Decompressive craniectomy following traumatic brain injury

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Escalating cycle of brain swelling

Primary insult → Brain swelling → Secondary insult

Energy failure

Increase in brain injury and poor outcome

Decrease in O² delivery

Increase in ICP

Decrease in cerebral blood flow
Decompressive Craniectomy

‘If there is no CSF pressure, but brain pressure exists, then pressure relief must be achieved by opening the skull’

Kocher 1901

Decompressive Craniectomy in TBI

Concerns

• Does it control raised ICP?
• Does herniated brain escalate the problems?
• Do the results justify the treatment?
  – Good prognosis patients
    • will do well anyway
  – Poor prognosis patients
    • move from mortality to persistent vegetative state and severe disability
• What are the complications?
NCCU – Head injury management

ICP<25 mmHg    CPP>60 mmHg

• Stage I
  – Propofol, fentanyl, atracurium
  – 10-15 ° head up
  – PaCO₂ 4.5-5.0 kPa
  – SaO₂ >97%, PaO₂ >11kPa
  – Temp < 37 °C

• Stage II
  – External ventricular drain

• Stage III
  – Inotropes / 5% NaCl / Mannitol
  – PaCO₂ 4.0 kPa
  – Temp 35 °C

• Stage IV
  – Temp 33-34 °C

• Stage V
  – Thiopentone
  – Decompressive craniectomy

Decompressive craniectomy – pubmed publications
F Servadei
Decompressive craniectomy in TBI

<table>
<thead>
<tr>
<th>First author</th>
<th>Year</th>
<th>Number of patients</th>
<th>Outcome based on Glasgow Outcome Scale</th>
<th>Additional details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vesin</td>
<td>1975</td>
<td>13</td>
<td>Increase in survival, high mortality</td>
<td>Retrospective, observational study</td>
</tr>
<tr>
<td>Cooper</td>
<td>1976</td>
<td>20</td>
<td>4 6 90</td>
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<td>Reveska</td>
<td>1977</td>
<td>12</td>
<td>42 8 50</td>
<td>Biographical</td>
</tr>
<tr>
<td>Grotz</td>
<td>1978</td>
<td>42</td>
<td>85</td>
<td></td>
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<tr>
<td>Grotz</td>
<td>1960</td>
<td>30</td>
<td>17 13 70</td>
<td>Retrospective case series</td>
</tr>
<tr>
<td>Greiner</td>
<td>1980</td>
<td>15</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Presser</td>
<td>1988</td>
<td>10 and 17</td>
<td>40 (8 in barbiturate group)</td>
<td>Comparison of decompressive and barbiturate versus barbiturate alone.</td>
</tr>
<tr>
<td>Strate</td>
<td>1990</td>
<td>3</td>
<td>78 8 14</td>
<td>Retrospective single centre study with exclusion criteria</td>
</tr>
<tr>
<td>Armer</td>
<td>1991</td>
<td>5</td>
<td>Improvement in brain function</td>
<td>Observational study in paediatric patients</td>
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<tr>
<td>Raznovskij</td>
<td>1997</td>
<td>20</td>
<td>20</td>
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<td>Honek</td>
<td>1997</td>
<td>25</td>
<td>37 40 23</td>
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<tr>
<td>Norton</td>
<td>1998</td>
<td>28</td>
<td>56 22 11</td>
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<td>Guerra</td>
<td>1999</td>
<td>57</td>
<td>56 10 19</td>
<td>Patients over 60 are excluded</td>
</tr>
<tr>
<td>March</td>
<td>2000</td>
<td>49</td>
<td>No beneficial effect on outcome</td>
<td>Same improvement in CT appearance</td>
</tr>
<tr>
<td>De Luca</td>
<td>2002</td>
<td>22</td>
<td>40 41 18</td>
<td>23% of patients with persistent vegetative state</td>
</tr>
<tr>
<td>Guglielmi</td>
<td>2001</td>
<td>29</td>
<td>Similar outcome with higher severity</td>
<td>Retrospective randomized controlled trial</td>
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<tr>
<td>Taylor</td>
<td>2001</td>
<td>56</td>
<td>96 vs. 14</td>
<td>Case series</td>
</tr>
<tr>
<td>Whitting</td>
<td>2001</td>
<td>26</td>
<td>69 8 23</td>
<td>Cranectomies compared to craniumotomy</td>
</tr>
<tr>
<td>Clark</td>
<td>2002</td>
<td>21</td>
<td>38 19 43</td>
<td>Retrospective case series</td>
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<tr>
<td>Soukasian</td>
<td>2002</td>
<td>42</td>
<td>29 vs. 18</td>
<td>Documented improvement in ICP control</td>
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<tr>
<td>Nolte-Mankie</td>
<td>2002</td>
<td>9</td>
<td>66 22 22</td>
<td>Case series</td>
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<tr>
<td>Schinder</td>
<td>2002</td>
<td>62</td>
<td>22 22 23</td>
<td>Cranectomies compared to craniumotomy</td>
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<tr>
<td>Almeier</td>
<td>2003</td>
<td>91</td>
<td>Same benefit, particularly in younger patients</td>
<td>Early versus late decompression</td>
</tr>
<tr>
<td>Allamano</td>
<td>2003</td>
<td>40</td>
<td>38 38 23</td>
<td>Case series</td>
</tr>
<tr>
<td>Zili</td>
<td>2003</td>
<td>18</td>
<td>30 48 22</td>
<td>Cranectomies compared to craniumotomy</td>
</tr>
<tr>
<td>Gist</td>
<td>2005</td>
<td>100</td>
<td>38 54 22</td>
<td>Mixed group</td>
</tr>
<tr>
<td>Vitelesius</td>
<td>2005</td>
<td>89</td>
<td>38 24 18</td>
<td>Cranectomies compared to craniumotomy</td>
</tr>
</tbody>
</table>

