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4 1 **The Clinical Significance of Post-Traumatic Intracranial Hemorrhage in Clinically Mild**  
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6 2 **Brain Injury: Radiographic Imaging and Surgical Management**  
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11 4 Justin Z. Wang<sup>1</sup>, Christopher Witiw<sup>2</sup>, Noah Ditkofsky<sup>3</sup>, Avery Nathens<sup>4</sup>, Leodante da Costa

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14 5 1. Department of Surgery, Division of Neurosurgery, University of Toronto  
15  
16 6 2. Department of Surgery, Division of Neurosurgery, University of Toronto  
17  
18 7 3. Department of Medical Imaging, Sunnybrook Health Sciences Centre, University of  
19  
20 8 Toronto.  
21  
22 9 4. Department of Surgery, University of Toronto  
23  
24 10 5. Department of Surgery, Division of Neurosurgery, Sunnybrook Health Sciences Centre,  
25  
26 11 University of Toronto  
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29

30 13 **Corresponding author:**

31  
32 14 **Leodante da Costa, MD, MSc.**

33  
34 15 **2075 Bayview Avenue**

35  
36 16 **Room A1-29**

37  
38 17 **Toronto, Ontario**

39  
40 18 **M4N 3M5**

41  
42 19 **[leo.dacosta@sunnybrook.ca](mailto:leo.dacosta@sunnybrook.ca)**  
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3 24 **Abstract**  
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6 25 **Background:** Much attention has been focused on the management of severe traumatic brain  
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8 26 injury (TBI), however comparatively little is known about management of traumatic hemorrhage  
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10 27 with a clinically mild TBI.  
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13 28 **Methods:** We queried the Neurotrauma database from Canada's largest Level I trauma center  
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15 29 between November 2014 and December 2016 to identify patients with CT findings of a traumatic  
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17 30 hemorrhage or calvarial fracture. Exclusionary criteria were age <16 years, Glasgow Coma Scale  
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19 31 (GCS) score <13, anticoagulant use, known bleeding diathesis, or radiographic evidence of  
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21 32 substantial mass effect (midline shift >5 mm). The primary outcome was need for neurosurgical  
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23 33 intervention.  
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27 34 **Results:** A total of 607 patients were included. The majority (61.3%) had a GCS score of 15,  
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29 35 while 30.4% and 8.2% had a GCS score of 14 and 13 respectively. Five patients (0.8%) required  
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31 36 surgical intervention, all within the first 72 hours due to clinical deterioration with subsequently  
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33 37 demonstrated radiographic evidence of expanding hemorrhage. Most patients (76.1%) had  
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35 38 routine repeat radiographic imaging without a documented change in their neurological status.  
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39 39 **Conclusion:** The likelihood of requiring neurosurgical intervention in a mild clinical TBI with  
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41 40 radiographic evidence of traumatic hemorrhage is low. When it occurs, it is typically within 72  
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43 41 hours of injury and is associated with clinical neurological deterioration. However, the vast  
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45 42 majority of patients in our cohort had repeat imaging studies that did not influence surgical  
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47 43 management, at substantial cost to the health system. These findings suggest the need to re-  
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49 44 evaluate repeat imaging protocols for this subset of the TBI patient population.  
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## 46 **Introduction**

47 The majority of patients arriving at emergency departments with a head trauma will have  
48 only a mild clinical brain injury (mTBI).<sup>1,2</sup> Although much attention has been directed toward  
49 identifying which patients with mild traumatic brain injury (TBI) should have a computed  
50 tomography (CT) study of the brain, despite the clinically mild injuries, the vast majority of  
51 these patients will have imaging, more often a non-contrast computerized tomography (CT) scan  
52 of the head. Guidelines such as the Canadian CT head rules are helpful select mTBI patients  
53 who are more likely to have an intracranial injury and to optimize resource utilization.

54 However, when imaging demonstrates the presence of traumatic intracranial hemorrhage,  
55 management becomes more complex.<sup>3</sup> Comparatively less information is available to direct  
56 clinical management of these patients who have post-traumatic intracranial hemorrhage but only  
57 a mild clinical TBI and are without indication for surgical intervention.

58 The aim of the present investigation is to elucidate the role of clinical observation and repeat  
59 radiographic imaging for patients with mTBI who present with a CT scan of the brain  
60 demonstrating traumatic intracranial hemorrhage.

