

Supplementary materials

Appendix 1. Overview of decision rules CCHR, NOC, CHIP and NICE

Study	Patient population	Indications for CT
NOC: New Orleans Criteria Haydel et al, 2000	GCS score of 15, loss of consciousness, normal findings on brief neurological examination, >3y	<u>Clinical findings:</u> <ul style="list-style-type: none"> - Headache (diffuse or local) - Vomiting - Age >60 years - Drug or alcohol intoxication - Deficits in short-term memory (persistent anterograde amnesia in patient with otherwise normal GCS) - Physical evidence of trauma above clavicles - Seizure
CCHR: Canadian CT Head Rule Stiell et al, 2001	GCS score 13-15, witnessed LOC, definite amnesia or witnessed disorientation, age >16y Exclusion: use of anticoagulation or obvious open skull fracture	<u>High risk for intervention:</u> <ul style="list-style-type: none"> - GCS<15 at 2 hours after injury - Suspected open or depressed skull fracture - Any sign of basal skull fracture - Vomiting 2 or more episodes - Age 65 years or older <u>Medium risk for brain injury on CT:</u> <ul style="list-style-type: none"> - Amnesia before impact 30 min or more - Dangerous mechanism (pedestrian vs vehicle, occupant ejected from vehicle, fall from elevation 3 feet or more, or 5 stairs)
CHIP: CT in Head Injury Patients Smits et al, 2007	GCS 13-14 or GCS of 15 and 1 risk factor, age ≥16	<u>CT indicated if ≥1 major criterion:</u> <ul style="list-style-type: none"> - Pedestrian or cyclist vs vehicle - Ejected from vehicle - Vomiting - PTA of 4 hours or more - Clinical sign of skull fracture - GCS<15 - GCS deterioration 2 or more points (1hr after presentation) - Use of anticoagulant therapy - Posttraumatic seizure - Age 60 years or older <u>CT indicated if ≥2 minor criteria:</u> <ul style="list-style-type: none"> - Fall from any elevation - Persistent anterograde amnesia - PTA of 2-4 hours - Contusion of skull - Neurologic deficit - LOC - GCS deterioration of 1 point (1 hour after presentation) - Age 40-60 years
NICE: National Institute for Health and Care Excellence guideline: Head injury	Adults with head injury	<u>Perform CT within 1 hour:</u> <ul style="list-style-type: none"> - GCS<13 - GCS<15 at 2 hours after injury - Suspected open or depressed skull fracture - Any sign of basal skull fracture - Posttraumatic seizure - Focal neurologic deficit - More than one episode of vomiting since head injury <u>Perform CT within 8 hours:</u> <ul style="list-style-type: none"> - Current warfarin treatment <u>LOC and/or PTA and:</u> <ul style="list-style-type: none"> - Age >65 years - History bleeding or clotting disorder - Dangerous mechanism of injury - More than 30minutes retrograde amnesia of events before head injury

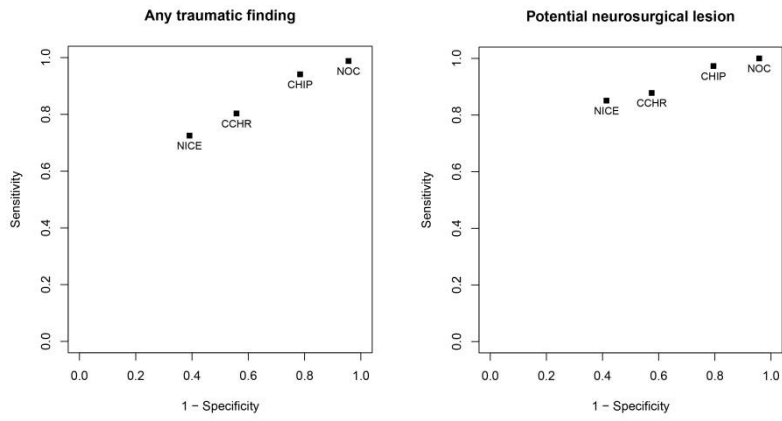
CT = computed tomography, GCS = Glasgow Coma Scale, PTA = posttraumatic amnesia, LOC = loss of consciousness

