Scores were given by two separate assessors and results
43 averaged.
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50 Craniectomy size was measured using a 3-dimensional reconstruction of the cranium and the volume
51 measurement tool. If the difference in volume measured by the two assessors was greater than 3cm², a
52 third assessor recorded an additional measurement and the two closest were retained and averaged.
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56 Extent of subtemporal decompression was measured as the height of the remaining bone from the middle
57 fossa floor to the inferior limit of the craniectomy, typically the lip of squamous temporal bone (Figure
58 3). It was taken at a point that correlated with the centre of the midbrain using a localizer. This equated
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1 to a point approximately 2cm anterior to the root of the zygoma. The lower the figure the greater the
2 extent of subtemporal decompression, for example a result of zero would be completely flush with the
3 middle fossa floor.
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5 All data was stored in accordance with General Data Protection Regulations and the Data Protection
6 Act 2018. It was kept in encrypted pseudo-anonymised files on a computer in a locked room at the
7 hospital. Access was limited to the clinical research team. Data was analysed with simple statistics, two
8 tailed student t-test, and simple linear regression with Bonferroni correction as appropriate.
9

10 **Results**

11 36 patients underwent a primary decompressive craniectomy for an acute subdural haematoma in a 5-
12 year period between June 2008 and August 2013 and fulfilled our strict inclusion and exclusion criteria.
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14 The mean age was 36.1 +/- 12.5 (range 16-62) and 69.4% were male (25/36). The mechanism of injury
15 was due to falls, road traffic accidents or assaults in 94.4% of cases (Table 1). The median GCS at
16 presentation was 5, with 76.2% presenting as severe traumatic brain injury (TBI) with a GCS of 3-8,
17 14.3% with moderate (GCS 9-13), and 9.5% with mild TBI (GCS 14-15). Pre-operative pupil response
18 was normal in 46.2% of cases, unilaterally fixed in 38.4% and bilaterally fixed and dilated in 15.4%. The
19 time taken between admission and operation was a median of 4.2 hours (interquartile range 1.8 hours –
20 1 day).
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22 There were an equal number of left and right sided convexity haematomas (18 of each). Two patients
23 had an associated smaller extradural, and one patient had bilateral subdural haematomas (the larger left
24 sided subdural was causing the mass effect requiring unilateral craniectomy and hence inclusion in this
25 study). The median size of the haematoma was 8.3mm, with a midline shift of 8.4mm and brainstem shift
26 of 1.65mm (Table 2). 63.9% of patients had contusions on imaging, and 88.9% had evidence of traumatic
27 SAH blood.
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29 The median craniectomy size was 88.7cm² (range 43.5–123.2cm²) (Figure 4) and the median
30 subtemporal decompression was 15.0mm (range 3.0– 57.2mm). There was no association with either the
31 size of craniectomy or subtemporal decompression with the change in midline shift, brainstem shift or
32 cisternal effacement score (Table 3). This can be seen graphically in Figures 5-7. In 17 patients (47.2%)
33 there was an element of brain herniation through the craniectomy defect on post-operative imaging, as
34 reported by a consultant Neuroradiologist. There was no relationship between brain herniation through
35 the craniectomy defect and pre-operative midline shift (p = 0.679), brainstem shift (p = 0.642), or
36 craniectomy size (p = 0.595) on a two-tailed t-test.
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38 33 patients (91.7%) had a post prognostication Magnetic Resonance Imaging (MRI) scan post-
39 operatively. 20 (60.6%) had no evidence of DAI on imaging, and 6 (18.2%), 5 (15.2%), and 2 (6.1%)
40 had evidence of grade 1, 2, and 3 DAI respectively.
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1 Long term follow-up was available in 97.2% of cases (35/36) with a median of 23.5 months (range 2.2
2 – 109.6 months). There was no mortality in this cohort. The majority of the patients made a good recovery
3 with 82.8% having a favourable modified Rankin score of 2 or less (Table 4). Additionally, there was no
4 association between craniectomy size or subtemporal decompression and outcome ($R^2 = 0.0092$ and
5 0.0487 respectively). 100% of patients had a cranioplasty at a median of 9.3 months (range 1.6 – 53.1
6 months).
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10 11 **Discussion**