## 62 **Methods:**

63 The study was approved by the Research Ethics Board at Sunnybrook Health. Since all  
64 data were de-identified prior to collection, informed consent from the patients was not required.  
65 Data for this study were obtained from the prospectively maintained Ontario Trauma Registry.  
66 This is a database maintained by the government of Ontario with “detailed data on major trauma  
67 and data on all deaths resulting from injury in Ontario” (<https://www.ontario.ca/data/ontario->

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3 68 [trauma-registry-otr](#)). The information is collected on all patients where the trauma team is  
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5 69 activated (with or without TBI) as well as non-trauma team activations with a mechanism of  
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7 70 injury and ISS $\geq$ 12.  
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11 71 The database was screened between November 2014 and December 2016. Patients with  
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13 72 mTBI defined as a Glasgow Coma Scale (GCS) at presentation equal or higher than 13, and  
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15 73 confirmed post-traumatic hemorrhage on non-contrast CT head were included. From this list,  
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17 74 patients were excluded from the analysis if they were less than 16 years of age, had an initial  
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19 75 presenting Glasgow Coma Scale (GCS) score less than 13, had a comorbid neurological or  
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21 76 psychological condition precluding a reliable neurological exam, were documented as  
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23 77 taking anticoagulation or antiplatelet medication, had a previously diagnosed bleeding diathesis,  
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25 78 had radiographic evidence of substantial mass effect (midline shift greater than 5 mm), had a  
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27 79 penetrating mechanism of injury, did not have sufficient clinical or radiographic information on  
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29 80 their patient record, or otherwise had a clear, immediate neurosurgical indication based on their  
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31 81 initial presentation and CT scan as determined by the admitting neurosurgical staff physician.  
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36 82 All patients were initially assessed in the trauma bay or emergency department. Initial imaging  
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38 83 was ordered as deemed appropriate by the treating physician in the ED (emergency doctor or  
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40 84 trauma team leader). Although there is no established protocol at our institution, often repeat CT  
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42 85 head scans after an initial positive scan are ordered routinely after a specific period of time  
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44 86 (usually 4-6 hours after the initial scan) or for a specific indication such as neurological  
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46 87 deterioration. All CT scans were read by a staff radiologist and compared to their previous scans.  
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50 88 Patient characteristics including age, gender, presenting GCS, and alcohol use status were  
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52 89 collected. Trauma characteristics including mechanism of injury, concomitant other injuries  
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54 90 identified using the Abbreviated Injury Scale (AIS) codes and total AIS Injury Severity Score  
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3 91 (ISS) were also collected. The patient's subsequent course including number of head CT scans,  
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5 92 indication for repeat head CTs, disposition after the emergency department, length of stay in  
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7 93 hospital, length of stay in the intensive care unit (ICU) and need for neurosurgical intervention  
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10 94 were also collected.

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13 95 The primary outcome of interest was defined as the need for neurosurgical intervention,  
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15 96 defined using ICD-10 procedure codes, including but not limited to insertion of an intracranial  
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17 97 monitoring device, external ventricular drain, or decompression by craniotomy or craniectomy.  
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20 98 The ICD-10 codes of the study cohort are detailed in Supplementary Table 2. Secondary  
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22 99 outcomes included number of repeat CT scans, indication for repeat scans, ICU admission,  
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24 100 length of stay in the ICU, and total length of hospital stay.

## 25 26 27 101 **Analysis**

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30 102 We conducted a descriptive data analysis on admission patterns, radiographic follow-up,  
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32 103 and its associations with our primary outcome of interest. Continuous variables are presented as  
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34 104 medians with their respective interquartile range (IQR) whereas categorical variables are  
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37 105 generally presented as percentages.

## 38 39 40 106 41 42 107 **Results:**

### 43 44 45 108 **Patient Information**

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48 109 From November 2014 to December 2016, 617 patients with a mild traumatic brain injury  
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50 110 were identified and met the initial criteria for inclusion (mTBI and post-traumatic hemorrhage).  
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52 111 After application of our exclusion criteria (detailed in Figure 1), our final study cohort consisted  
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55 112 of 607 patients.

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3 113 Patient demographic and trauma information are presented in Table 1. The majority of  
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5 114 patients presenting with mild TBI were male (68.4%) and median age was 55 (IQR 37-70). Only  
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7 115 9.4% of patients presented with an isolated intracranial injury. The most common system  
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9 116 concurrently injured was the face and neck (46.2%).  
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13 117 The most common mechanism of injury was a fall (38.6%), of which only a minority  
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15 118 (21.2%) were from standing height, with all others from elevation ranging from several steps to  
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17 119 ladders and scaffolds (Table 1). The second most common mechanism was motor vehicle  
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19 120 collision (22.8%). ‘Other’ unlisted mechanisms in Table 1 included intentional self-harm,  
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21 121 snowmobile accidents, diving injury, and watercraft related injuries.  
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## 25 122 **Neuroimaging**