| Brain Trauma Foundation | www.braintrauma.org |

- Bifrontal decompressive craniectomy within 48 hours of injury is a treatment option for patients with diffuse, medically refractory posttraumatic cerebral edema and resultant intracranial hypertension
Cochrane review

• No evidence from RCTs that supports the routine use of secondary decompressive craniectomy to reduce unfavorable outcomes in adults with severe TBI and refractory high ICP.

• **Brain trauma Foundation** – “option”

• 2 trials started recruiting in 2002-4
  - DECRA (Australia, New Zealand, Saudi Arabia)
  - RESCUEicp (43 centres in 17 countries, mainly UK)

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**Effect of DC on ICP**

![Graph showing impact of decompressive craniectomy on intracranial pressure](image)

Timofeev et al, J Neurosurgery, 2008
Physiological effects of craniectomy impact on autoregulation

Operative technique

- **Primary decompressive craniectomy**
  - Leaving the bone flap out following initial surgery for a mass lesion – acute haematoma

- **Secondary decompressive craniectomy**
  - Removing the bone flap to control raised and refractory intracranial pressure
Operation type

• Unilateral - frontotemporoparietal
  – Unilateral brain swelling with midline shift
  – Large unilateral craniectomy

• Bilateral
  – Diffuse brain injury
  – Bi-coronal scalp flap
  – Bilateral frontal craniectomy to coronal suture posteriorly and pterion laterally

Unilateral decompressive craniectomy
Unilateral decompressive craniectomy
Bifrontal decompressive craniectomy
Bifrontal decompressive craniectomy

Division of the falx
Cranialisation and occlusion of the frontal sinus

Calculated Volume gained by Surgical Compression

Volume [ml] vs. Diameter Defect [cm]

- < 10 cm³
- < 50 cm³
- Effective!

Acknowledgement Aschoff and Piek
Complications of decompressive craniectomy for traumatic brain injury

S Stiver,

Neurosurgical Focus 2009 ed G Manley

- Subdural hygroma
- Contusion / hematoma progression
- Infection
- New contralateral extraaxial haematoma
- Hydrocephalus
- Bone flap resorption
- Re-operation
- Complications of cranioplasty

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Skull reconstruction – is not without its complications

- Management of hydrocephalus
- Infection
- Seizures
- Cosmesis
Randomised trials of decompressive craniectomy for TBI

- RESCUEicp
  - Cambridge UK
  - 400 patients
  - Recruitment on-going
  - 10-65 years
  - Raised ICP refractory to protocol-based medical management
  - ICP threshold 25mmHg

- DECRA
  - Melbourne Australia
  - 155 patients randomised
  - Completed
  - 15-60 years
  - Severe diffuse brain injury within 72 hours injury
  - ICP threshold 20mmHg

Li et al, Anaesth Analg, 2010

Hypotheses of trials

- RESCUEicp
  - Decompressive craniectomy can improve outcomes (compared to barbiturates) as last-tier therapy for refractory post-traumatic intracranial hypertension

- DECRA
  - Early/neuroprotective bifrontal decompression can improve outcomes following diffuse TBI
DECRA - CONSORT

Supplementary Figure 1. Assessment, randomization and follow-up of the trial.