Appendix 2. Overview CT guidelines used in participating centres

	National guideline	Local guideline 1	Local guideline 2
Number of centres	7	1	1
1 or more major criteria	<ul style="list-style-type: none"> - GCS < 15 (including persisting PTA) - 2 or more points deterioration in GCS (1 hour after presentation) - Vomiting - Posttraumatic seizure - Signs of skull fracture - Pedestrian or cyclist versus vehicle - Ejected from motor vehicle - PTA ≥ 4 hours - Use of anticoagulants - Focal neurologic deficit - Suspicion of intracranial injury after focal “high impact” injury 	<ul style="list-style-type: none"> - GCS < 15 - 2 or more points deterioration in GCS (1 hour after presentation) - Vomiting - Posttraumatic seizure - Age ≥60 years - Signs of skull fracture - Dangerous mechanism (Pedestrian or cyclist versus vehicle; Ejected from motor vehicle; Fall from more than 1m or 5 stairs; Or equivalent mechanism) - Post traumatic amnesia ≥ 4 hours - Coagulopathy, e.g. use of coumarin derivate (INR >1.7), NOACs, or chronic alcohol abuse - Focal neurologic deficit - Intoxication that impairs neurological examination 	<ul style="list-style-type: none"> - GCS < 15 (including persisting PTA) - Deterioration in GCS - Vomiting > 1 time - Posttraumatic seizure - Signs of skull fracture - Dangerous mechanism (Pedestrian or cyclist versus vehicle; Ejected from motor vehicle; Fall from high elevation) - Post traumatic amnesia > 1 hour - Use of anticoagulants/coagulopathy - Focal neurologic deficit
2 or more minor criteria	<ul style="list-style-type: none"> - Fall from any elevation - LOC - Posttraumatic amnesia 2-4 hours - Visible injury to the head, excluding the face (without signs of fracture) - 1 point deterioration in GCS (1 hour post presentation) - Age > 40 years 	<ul style="list-style-type: none"> - Fall from < 1 m - LOC - PTA 2-4 hours - Persisting PTA (recall deficit) - Traumatic injury above the clavicles - 1 point deterioration in GCS (1 hour post presentation) - Age 40-60 years 	<ul style="list-style-type: none"> - Fall from any elevation - LOC - Unclear trauma mechanism - Visible injury to the head, excluding the face (without signs of fracture) - Violence - Age > 65 years

CT = computed tomography, GCS = Glasgow Coma Scale, PTA = posttraumatic amnesia, LOC =loss of consciousness, INR = international normalized ratio, NOACS = novel oral anticoagulants

Appendix 3. Performance of the CT decision rules



CT = computed tomography, CHIP = CT in head Injury Patient rule, NICE = National Institute for Health and Care Excellence, NOC = New Orleans Criteria, CCHR = Canadian CT Head Rule

Appendix 4. Overview of missed neurosurgical lesions

	Patient characteristics	CT result	Missed by rule
1	32y, assault blunt instrument, intoxication, significant injury to the head, focal high impact injury	Small EDH, skull fracture	CHIP, NICE, CCHR
2	21y, scooter vs motor vehicle, high energy trauma, significant injury to face and head	Small EDH, small ASDH, skull fracture	CHIP, NICE, CCHR
3	69y, fall from scooter, headache, significant injury to the head	Small EDH	NICE
4	52y, fall from standing height, LOC, PTA, significant injury to the head	Small EDH, tSAH	NICE, CCHR
5	37y, fall from scooter, intoxication, LOC, retrograde amnesia <30 min, PTA 2-4hrs	Small EDH, tSAH, small ASDH	NICE, CCHR
6	26y, forklift against head, LOC, PTA, headache, significant injury to the head, focal high impact injury	Small EDH, tSAH, small ASDH, contusion (small), skull fracture	NICE, CCHR
7	22y, fall from standing height, LOC, retrograde amnesia <30min	Small EDH	NICE, CCHR
8	36y, assault blunt instrument, LOC, PTA, significant injury to the head, focal high impact injury	Small EDH, skull fracture (depressed)	NICE, CCHR
9	88y, scooter vs truck, high energy trauma, significant injury to the head	Small EDH, skull fracture	NICE
10	24y, bicycle vs motor vehicle, high energy trauma, significant injury to the face, LOC, PTA, headache	Small EDH, contusion (small), skull fracture	CCHR
11	40y, bicycle vs bicycle, significant injury to the head, PTA, headache	Small EDH, contusion (small), skull fracture	NICE, CCHR
12	89y, fall from standing height, significant injury to the face	Large ASDH	NICE