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27 123 Most patients (83.4%) received serial neuroimaging with repeat CT scans of the head. Of  
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29 124 these patients, 50.1% had only one repeat CT scan, 19.4% had two repeat scans, and 13.9% had  
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31 125 3 or more repeat scans after their initial neuroimaging. The most common indication (76.1%) for  
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33 126 repeating a CT head was for “routine” surveillance and radiographic follow-up in the absence of  
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35 127 any clinical change, traditionally done 4 to 6 hours after admission. Only 36 patients (5.9%)  
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37 128 received a repeat CT scan due to documented neurological deterioration, and only 5 (0.8%) of  
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39 129 these patients subsequently required neurosurgical intervention. There was no difference in the  
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41 130 median number of head CT scans done per patient based on their initial GCS.  
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## 46 131 **Disposition and Duration of Stay**

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49 132 The patients’ hospital course and imaging/intervention are presented in Table 2. After  
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51 133 assessment in the trauma bay and emergency department, most patients were admitted to the  
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53 134 dedicated hospital trauma/general surgery service (46.5%) followed by the neurosurgical service  
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3 135 (26.4%; Table 2). The patient's overall AIS severity score and presenting GCS did not affect  
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5 136 overall admission patterns. Only 4.7% of patients were able to be discharged directly from the  
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7 137 emergency department after observation (most back to their own home or their home hospital),  
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10 138 and of these patients, 86.3% received repeat head CT scans during this observation period, with  
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12 139 25% receiving more than one repeat CT.  
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15 140 The majority of patients (63.0%) were admitted to the ICU for at least a short period of  
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17 141 time, with the median length of ICU stay being 3 days (IQR 1-6 days). The overall mean length  
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19 142 of stay in hospital was 7 days (IQR 3-13.25 days). Most patients (52.3%) stayed one week or less  
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22 143 in hospital.  
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#### 25 144 **Neurosurgical Intervention**

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28 145 Of the 607 patients included in this study, 5 (0.8%) required neurosurgical intervention  
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30 146 (Table 3, Supplementary Table 1). All of these patients deteriorated neurologically within 72  
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32 147 hours of their presentation to the ED and subsequently received a repeat CT scan which showed  
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34 148 worsening of their intracranial pathology such as expansion of an intracranial hematoma and/or  
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36 149 worsening mass effect that mandated operative intervention. The specific operation, findings on  
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39 150 the initial plain head CT, and the indication for the operation for each of these 5 patients are  
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41 151 described in detail in Supplementary Table 1.  
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#### 47 153 **Discussion**

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50 154 Although there has been a significant amount of research on mild traumatic brain injury,  
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52 155 most has been focused on concussion, which by definition excludes patients with an abnormal  
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54 156 initial head CT.<sup>4</sup> However, there are no guidelines to facilitate clinical management of trauma  
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3 157 patients with a mild traumatic brain injury and posttraumatic intracranial hemorrhage. Our study  
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5 158 is the largest single institution, retrospective analysis of patients assessed at a level 1 trauma  
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7 159 centre with mild traumatic injury (GCS 13-15) and a positive initial head CT.  
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11 160 In particular, we were interested in the utility of “routine” head CT scans in the  
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13 161 management of mTBI, particularly in predicting deterioration and the need for neurosurgical  
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15 162 intervention. A retrospective study by Anandalwar et al. in 2016<sup>5</sup> assessed a cohort of 95 patients  
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17 163 initially GCS 13-15 with a positive head CT that were followed without repeated CT head. This  
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19 164 cohort was compared to 47 patients treated at the same institution and randomized to “standard  
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21 165 management”, i.e. repeat CT head within 24h. Of the 95 patients without routine repeat CT head,  
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23 166 8 (8.4%) ended up having a scan either because of treating MD judgment or a documented  
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25 167 change in mental status. Interestingly, none of the repeat CT scans led to an intervention  
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27 168 (medical or surgical), and of the 47 patients in the control group who had a scan regardless of  
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29 169 neurological change, only 1 (2.1%) required medical intervention (aggressive hydration for  
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31 170 asymptomatic venous sinus thrombosis)  
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36 171 Additional retrospective and prospective studies, usually with a focus on elderly patients,  
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38 172 have also shown that routine repeat CT scans in the absence of neurological deterioration do not  
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40 173 predict the need for neurosurgical intervention in mild TBI.<sup>6-9</sup> Similarly, in our study, all  
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42 174 patients who eventually required neurosurgical intervention first deteriorated neurologically,  
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44 175 which then prompted a repeat CT scan that showed significant progression of their initial  
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46 176 hematoma. Conversely, patients who may have only mild radiographic progression on a routine  
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48 177 repeat CT in the absence of neurological worsening were observed without an operation,  
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50 178 suggesting that it is safe to base management decisions on clinical condition.  
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3 179 At most institutions, the use of routine CT scans seems to be motivated by an attempt to  
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5 180 identify early radiographic change, and plan surgical intervention before inevitable neurological  
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7 181 deterioration. This concept is important when treating severe TBI patients who often cannot be  
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9 182 examined or have very limited neurological examination for hours or days after injury.