Patients with severe traumatic brain injury assessed for eligibility (n=1471)
- Excluded (n=330)
  - Mixx lesion (n=1222)
  - Unsurvivable poor prognosis (n=420)
  - Age > 65.6 (n=213)
  - ICP controlled (n=1105)
  - Other (n=344)
- Declined Consent (n=23)

Randomized (n=1553)

Allocated to craniectomy (n=733)
- Received craniectomy (n=70)
  - ICP stabilized prior to craniectomy (n=2)
  - Incorrectly randomized (n=1)

Allocated to standard care (n=820)
- Received standard care (n=780)
- Received craniectomy (n=40)

Analyzed (n=733)
- Lost to follow up (n=0)
- Withdraw consent (n=0)

Analyzed (n=820)
- Lost to follow up (n=0)
- Withdraw consent (n=0)

DECRA - Demographics

Table 1. Baseline Characteristics of the Patients.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Decompressive Craniectomy (n=733)</th>
<th>Standard Care (n=820)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age — yr</td>
<td>Median 37</td>
<td>34.6</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>Interquartile range 19.4–36.4</td>
<td>18.5–34.9</td>
<td></td>
</tr>
<tr>
<td>Male sex — no. (%)</td>
<td>59 (81)</td>
<td>41 (74)</td>
<td>0.44</td>
</tr>
<tr>
<td>Systolic blood pressure — mmHg</td>
<td>135.4±32.0</td>
<td>135.7±27.6</td>
<td>0.95</td>
</tr>
<tr>
<td>Glasgow Coma Scale</td>
<td>Overall score</td>
<td>3.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Median 3</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interquartile range 1–7</td>
<td>4.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Median 3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interquartile range 1–4</td>
<td>3–5</td>
<td></td>
</tr>
<tr>
<td>Maximum score for head injury on Abbreviated Injury Scale — no. (%)</td>
<td>15 (48)</td>
<td>44 (54)</td>
<td>0.52</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>38 (52)</td>
<td>38 (46)</td>
</tr>
<tr>
<td>Injury Severity Score†</td>
<td>Median 33</td>
<td>32</td>
<td>0.88</td>
</tr>
<tr>
<td></td>
<td>Interquartile range 25–58</td>
<td>24–41</td>
<td></td>
</tr>
<tr>
<td>Trauma Score-injury Severity Score‡</td>
<td>Median 4.72</td>
<td>3.72</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td>Interquartile range 4.42–6.88</td>
<td>4.53–8.90</td>
<td></td>
</tr>
<tr>
<td>Reactivity of pupils — no./total no. (%)</td>
<td>Neither pupil</td>
<td>35/71 (47)</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>One in both pupils</td>
<td>52/71 (73)</td>
<td></td>
</tr>
</tbody>
</table>

(Continued on next page)
## DECRA - Complications

### Table 3. Medical and Surgical Complications.

<table>
<thead>
<tr>
<th>Adverse Event</th>
<th>Decompressive Cranietomy (N=73)</th>
<th>Standard Care (N=82)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number (percent)</td>
<td></td>
</tr>
<tr>
<td>Wound infection or breakdown</td>
<td>5 (7)</td>
<td>7 (9)</td>
</tr>
<tr>
<td>Meningitis or ventriculitis</td>
<td>2 (3)</td>
<td>3 (4)</td>
</tr>
<tr>
<td>Subgaleal infection</td>
<td>2 (3)</td>
<td>3 (4)</td>
</tr>
<tr>
<td>Cerebral abscess</td>
<td>2 (3)</td>
<td>0</td>
</tr>
<tr>
<td>Cerebrospinal fluid leak</td>
<td>4 (5)</td>
<td>2 (2)</td>
</tr>
<tr>
<td>Hematoma</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subgaleal</td>
<td>5 (7)</td>
<td>2 (2)</td>
</tr>
<tr>
<td>Subdural, extradural, or intracerebral</td>
<td>1 (4)</td>
<td>1 (1)</td>
</tr>
<tr>
<td>Cerebral infarction</td>
<td>1 (1)</td>
<td>0</td>
</tr>
<tr>
<td>Hydrocephalus</td>
<td>7 (10)</td>
<td>4 (1)</td>
</tr>
<tr>
<td>Cranioplasty revision for cosmetic defect</td>
<td>2 (3)</td>
<td>0</td>
</tr>
<tr>
<td>Pulmonary embolus</td>
<td>1 (1)</td>
<td>2 (2)</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>0</td>
<td>3 (4)</td>
</tr>
<tr>
<td>Septic shock</td>
<td>1 (1)</td>
<td>2 (2)</td>
</tr>
<tr>
<td>Acute renal failure</td>
<td>1 (1)</td>
<td>1 (1)</td>
</tr>
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</table>