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14 This study demonstrates a statistically significant reduction in post-operative midline shift, brainstem
15 shift and cisternal effacement following primary craniectomy for acute subdural haematoma evacuation.
16 However, the size of craniectomy or extent of subtemporal decompression showed a striking lack of
17 correlation with the degree of midline shift, brainstem shift or cisternal effacement resolution. In this
18 study, the size of the craniectomy and subtemporal decompression was patient and surgeon specific, with
19 the aim to resolve midline shift and brainstem compression, and improve patient outcomes. This gave us
20 the opportunity to pragmatically correlate different sizes of craniectomy with subtypes of brain shift.
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27 Despite being one of the oldest and most common cranial neurosurgical procedures the exact indications
28 and rationale for a primary craniectomy are still being elucidated. A large craniectomy with a
29 subtemporal decompression is not a benign procedure and should only be undertaken if there is likely to
30 be a benefit to the patient. Evidence suggests that primary decompressive craniectomy is performed in a
31 significant proportion of acute subdural haematoma evacuations in the UK.[20] The decision to perform
32 a craniectomy must be balanced against several negative consequences. There is the risk of surgical
33 complication and morbidity, a cosmetic bony defect as well as risk of damage to the temporalis
34 muscle/innervation, and the potential need for a later operation to insert a cranioplasty which itself carries
35 additional risks including infection.[6, 14, 15, 24] It is important to know if the craniectomy size
36 correlates with shift resolution, to determine if there is a critical size required, and to help decide if a
37 craniotomy will suffice. The benefit of a primary craniectomy versus craniotomy for acute subdural
38 haematomas is uncertain, and is being investigated in the RESCUE-ASDH trial.[19, 22]
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47 The finding that craniectomy size does not correlate with the degree of midline shift can reasonably be
48 explained by the assertion that the primary mediators of midline shift are a) residual haematoma and b)
49 brain swelling and underlying parenchymal injury. The European Brain Injury Consortium had a mean
50 craniectomy size of 67cm^2 and determined that less than 30cm^2 was inadequate.[8] By this definition, all
51 the bone flaps in our study were of adequate size (Figure 4), which may explain the lack of correlation.
52 Decompression is a secondary factor and any role it plays in resolution of midline shift did not show a
53 correlation. It may be the case that more swollen brains, and worse injuries, received larger flaps,
54 essentially masking any effect on reducing shift. Additionally, not all the cases were planned as primary
55 decompressive craniectomies, some were planned as craniotomies, but swelling and intraoperative
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1 appearance may have led to the decision to leave the bone out. The confounding role of a progression in
2 pathological process in the intervening time between the preoperative and postoperative scans also
3 cannot be discounted. In 47% of cases there was herniation of brain through the craniectomy defect on
4 post-operative imaging, suggesting a degree of brain swelling post-operatively. This showed no
5 association with pre-operative shift or craniectomy size.
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9 Subtemporal decompression was described by Harvey Cushing as a method of controlling pressure
10 resulting from brain tumours and traumatic blast injuries.[9, 10] It was initially used as an isolated
11 method without the larger craniectomy seen with modern decompressions.[2, 13, 16] Today, a
12 craniectomy including the subtemporal decompression is common practice. However, it has associated
13 risks, including bleeding (particularly with skull base fractures), need for a preauricular incision,
14 prolonged operative time, lateral brain herniation, poor cosmesis and the risk of damaging the frontalis
15 branch of the facial nerve. It is important to determine whether subtemporal decompression improves
16 brain shift or cisternal effacement before continuing to routinely perform this additional step.
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22 The theory behind subtemporal decompression is that any pressure generated at the middle fossa floor,
23 for example due to brain swelling or contusions, will be transferred medially to the brainstem in the form
24 of uncal herniation if there is not a sufficiently low craniectomy to allow expansion of the mass laterally.
25 Although an intuitively appealing theory this has never been empirically tested. The subtemporal region
26 is not a true 'closed box' with only a medial opening. Although there are bone limits anteriorly (greater
27 wing of sphenoid), laterally (squamous temporal bone), inferiorly (fossa floor) and posteriorly (petrous
28 ridge), the fossa is largely open superiorly apart from an anterior portion of the temporal pole covered
29 by the lesser wing of sphenoid. This means that pressure transfer can occur from the middle fossa floor
30 superiorly to the cerebral hemisphere, and vice versa. Whether pressure shifts brain medially or
31 superiorly from the middle fossa will depend on the pressure differential within these spaces. By 'opening
32 the box' with a craniectomy above the middle temporal fossa it may be the case that this route of pressure
33 equalization is adequate to lead to a resolution in brainstem shift and cisternal effacement. The
34 contribution of the subtemporal portion of this decompression was not evident in this study and it may
35 be that it contributes far less to resolution of pressure on the brainstem than classically taught. Another
36 factor to consider is the pliability of the skin and soft tissue lateral to the middle fossa after closure, in
37 comparison to the convexity. The extra bulk of temporalis and tension provided by proximity to bone
38 attachments may make expansion here less likely to occur, particularly in the context of a large
39 hemispheric decompression.
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51 The outcomes over a median of 23.5 months were very positive. Despite significant TBI, with patients
52 having a median presentation GCS of 5 (three quarters of the cohort presented as a severe TBI and half
53 had at least one fixed pupil), there were no mortalities and the majority of the patients made a good
54 recovery. Our inclusion criteria necessitated a post-operative CT scan, so patients who were too unstable
55 for a post-operative scan, and may have gone on to die, were excluded. In addition, as over 85% of our
56 cohort had good outcomes, we found no association between pre-operative compression or craniectomy
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1 size and outcome. This is likely to be a result of too few patients having poor outcomes for conclusions
2 to be reliably drawn.
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4 There are several limitations to this study. It was a retrospective, single centre study, with a relatively
5 small sample size, reflecting out strict inclusion and exclusion criteria. We were unable to elucidate
6 whether the craniectomy was planned preoperatively or intraoperatively. A decision may provisionally
7 be made on the preoperative scan but the final decision is usually made after the state of the brain and
8 the space available after clot evacuation has been visualised. We were unable to assess whether the bone
9 opening was increased intraoperatively, for example, as a result of unexpected brain swelling, and post-
10 operative pupil response documentation was poor. ICP data was unavailable, so we were unable to
11 compare pre and post-operative data and compare it to craniectomy size, or stratify it with pathology.
12 However, brain herniation through the defect acted as a crude surrogate. We hope to assess this in future
13 work.
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21 We would argue that knowledge of these factors was not necessary to determine a correlation between
22 extent of craniectomy and shift. This was a pragmatic analysis and demonstrated the real-life correlation
23 between craniectomy size and various subtypes of brain shift. The lack of a clear linear relationship, or
24 even a correlation, between craniectomy size and markers of brain shift urges us to re-examine the
25 importance of the bone opening in a craniectomy for evacuation of subdural haematomas.
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31 **Conclusion**