CT = computed tomography, EDH = epidural hematoma, CHIP = CT in head Injury Patient rule, NICE = National Institute for Health and Care Excellence, CCHR = Canadian CT Head Rule ASDH = acute subdural hematoma, LOC = loss of consciousness, PTA = posttraumatic amnesia, tSAH = traumatic subarachnoid hemorrhage

Appendix 5a. NOC and CCHR validation in population with in- and exclusion criteria as in development cohort from six centres*

	Positive outcome (No)	Negative outcome (No)	Sensitivity (%; 95% CI)	Specificity (%; 95% CI)
<i>Original NOC n=1147 (subset of population with in- and exclusion criteria of original NOC study)</i>				
Any traumatic finding on CT			98.6 (96.4 to 100)	3.5 (2.4 to 4.5)
NOC - Positive	137	973		
NOC - Negative	2	35		
Potential neurosurgical lesion			100 (100 to 100)	3.3 (2.3 to 4.2)
NOC - Positive	20	1090		
NOC - Negative	0	37		
<i>Original CCHR n= 1683 (subset of population with in- and exclusion criteria of original CCHR study)</i>				
Any traumatic finding on CT			81.6 (76.8 to 86.2)	42.5 (39.9 to 45.1)
CCHR - Positive	209	821		
CCHR - Negative	47	606		
Potential neurosurgical lesion			85.1 (74.0 to 94.2)	39.5 (37.2 to 41.9)
CCHR - Positive	40	990		
CCHR - Negative	7	646		

NOC = New Orleans Criteria, CCHR = Canadian CT Head Rule, CT= computed tomography

*These centres refer to those on the left hand side of figure 1

Appendix 5b. Adjusted NOC and adjusted CCHR validation in entire study population from six centres*,

	Positive outcome (No)	Negative outcome (No)	Sensitivity (%; 95% CI)	Specificity (%; 95% CI)
<i>Adjusted NOC n=4557 (including in- and exclusion criteria of original study as risk factors)</i>				
Any traumatic finding on CT			98.8 (97.6 to 99.8)	4.0 (3.4 to 4.5)
NOC - Positive	402	3984		
NOC - Negative	5	166		
Potential neurosurgical lesion			100 (100 to 100)	3.8 (3.2 to 4.3)
NOC - Positive	74	4312		
NOC - Negative	0	171		
<i>Adjusted CCHR n=4557 (including in- and exclusion criteria of original study as risk factors)</i>				
Any traumatic finding on CT			81.8 (77.6 to 85.7)	42.0 (40.4 to 43.6)
CCHR - Positive	333	2409		
CCHR - Negative	74	1741		
Potential neurosurgical lesion			87.8 (79.7 to 94.9)	40.3 (38.9 to 41.7)
CCHR - Positive	65	2677		
CCHR - Negative	9	1806		

NOC = New Orleans Criteria, CCHR = Canadian CT Head Rule, CT= computed tomography

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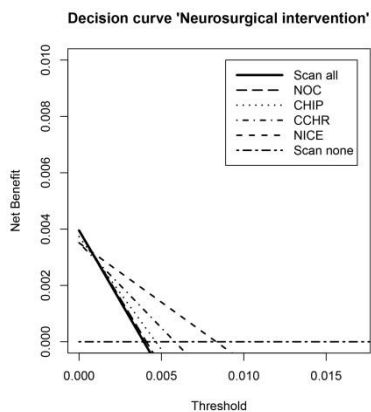
Appendix 6a. Performance of rules with outcome neurosurgical intervention from six centres*,

	Positive outcome (No)	Negative outcome (No)	Sensitivity (%; 95% CI)	Specificity (%; 95% CI)
<i>CHIP n=4557</i>				
Neurosurgical intervention			94.4 (81.8 to 100)	20.3 (19.2 to 21.4)
CHIP - Positive	17	3619		
CHIP - Negative	1	920		
<i>NICE n=4557</i>				
Neurosurgical intervention			88.9 (71.4 to 100)	58.1 (56.6 to 59.6)
NICE - Positive	16	1903		
NICE - Negative	2	2636		
<i>NOC n=4557</i>				
Neurosurgical intervention			100 (100 to 100)	4.2 (3.6 to 4.7)
NOC - Positive	18	4350		
NOC - Negative	0	189		
<i>CCHR n=4557</i>				
Neurosurgical intervention			88.9 (71.4 to 100)	42.2 (40.7 to 43.8)
CCHR - Positive	16	2625		
CCHR - Negative	2	1914		

CHIP = CT in head Injury Patient rule, NICE = National Institute for Health and Care Excellence, NOC = New Orleans Criteria, CCHR = Canadian CT Head Rule

**These centres refer to those on the left hand side of figure 1*

Appendix 6b Decision curves showing net proportional benefit for the outcome neurosurgical intervention.