## DECRA - Endpoints

### Outcome

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Decompressive Cranietomy (N=73)</th>
<th>Standard Care (N=82)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extended Glasgow Outcome Scale</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Score — no. (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 (dead)</td>
<td>14 (19)</td>
<td>15 (18)</td>
<td></td>
</tr>
<tr>
<td>2 (vegetative state)</td>
<td>9 (12)</td>
<td>2 (2)</td>
<td></td>
</tr>
<tr>
<td>3 (lower severe disability)</td>
<td>18 (25)</td>
<td>17 (21)</td>
<td></td>
</tr>
<tr>
<td>4 (upper severe disability)</td>
<td>10 (14)</td>
<td>8 (10)</td>
<td></td>
</tr>
<tr>
<td>5 (lower moderate disability)</td>
<td>13 (18)</td>
<td>20 (24)</td>
<td></td>
</tr>
<tr>
<td>6 (upper moderate disability)</td>
<td>6 (8)</td>
<td>33 (16)</td>
<td></td>
</tr>
<tr>
<td>7 (lower good recovery)</td>
<td>2 (3)</td>
<td>4 (5)</td>
<td></td>
</tr>
<tr>
<td>8 (upper good recovery)</td>
<td>1 (1)</td>
<td>3 (4)</td>
<td></td>
</tr>
<tr>
<td>Median score (IQR)</td>
<td>3 (2–5)</td>
<td>4 (3–5)</td>
<td>0.03</td>
</tr>
<tr>
<td>Unfavorable score of 1 to 4 — no. (%)</td>
<td>51 (70)</td>
<td>42 (53)</td>
<td>0.02</td>
</tr>
</tbody>
</table>
DECRA - Results

- Craniectomy group had
  - less time with ICP above the treatment threshold (P<0.001)
  - fewer interventions for increased ICP (P<0.02)
  - fewer days in ITU (P<0.001)

- However, craniectomy group had
  - worse scores on the eGOS
    (OR: 1.84; 95% CI: 1.05 to 3.24; P = 0.03)
  - greater risk of an unfavourable outcome
    (OR 2.21; 95% CI: 1.14-4.26; P = 0.02)

- Mortality at 6 months similar in the craniectomy group (19%) and the standard-care group (18%)

DECRA - comments

- ICP was lower in the craniectomy group but it was not excessively high (i.e. remained less than 25mmHg) in the medical group

- 27% of craniectomy patients had neither pupil reacting vs 12% in the medical group
  - post hoc adjustment for pupil reactivity at baseline → outcome differences not significant

- Low median GCS motor response (3) and pupil reactivity indicate that
  - DECRA included predominantly patients with significant diffuse axonal injury and possibly some with brainstem injury
  - These patients, without significant intracranial hypertension, were shifted from mortality to unfavourable outcomes by decompressive craniectomy
• ICP was lower in the craniectomy group but it was not excessively high (i.e. remained less than 25mmHg) in the medical group

• 27% of craniectomy patients had neither pupil reacting vs 12% in the medical group
  – post hoc adjustment for pupil reactivity at baseline → outcome differences not significant

• Low median GCS motor response (3) and pupil reactivity indicate that
  – DECRA included predominantly patients with significant diffuse axonal injury and possibly some with brainstem injury
  – These patients, without significant intracranial hypertension, were shifted from mortality to unfavourable outcomes by decompressive craniectomy
The RESCUE_{icp} study

Randomised Evaluation of Surgery with Craniectomy for Uncontrollable Elevation of ICP

- The application of decompressive craniectomy to head-injured patients with raised and refractory ICP results in improvement in outcome compared to optimal medical management

Prospective randomised study

Target study group
Ventilated patients with refractory intracranial hypertension

Advanced medical management (inc barbiturates)

Surgical management (decompressive craniectomy)

Outcome assessed at 6 months and 2 years using extended Glasgow Outcome Score and SF-36 includes health economic analysis
Study population

• Inclusion criteria
  – Patients with head injury requiring ICP monitoring
  – Age 10-65 years
  – Abnormal CT scan
  – Patients may have had an immediate operation for a mass lesion but not a “decompressive” craniectomy

• Exclusion criteria
  – Bilateral fixed and dilated pupils
  – Bleeding diathesis
  – Devastating injury not expected to survive 24 hours
  – Brainstem damage
  – Follow up not possible

*If continued medical treatment is drawn no decompressive surgery will be performed at that time. However, decompressive surgery may be performed later if the patient deteriorates.