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34 This study suggests that there is no clear relationship between craniectomy size or extent of subtemporal
35 decompression and resolution of brain shift or outcome. This includes midline shift at the level of the
36 foramen of Monro, shift at the level of the midbrain and cisternal effacement. Other factors, including
37 adequacy of haematoma evacuation, surgeon's prediction of subsequent brain swelling, and the
38 heterogenous nature of TBI, are likely to be critical.[5] Further studies should focus on larger prospective
39 series or randomised controlled studies to assess the relative efficacy of large craniectomies and the role
40 of subtemporal decompression.
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49
50

51 **Conflict of Interest**

52 All authors certify that they have no affiliations with or involvement in any organization or entity with
53 any financial interest (such as honoraria; educational grants; participation in speakers' bureaus;
54 membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony
55 or patent-licensing arrangements), or non-financial interest (such as personal or professional
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relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Ethical approval

This study was registered locally with the Clinical Effectiveness Unit as a Service Evaluation prior to data collection. Data was fully anonymised so formal consent was not required.

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Figures

Figure 1

CT scan at level of perimesencephalic cistern demonstrating the 4 borders used to calculate cisternal effacement score.

Figure 2

CT scan at level of quadrigeminal cistern demonstrating the 3 borders used to calculate the cisternal effacement score.

Figure 3

CT with bone windows demonstrating a subtemporal decompression as measured in the coronal plane.

Figure 4

Histogram of craniectomy size

Figure 5

Graph to show the change in midline shift in relation to craniectomy size

Figure 6

Graph to show the change in brainstem shift in relation to subtemporal decompression

Figure 7

Graph to show the change in cisternal effacement in relation to subtemporal decompression

Figure 8

CT brain showing pre and post-operative midline shift

Tables

Mechanism	Patients (n)	Percentage (%)
Fall from height	10	25.0
Assault	9	27.8
Pedestrian versus vehicle	6	11.1
Other road traffic accident	4	16.7
Fall from standing	5	13.9
Pre-eclampsia	1	2.8
Unknown mechanism	1	2.8

Table 1: The mechanism of injury for acute subdural haemorrhage.

Variable	Pre-operative	Post-operative	p value
Haematoma size (mm)	8.3 (3.1 – 32.3)		
Septum pellucidum midline shift (mm)	8.4 (0 – 18.8)	0.45 (-12.1 – 12.1)	< .00001
Brainstem shift (mm)	1.65 (0 – 5.1)	0 (-2.6 – 3)	< .00001
Cistern effacement score	6 (0 – 14)	0.5 (0 – 12)	< .00001

Table 2: Pre and post-operative imaging measurements, including haematoma size, septum pellucidum midline shift, brainstem shift and cistern effacement score. Results given as median with range in brackets. P values calculated with two tailed t-test. All p values are statistically significant.