CT = computed tomography, CHIP = CT in head Injury Patient rule, NICE = National Institute for Health and Care Excellence, NOC = New Orleans Criteria, CCHR = Canadian CT Head Rule

Per rule net proportional benefit was calculated using the formula: (true positives/total number) – weight(false positives/total number).*

Appendix 7a. Baseline characteristics all patients with a CT scan from nine centers*

	Patients with normal CT findings (n=4174)	Patients with abnormal CT findings (n=528)	All patients with a CT scan (n=4702)
Age (years; mean(range))	55.5 (16-101)	58.6 (16-98)	55.9 (16-101)
Male sex	2372 (56.8%)	337 (63.8%)	2709 (57.6%)
Glasgow coma scale score at presentation			
- 13	138 (3.3%)	69 (13.1%)	207 (4.4%)
- 14	557 (13.3%)	140 (26.5%)	697 (14.8%)
- 15	3479 (83.3%)	319 (60.4%)	3798 (80.8%)
Use of anticoagulation			
- None	3581 (85.8%)	474 (89.8%)	4055 (86.2%)
- Coumarin	490 (11.7%)	45 (8.5%)	535 (11.4%)
- Direct oral anticoagulants	56 (1.3%)	3 (0.6%)	59 (1.3%)
Bleeding disorder	47 (1.1%)	3 (0.6%)	50 (1.1%)
Mechanism of injury			
- Pedestrian in road traffic accident	60 (1.4%)	12 (2.3%)	72 (1.5%)
- Cyclist in road traffic accident	164 (3.9%)	36 (6.8%)	200 (4.3%)
- Fall from height	574 (13.8%)	124 (23.5%)	698 (14.8%)
- Other†	3325 (79.7%)	348 (65.9%)	3673 (78.1%)
Ejected from vehicle	183 (4.4%)	32 (6.1%)	215 (4.6%)
Loss of consciousness			
- None	2192 (52.5%)	153 (29.0%)	2345 (49.9%)
- 15 minutes or less	1238 (29.7%)	225 (42.6%)	1463 (31.1%)
- More than 15 minutes	30 (0.7%)	18 (3.4%)	48 (1.0%)
Retrograde amnesia			
- None	2819 (67.5%)	227 (43.0%)	3046 (64.8%)
- 30 minutes or less	445 (10.7%)	96 (18.2%)	541 (11.5%)
- More than 30 minutes	142 (3.4%)	58 (11.0%)	200 (4.3%)
Post-traumatic amnesia			
- None	2456 (58.8%)	154 (29.2%)	2610 (55.5%)
- Up to 2 hours	970 (23.2%)	200 (37.9%)	1170 (24.9%)
- 2-4 hours	80 (1.9%)	22 (4.2%)	102 (2.2%)
- More than 4 hours	144 (3.4%)	64 (12.1%)	208 (4.4%)
Intoxication with drugs or alcohol‡	1075 (25.8%)	117 (22.2%)	1192 (25.4%)
Post-traumatic seizure	31 (0.7%)	11 (2.1%)	42 (0.9%)
Headache	1358 (32.5%)	184 (34.8%)	1542 (32.8%)
Vomiting			
- Once	173 (4.1%)	27 (5.1%)	200 (4.3%)
- Twice or more	161 (3.9%)	35 (6.6%)	196 (4.2%)
Deterioration in Glasgow coma scale (1 h after presentation)			
- 1 point	35 (0.8%)	6 (1.1%)	41 (0.9%)
- 2 or more points	9 (0.2%)	9 (1.7%)	18 (0.4%)
Neurological deficit	104 (2.5%)	29 (5.5%)	133 (2.8%)
Signs of skull base fracture	109 (2.6%)	77 (14.6%)	186 (4.0%)
Visible injury of the head	2237 (53.6%)	338 (64.0%)	2575 (54.8%)
Visible injury of the face	1420 (34.0%)	178 (33.7%)	1598 (34.0%)
Suspicion of open fracture	8 (0.2%)	17 (3.2%)	25 (0.5%)
Injury Severity Score (mean (range))	6.5 (0-54)	15.3 (1-75)	7.5 (0-75)

Data are number (%) of patients unless stated otherwise. CT = computed tomography, .