**If decompressive craniectomy is drawn barbiturates should not be administered at that time. However barbiturates may be given later if the patient deteriorates.
Study centres

- 46 centres are currently contributing patients
- 40 initiating / ready to start recruitment
- Aim = 80 centres worldwide
- > 100 interested centres,

N=326 / 400

As of 10 Dec 2011
RESCUEicp recruitment by country (n=323)

- UK: 69%
- Italy: 5%
- Spain: 4%
- Brazil: 3%
- Canada: 3%
- Saudi Arabia: 3%
- China: 2%
- Singapore: 2%
- Peru: 3%
- Other: 5%
Highest recruiter per quarter

<table>
<thead>
<tr>
<th>Quarter</th>
<th>Hospital</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st 2010</td>
<td>Leeds</td>
</tr>
<tr>
<td>2nd 2010</td>
<td>Royal London</td>
</tr>
<tr>
<td>3rd 2010</td>
<td>Hospital De Oeste, Brazil</td>
</tr>
<tr>
<td>4th 2010</td>
<td>Southampton</td>
</tr>
<tr>
<td>1st 2011</td>
<td>AMH/St George’s</td>
</tr>
<tr>
<td>2nd 2011</td>
<td>Southampton</td>
</tr>
<tr>
<td>3rd 2011</td>
<td>Liverpool and Lima, Peru</td>
</tr>
<tr>
<td>4th 2011</td>
<td>???</td>
</tr>
</tbody>
</table>
Cumulative recruitment
(actual & projected)

Project timeline

• August 2011: trial extension granted by MRC/NIHR (£117,000)

• December 2012: end of recruitment (according to extension request)
  – May need to be extended by 1 year if decreased recruitment of last 2 quarters continues

• June 2013: 6 months follow-up completed (primary endpoint)
• December 2013: 1 year follow-up completed
• December 2014: 2 year follow-up completed (end of trial)
Surgical and medical arms (n=270; 2004 – Sept 2010)

- Crossover: n=56 (21%)
- No crossover: n=214 (79%)

Surgical arm (n=140)

- Crossover: n=13 (9%)
- No crossover: n=127 (91%)
Medical arm (n=130)

- Crossover
- No crossover

- n= 87 (67%)
- n= 43 (33%)

Decompressive craniectomy survey
Participating societies
n=378

- SBNS/BNTA
- EANS
- NeuroCritical Care Network (UK)
- Neurocritical Care Society (mainly USA)

Survey closed 30 Nov 2011
- https://www.surveymonkey.com/s/MJFYK9N
How much do you agree or disagree with the following statement: "Decompressive craniectomy improves the long-term functional outcome of head-injured patients with refractory intracranial hypertension (i.e. ICP raised despite standard medical treatment and the optics of EVD)"?

<table>
<thead>
<tr>
<th></th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>Neutral - undecided</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>2.8% (18)</td>
<td>9.5% (36)</td>
<td>40.6% (176)</td>
<td>33.1% (125)</td>
<td>8.2% (31)</td>
</tr>
</tbody>
</table>

How were you managing head-injured patients with refractory intracranial hypertension before publication of the DECRA results (March 2011)?

- Decompressive craniectomy: 60%
- Continuous medical therapy (including barbiturates): 20%
- Randomise patient into the RESCUEpa study: 20%
Conclusion

- Decompressive craniectomy is a treatment option for patients with refractory posttraumatic cerebral oedema and resultant intracranial hypertension.
- But!!
  - Has a significant complication rate
  - May being performed in patients who will do well with medical treatment alone
  - Risks severe disability and vegetative state
  - DECRA trial completed; RESCUEicp continues

- Secondary decompressive craniectomy to control raised intracranial pressure is an unproven therapy that ideally should be undertaken as part of a randomised study.
Acknowledgements- thank you!

- Peter Kirkpatrick
- John Pickard
- Angelos Kolias
- Ivan Timofeev
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- David Menon
- Barbara Sahakian
- Medical / Nursing Staff on NCCU
- Martin Buxton
- David Mendelow
- Patrick Mitchell
- Graham Teasdale
- Franco Servadei
- Gordon Murray
- Juan Sahuquillo
- Andy Unterberg
- Local investigators

- Hugh Richards
- Donald Shaw
- Martin Smith
- Lennart Persson
- Anthony Bell
- Mark Dearden
- Nicola Latronico
- Eckhard Rickels

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