Association	R²
Craniectomy size and:	
Midline shift	0.0002
Brainstem shift	0.0133
Cisternal effacement score	0.049
Subtemporal decompression and:	
Midline shift	0.0218
Brainstem shift	0.0008
Cisternal effacement score	0.0001

Table 3: Association of craniectomy size and subtemporal decompression with the change in midline shift, brain stem shift and cisternal effacement score. Correlation co-efficient (R²) calculated with linear regression.

Modified Rankin Scale	Patients n (%)
6 – death	0
5 – severe disability	0

4 – moderate severe disability	5 (14.3)
3 – moderate disability	1 (2.9)
2 – slight disability	4 (11.4)
1 – no significant disability	9 (25.7)
0 – no symptoms	16 (45.7)

Table 4: Patient outcomes on the Modified Rankin Scale. Data is given as raw numbers and percent. One patient was lost to follow up.

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Title page

Craniectomy size for subdural haematomas and the impact on brain shift and outcomes

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Abbreviations and acronyms

ICP = intracranial pressure

MCA = middle cerebral artery

SAH = subarachnoid haemorrhage

GCS = Glasgow coma scale

PACS = picture archiving and communication software

CT = computed tomography

TBI = traumatic brain injury

MRI = magnetic resonance injury

DAI = diffuse axonal injury

1 **Abstract**
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3
4 **Background**
5

6 Midline shift in trauma relates to the severity of head injury. Large craniectomies are thought to help
7 resolve brain shift but can be associated with higher rates of morbidity. This study explores the
8 relationship between craniectomy size and subtemporal decompression for acute subdural haematomas
9 with the resolution of brain compression and outcomes. No systematic study correlating these measures
10 has been reported.
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14 **Method**
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16 A retrospective study of all adult cases of acute subdural haematomas that presented to a Major Trauma
17 Centre and underwent a primary decompressive craniectomy between June 2008 and August 2013. Data
18 collection included patient demographics and presentation, imaging findings and outcomes. All imaging
19 metrics were measured by two independent trained assessors. Compression was measured as midline
20 shift, brainstem shift and cisternal effacement.
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25 **Results**
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27 36 patients with mean age was 36.1 +/- 12.5 (range 16-62) were included, with a median follow-up of
28 23.5 months (range 2.2-109.6). The median craniectomy size was 88.7cm² and the median subtemporal
29 decompression was 15.0mm. There was significant post-operative resolution of shift as measured by
30 midline shift, brainstem shift and cisternal effacement score (all p<.00001). There was no mortality, and
31 the majority of patients made a good recovery with 82.8% having a Modified Rankin Score of 2 or less.
32 There was no association between craniectomy size or subtemporal decompression and any markers of
33 brain shift or outcome (all R² < 0.05).
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39 **Conclusions**
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41 This study suggests that there is no clear relationship between craniectomy size or extent of subtemporal
42 decompression and resolution of brain shift or outcome. Further studies are needed to assess the relative
43 efficacy of large craniectomies and the role of subtemporal decompression.
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46 **Keywords:** Craniectomy, Decompression, Subdural Hematoma, Shift, Herniation, Brainstem
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Introduction

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3 Head injury is the leading cause of morbidity and mortality in people aged between one and forty years
4 in the United Kingdom, severely disabling 150-200 people per million annually.[12, 17, 18, 25] Elevated
5 intracranial pressure (ICP) within the fixed-volume skull is one of the most important causes of death
6 and disability, and the management remains a challenge.[4, 26] Primary decompressive craniectomy,
7 when a craniectomy is performed at the time of mass lesion evacuation, may be planned pre- or intra-
8 operatively depending on the degree of brain swelling and ICP. Surgery attempts to reduce global ICP,
9 focal compression and subsequent herniation with the aim to increase survival and reduce morbidity.
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15 Compression is assessed by radiological midline shift at the level of the lateral ventricles and by
16 brainstem compression inferred as the presence or absence of cisternal effacement. The degree of midline
17 shift relates to the severity of the head injury and has been correlated with outcome.[1, 7, 11, 27, 28]
18 Shift in excess of haematoma depth is an additional poor prognostic factor.[21, 23] Although it has not
19 been formally demonstrated it is intuitive that resolution of compression would occur with
20 decompression, and correlate with improved outcome.
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26 This study investigates the results of primary decompressive craniectomy for acute traumatic subdural
27 haematomas. It explores the relationship between craniectomy size and degree of subtemporal
28 decompression with the resolution of compression and outcomes. No systematic study correlating these
29 measures has been reported. The primary aims were (i) does the size of the craniectomy relate to the
30 degree of midline shift, brainstem shift, or cisternal effacement resolution? (ii) does the extent of
31 subtemporal decompression relate to the degree of midline shift, brainstem shift, or cisternal effacement
32 resolution? The secondary aim was to look at the long-term patient outcomes.
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Materials and Methods