*These centres refer to those on the right hand side of figure 1

†Includes patients with mild head injury such as a bumped head against an object

‡history or suggestive findings on examination (for example nystagmus, abnormal walking, etc.)

Appendix 7b. Traumatic CT findings all patients with a CT scan from nine centers*

CT finding	N (%)*
CT finding	528 (11.2%)
Skull fracture	213 (4.5%)
- Depressed fracture	25 (0.5%)
- Linear fracture	103 (2.2%)
- Skull base fracture	89 (1.8%)
Subarachnoid hemorrhage	266 (5.7%)
Contusion	
- Small	154 (3.3%)
- Large (mass)	14 (0.3%)
Subdural hematoma	
- Small	173 (3.7%)
- Large (mass)	27 (0.6%)
Epidural hematoma	
- Small	47 (1.0%)
- Large (mass)	5 (0.1%)
Suspicion of diffuse axonal injury on CT	14 (0.3%)
Basal cisterns compressed or obliterated	13 (0.3%)
CT shift	
- 0-4mm	22 (0.5%)
- 5mm or more	13 (0.3%)

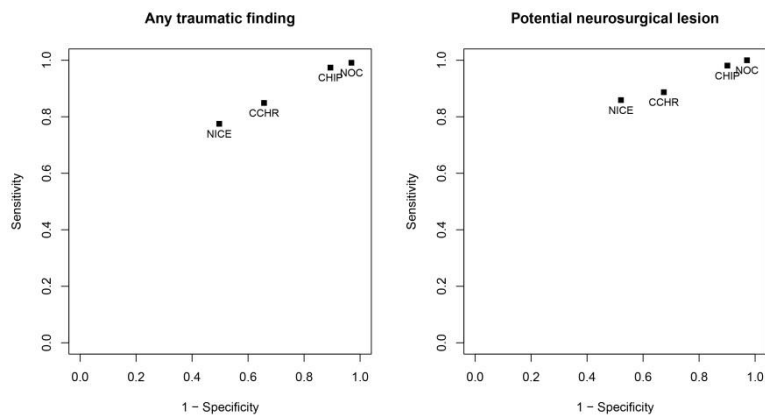
CT = computed tomography

**These centres refer to those on the right hand side of figure 1*

**some patients had more than 1 CT finding*

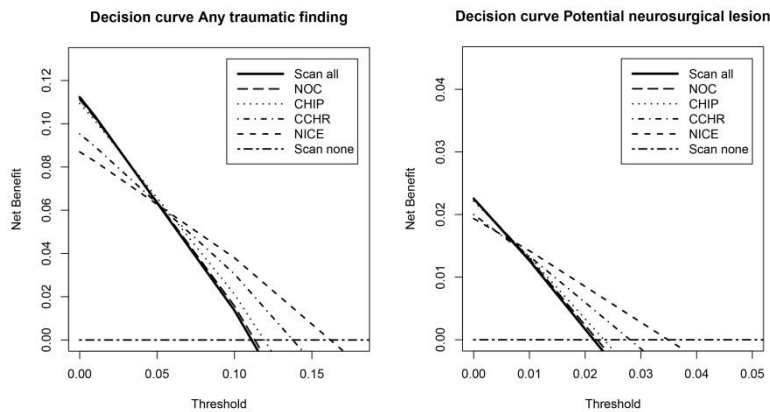
Appendix 7c. Figures secondary analysis all patients with a CT

I. Performance CT decision rules



CT = computed tomography, CHIP = CT in head Injury Patient rule, NICE = National Institute for Health and Care Excellence, NOC = New Orleans Criteria, CCHR = Canadian CT Head Rule

II. Decision curves showing net proportional benefit per decision rule



CT = computed tomography, CHIP = CT in head Injury Patient rule, NICE = National Institute for Health and Care Excellence, NOC = New Orleans Criteria, CCHR = Canadian CT Head Rule

Per rule net proportional benefit was calculated using the formula: $(\text{true positives}/\text{total number}) - \text{weight} * (\text{false positives}/\text{total number})$.