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41 A retrospective study of cases of acute subdural haematomas that presented to a Major Trauma Centre
42 (MTC) and underwent a primary decompressive craniectomy in a 5-year period, **between June 2008 and**
43 **August 2013. The study was carried out in the largest of the four MTCs in London, serving a population**
44 **of over 2.5 million people. Inclusion criteria were adult patients who underwent a unilateral**
45 **decompressive craniectomy with a primary diagnosis of acute subdural causing mass effect, including**
46 **those with evidence of additional brain injury on computed tomography (CT) scan (including contusions**
47 **(1cm³ or less), traumatic SAH, extradural haematomas <1cm in thickness). Patients who underwent**
48 **bifrontal or bilateral craniectomies were excluded.** Patients were excluded if they underwent a
49 craniectomy for other causes; including extradural haemorrhage, diffuse brain injury, malignant middle
50 cerebral artery (MCA) infarction, aneurysmal subarachnoid haemorrhage (SAH), or tumour. Other
51 exclusion criteria included patients under the age of 16, and patients in whom there was no pre-operative
52 imaging within six hours of surgery, or post-operative imaging within seven days. This requirement
53 allowed us to calculate the degree of shift or effacement resolution. **The decision to undergo a**
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decompressive craniectomy was made by the on-call consultant Neurosurgeon in charge of the patient's care, based on the patient's demographics, clinical status, imaging findings and neurotrauma experience.

Data collection included patient demographics, the nature of trauma, admission Glasgow Coma Score (GCS) and pupils, imaging findings (including location of bleed, size of haematoma, contusions, traumatic SAH, brain shift, brainstem compression, craniectomy size, **herniation through the craniectomy defect, diffuse axonal injury (DAI)**), and outcomes (Modified Rankin Scale, **cranioplasty**). All imaging metrics were measured using in-house Citrix picture archiving and communication software (PACS). Measurements were undertaken independently by two trained assessors and the mean was then determined. Pre and post-operative CT scans were used. Where there was more than one post-operative scan only the earliest scan was included.

Midline shift was calculated as the displacement of the septum pellucidum in millimetres in an orthogonal plane from the midline. Brainstem shift was calculated as the displacement of the centre point of the midbrain in millimetres in an orthogonal plane from the midline. The midline was defined as a line drawn from the anterior attachment of the falx cerebri on the frontal bone to its posterior attachment on the occipital bone. The centre point of the midbrain was defined as the midpoint of a line drawn from between the cerebral peduncles to between the superior colliculi. Both determination of the midline and measurement of shift were made on the same axial CT slice, at the rostro-caudal midpoint of the lateral ventricle and at the level of the superior colliculi respectively. Haematoma size was calculated as the maximum diameter on axial imaging. Results were averaged and if the deviation between the two assessors' scores were 3mm or more for midline shift or 1mm or more for brainstem shift then a third assessor took a final measurement. The two measurements that were closest were then retained as an average.

Brainstem compression was assessed using a cisternal effacement score.[3] Measurements were taken at 2 cisternal levels, perimesencephalic at the level of dorsum sellae and 10mm above at the level of the quadrigeminal. The perimesencephalic cistern was divided into 4 sections (rhomboid) and the quadrigeminal into 3 (semilunar) (Figure 1 and 2). Each of these 7 segments was scored: 0 = no effacement, 1 = some effacement, 2 = complete effacement. The total score could range from 0 (no effacement) to 14 (complete effacement). Scores were given by two separate assessors and results averaged.

Craniectomy size was measured using a 3-dimensional reconstruction of the cranium and the volume measurement tool. If the difference in volume measured by the two assessors was greater than 3cm², a third assessor recorded an additional measurement and the two closest were retained and averaged.

Extent of subtemporal decompression was measured as the height of the remaining bone from the middle fossa floor to the inferior limit of the craniectomy, typically the lip of squamous temporal bone (Figure 3). It was taken at a point that correlated with the centre of the midbrain using a localizer. This equated

1 to a point approximately 2cm anterior to the root of the zygoma. The lower the figure the greater the
2 extent of subtemporal decompression, for example a result of zero would be completely flush with the
3 middle fossa floor.
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6 All data was stored in accordance with General Data Protection Regulations and the Data Protection
7 Act 2018. It was kept in encrypted pseudo-anonymised files on a computer in a locked room at the
8 hospital. Access was limited to the clinical research team. Data was analysed with simple statistics, two
9 tailed student t-test, and simple linear regression with Bonferroni correction as appropriate.
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12 Results

13 36 patients underwent a primary decompressive craniectomy for an acute subdural haematoma in a 5-
14 year period between June 2008 and August 2013 and fulfilled our strict inclusion and exclusion criteria.
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17 The mean age was 36.1 +/- 12.5 (range 16-62) and 69.4% were male (25/36). The mechanism of injury
18 was due to falls, road traffic accidents or assaults in 94.4% of cases (Table 1). The median GCS at
19 presentation was 5, with 76.2% presenting as severe traumatic brain injury (TBI) with a GCS of 3-8,
20 14.3% with moderate (GCS 9-13), and 9.5% with mild TBI (GCS 14-15). Pre-operative pupil response
21 was normal in 46.2% of cases, unilaterally fixed in 38.4% and bilaterally fixed and dilated in 15.4%. The
22 time taken between admission and operation was a median of 4.2 hours (interquartile range 1.8 hours –
23 1 day).
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26 There were an equal number of left and right sided convexity haematomas (18 of each). Two patients
27 had an associated smaller extradural, and one patient had bilateral subdural haematomas (the larger left
28 sided subdural was causing the mass effect requiring unilateral craniectomy and hence inclusion in this
29 study). The median size of the haematoma was 8.3mm, with a midline shift of 8.4mm and brainstem shift
30 of 1.65mm (Table 2). 63.9% of patients had contusions on imaging, and 88.9% had evidence of traumatic
31 SAH blood.
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34 The median craniectomy size was 88.7cm² (range 43.5–123.2cm²) (Figure 4) and the median
35 subtemporal decompression was 15.0mm (range 3.0– 57.2mm). There was no association with either the
36 size of craniectomy or subtemporal decompression with the change in midline shift, brainstem shift or
37 cisternal effacement score (Table 3). This can be seen graphically in Figures 5-7. In 17 patients (47.2%)
38 there was an element of brain herniation through the craniectomy defect on post-operative imaging, as
39 reported by a consultant Neuroradiologist. There was no relationship between brain herniation through
40 the craniectomy defect and pre-operative midline shift (p = 0.679), brainstem shift (p = 0.642), or
41 craniectomy size (p = 0.595) on a two-tailed t-test.
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44 33 patients (91.7%) had a post prognostication Magnetic Resonance Imaging (MRI) scan post-
45 operatively. 20 (60.6%) had no evidence of DAI on imaging, and 6 (18.2%), 5 (15.2%), and 2 (6.1%)
46 had evidence of grade 1, 2, and 3 DAI respectively.
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1 Long term follow-up was available in 97.2% of cases (35/36) with a median of 23.5 months (range 2.2
2 – 109.6 months). There was no mortality in this cohort. The majority of the patients made a good recovery
3 with 82.8% having a favourable modified Rankin score of 2 or less (Table 4). Additionally, there was no
4 association between craniectomy size or subtemporal decompression and outcome ($R^2 = 0.0092$ and
5 0.0487 respectively). 100% of patients had a cranioplasty at a median of 9.3 months (range 1.6 – 53.1
6 months).
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10 Discussion

11 This study demonstrates a statistically significant reduction in post-operative midline shift, brainstem
12 shift and cisternal effacement following primary craniectomy for acute subdural haematoma evacuation.
13 However, the size of craniectomy or extent of subtemporal decompression showed a striking lack of
14 correlation with the degree of midline shift, brainstem shift or cisternal effacement resolution. In this
15 study, the size of the craniectomy and subtemporal decompression was patient and surgeon specific, with
16 the aim to resolve midline shift and brainstem compression, and improve patient outcomes. This gave us
17 the opportunity to pragmatically correlate different sizes of craniectomy with subtypes of brain shift.
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27 Despite being one of the oldest and most common cranial neurosurgical procedures the exact indications
28 and rationale for a primary craniectomy are still being elucidated. A large craniectomy with a
29 subtemporal decompression is not a benign procedure and should only be undertaken if there is likely to
30 be a benefit to the patient. Evidence suggests that primary decompressive craniectomy is performed in a
31 significant proportion of acute subdural haematoma evacuations in the UK.[20] The decision to perform
32 a craniectomy must be balanced against several negative consequences. There is the risk of surgical
33 complication and morbidity, a cosmetic bony defect as well as risk of damage to the temporalis
34 muscle/innervation, and the potential need for a later operation to insert a cranioplasty which itself carries
35 additional risks including infection.[6, 14, 15, 24] It is important to know if the craniectomy size
36 correlates with shift resolution, to determine if there is a critical size required, and to help decide if a
37 craniotomy will suffice. The benefit of a primary craniectomy versus craniotomy for acute subdural
38 haematomas is uncertain, and is being investigated in the RESCUE-ASDH trial.[19, 22]
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47 The finding that craniectomy size does not correlate with the degree of midline shift can reasonably be
48 explained by the assertion that the primary mediators of midline shift are a) residual haematoma and b)
49 brain swelling and underlying parenchymal injury. The European Brain Injury Consortium had a mean
50 craniectomy size of 67cm^2 and determined that less than 30cm^2 was inadequate.[8] By this definition, all
51 the bone flaps in our study were of adequate size (Figure 4), which may explain the lack of correlation.
52 Decompression is a secondary factor and any role it plays in resolution of midline shift did not show a
53 correlation. It may be the case that more swollen brains, and worse injuries, received larger flaps,
54 essentially masking any effect on reducing shift. Additionally, not all the cases were planned as primary
55 decompressive craniectomies, some were planned as craniotomies, but swelling and intraoperative
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1 appearance may have led to the decision to leave the bone out. The confounding role of a progression in
2 pathological process in the intervening time between the preoperative and postoperative scans also
3 cannot be discounted. In 47% of cases there was herniation of brain through the craniectomy defect on
4 post-operative imaging, suggesting a degree of brain swelling post-operatively. This showed no
5 association with pre-operative shift or craniectomy size.
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9 Subtemporal decompression was described by Harvey Cushing as a method of controlling pressure
10 resulting from brain tumours and traumatic blast injuries.[9, 10] It was initially used as an isolated
11 method without the larger craniectomy seen with modern decompressions.[2, 13, 16] Today, a
12 craniectomy including the subtemporal decompression is common practice. However, it has associated
13 risks, including bleeding (particularly with skull base fractures), need for a preauricular incision,
14 prolonged operative time, lateral brain herniation, poor cosmesis and the risk of damaging the frontalis
15 branch of the facial nerve. It is important to determine whether subtemporal decompression improves
16 brain shift or cisternal effacement before continuing to routinely perform this additional step.
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22 The theory behind subtemporal decompression is that any pressure generated at the middle fossa floor,
23 for example due to brain swelling or contusions, will be transferred medially to the brainstem in the form
24 of uncal herniation if there is not a sufficiently low craniectomy to allow expansion of the mass laterally.
25 Although an intuitively appealing theory this has never been empirically tested. The subtemporal region
26 is not a true ‘closed box’ with only a medial opening. Although there are bone limits anteriorly (greater
27 wing of sphenoid), laterally (squamous temporal bone), inferiorly (fossa floor) and posteriorly (petrous
28 ridge), the fossa is largely open superiorly apart from an anterior portion of the temporal pole covered
29 by the lesser wing of sphenoid. This means that pressure transfer can occur from the middle fossa floor
30 superiorly to the cerebral hemisphere, and vice versa. Whether pressure shifts brain medially or
31 superiorly from the middle fossa will depend on the pressure differential within these spaces. By ‘opening
32 the box’ with a craniectomy above the middle temporal fossa it may be the case that this route of pressure
33 equalization is adequate to lead to a resolution in brainstem shift and cisternal effacement. The
34 contribution of the subtemporal portion of this decompression was not evident in this study and it may
35 be that it contributes far less to resolution of pressure on the brainstem than classically taught. Another
36 factor to consider is the pliability of the skin and soft tissue lateral to the middle fossa after closure, in
37 comparison to the convexity. The extra bulk of temporalis and tension provided by proximity to bone
38 attachments may make expansion here less likely to occur, particularly in the context of a large
39 hemispheric decompression.
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51 The outcomes over a median of 23.5 months were very positive. Despite significant TBI, with patients
52 having a median presentation GCS of 5 (three quarters of the cohort presented as a severe TBI and half
53 had at least one fixed pupil), there were no mortalities and the majority of the patients made a good
54 recovery. Our inclusion criteria necessitated a post-operative CT scan, so patients who were too unstable
55 for a post-operative scan, and may have gone on to die, were excluded. In addition, as over 85% of our
56 cohort had good outcomes, we found no association between pre-operative compression or craniectomy
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1 size and outcome. This is likely to be a result of too few patients having poor outcomes for conclusions
2 to be reliably drawn.

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4 There are several limitations to this study. It was a retrospective, single centre study, with a relatively
5 small sample size, reflecting out strict inclusion and exclusion criteria. We were unable to elucidate
6 whether the craniectomy was planned preoperatively or intraoperatively. A decision may provisionally
7 be made on the preoperative scan but the final decision is usually made after the state of the brain and
8 the space available after clot evacuation has been visualised. We were unable to assess whether the bone
9 opening was increased intraoperatively, for example, as a result of unexpected brain swelling, and post-
10 operative pupil response documentation was poor. ICP data was unavailable, so we were unable to
11 compare pre and post-operative data and compare it to craniectomy size, or stratify it with pathology.
12 However, brain herniation through the defect acted as a crude surrogate. We hope to assess this in future
13 work.
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21 We would argue that knowledge of these factors was not necessary to determine a correlation between
22 extent of craniectomy and shift. This was a pragmatic analysis and demonstrated the real-life correlation
23 between craniectomy size and various subtypes of brain shift. The lack of a clear linear relationship, or
24 even a correlation, between craniectomy size and markers of brain shift urges us to re-examine the
25 importance of the bone opening in a craniectomy for evacuation of subdural haematomas.
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31 **Conclusion**

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34 This study suggests that there is no clear relationship between craniectomy size or extent of subtemporal
35 decompression and resolution of brain shift or outcome. This includes midline shift at the level of the
36 foramen of Monro, shift at the level of the midbrain and cisternal effacement. Other factors, including
37 adequacy of haematoma evacuation, surgeon's prediction of subsequent brain swelling, and the
38 heterogenous nature of TBI, are likely to be critical.[5] Further studies should focus on larger prospective
39 series or randomised controlled studies to assess the relative efficacy of large craniectomies and the role
40 of subtemporal decompression.
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49
50

51 **Conflict of Interest**

52
53 All authors certify that they have no affiliations with or involvement in any organization or entity with
54 any financial interest (such as honoraria; educational grants; participation in speakers' bureaus;
55 membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony
56 or patent-licensing arrangements), or non-financial interest (such as personal or professional
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relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Ethical approval

This study was registered locally with the Clinical Effectiveness Unit as a Service Evaluation prior to data collection. Data was fully anonymised so formal consent was not required.

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Figures

Figure 1

CT scan at level of perimesencephalic cistern demonstrating the 4 borders used to calculate cisternal effacement score.

Figure 2

CT scan at level of quadrigeminal cistern demonstrating the 3 borders used to calculate the cisternal effacement score.

Figure 3

CT with bone windows demonstrating a subtemporal decompression as measured in the coronal plane.

Figure 4

Histogram of craniectomy size

Figure 5

Graph to show the change in midline shift in relation to craniectomy size

Figure 6

Graph to show the change in brainstem shift in relation to subtemporal decompression

Figure 7

Graph to show the change in cisternal effacement in relation to subtemporal decompression

Figure 8

CT brain showing pre and post-operative midline shift

Tables

Mechanism	Patients (n)	Percentage (%)
Fall from height	10	25.0
Assault	9	27.8
Pedestrian versus vehicle	6	11.1
Other road traffic accident	4	16.7
Fall from standing	5	13.9
Pre-eclampsia	1	2.8
Unknown mechanism	1	2.8

Table 1: The mechanism of injury for acute subdural haemorrhage.

Variable	Pre-operative	Post-operative	p value
Haematoma size (mm)	8.3 (3.1 – 32.3)		
Septum pellucidum midline shift (mm)	8.4 (0 – 18.8)	0.45 (-12.1 – 12.1)	< .00001
Brainstem shift (mm)	1.65 (0 – 5.1)	0 (-2.6 – 3)	< .00001
Cistern effacement score	6 (0 – 14)	0.5 (0 – 12)	< .00001

Table 2: Pre and post-operative imaging measurements, including haematoma size, septum pellucidum midline shift, brainstem shift and cistern effacement score. Results given as median with range in brackets. P values calculated with two tailed t-test. All p values are statistically significant.

Association	R²
Craniectomy size and:	
Midline shift	0.0002
Brainstem shift	0.0133
Cisternal effacement score	0.049
Subtemporal decompression and:	
Midline shift	0.0218
Brainstem shift	0.0008
Cisternal effacement score	0.0001

Table 3: Association of craniectomy size and subtemporal decompression with the change in midline shift, brain stem shift and cisternal effacement score. Correlation co-efficient (R²) calculated with linear regression.

Modified Rankin Scale	Patients n (%)
6 – death	0
5 – severe disability	0

4 – moderate severe disability	5 (14.3)
3 – moderate disability	1 (2.9)
2 – slight disability	4 (11.4)
1 – no significant disability	9 (25.7)
0 – no symptoms	16 (45.7)

Table 4: Patient outcomes on the Modified Rankin Scale. Data is given as raw numbers and percent.

One patient was lost to follow up.

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