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12 183 Traditionally, intracranial injuries are thought to progress within 24-48 hours and not  
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14 184 uncommonly within the first 6 hours, however the majority of the studies supporting repeat  
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16 185 imaging included patients with moderate to severe intracranial injuries as well as other high risk  
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18 186 patients such as those on anticoagulation or those who present with an epidural hematoma.<sup>10-12</sup>

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22 187 In mTBI patients, who can be followed reliably with a neurological exam, especially in  
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24 188 monitored settings, the use of routine repeat CT scans is likely unnecessary. This statement,  
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26 189 however, does not apply to mTBI patients who may be higher risk for hemorrhage or unnoticed  
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28 190 deterioration, such as those who cannot be reliably examined (e.g. significant alcohol or other  
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30 191 drug intoxication, need for sedation or anesthesia, language barrier, etc.), on anticoagulant or  
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32 192 antiplatelet therapy, or have significant concomitant, distracting injuries, etc.. In this  
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34 193 subpopulation of mTBI patients, routine CT scans may be beneficial.

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38 194 Although the risks of radiation exposure from a plain CT scan are low, they are not negligible,  
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40 195 particularly in younger patients such as those that were included in our study and whom are  
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42 196 known to be more exposed to head trauma.<sup>1, 2, 13-15</sup> Smith-Bindman et al. calculated that for a  
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44 197 routine head CT, the median adjusted lifetime attributable risk was 0.23 cancers per 1000  
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46 198 patients (range 0.03-0.70 cancers per 1000 patients) and that 1 in 8100 women age 40 will  
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48 199 develop a cancer due to a plain CT head.<sup>16</sup> Although the risks of adverse outcomes due to  
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50 200 progression of their intracranial injury may be significantly greater than the risks of radiation, for

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3 201 the majority of patients where the routine scan will not have any clinical utility, it can and should  
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5 202 be avoided.  
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8 203 Reducing the number of unnecessary CTs for mild TBI may also significant decrease  
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10 204 healthcare costs. The average operating cost of performing a single plain CT head at our  
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12 205 institution was \$56.00 CDN plus an additional \$43.25 CDN charged on behalf of the radiologist  
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14 206 for performance and interpretation of the scan, for a total of \$99.25 per scan. Complex CT heads  
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16 207 with three-dimensional reconstructions and vascular imaging further increase the cost. In this  
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18 208 cohort, a total of 1470 head CT scans were performed in 607 patients, 1225 of which were done  
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20 209 for “routine” follow-up without any documented neurological change in the patient and none of  
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22 210 which resulting in surgical intervention. If an assumption is made that all were plain CT scans, a  
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24 211 conservative estimate of \$145 897.50 CDN was spent. By eliminating the routine scans, \$121  
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26 212 581.25 CDN in health care costs would have been saved, without any harmful effect to patients.  
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28 213 By decreasing the number of head CTs for mild TBI by only 10% may result in savings of  
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30 214 greater than \$10 million USD annually.<sup>17, 18</sup> If, similar to in our study, over 75% of these CT  
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32 215 scans are done for routine monitoring and without a clinical reason, potential for health care  
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34 216 savings may be significant, without compromise of quality of care.  
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41 217 There are several limitations to our study. The majority of patients in our study had  
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43 218 multisystem injuries ranging in severity. Whereas this reflects the type of mild TBI patients that  
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45 219 more commonly present to level 1 trauma centres, it confounds our ability to quantitatively and  
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47 220 accurately assess ICU admissions, ICU stay, total hospital length of stay since these may be  
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49 221 affected by injuries other than their head injury. However, previous studies have shown that ICU  
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51 222 admission is generally unnecessary for isolated mild TBI and a significant subset of patients may  
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53 223 be safely observed in the emergency department for 6-8 hours before discharge under home  
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3 224 supervision if neurologically unchanged.<sup>19-21</sup> Because only 5 patients met our primary outcome  
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5 225 of interest - the need for neurosurgical intervention, we could not perform statistical analysis to  
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8 226 assess for common factors that may have contributed to their deterioration.  
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10 227 In conclusion, our study demonstrates that routine repeat neurological imaging in the  
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12 228 absence of clinical change is unnecessary for the majority of patients with a mild head injury  
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15 229 even in the presence of posttraumatic hemorrhage, and has no value for predicting the need for  
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17 230 neurosurgical intervention, rarely required for these patients. These routine CT scans may  
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20 231 represent an opportunity to optimize healthcare resource utilization and decrease the burden of  
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22 232 health care costs. A future large prospective, multicentre study of patients with mild TBI is likely  
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24 233 needed to better delineate the optimal care pathways in regards to serial clinical and radiographic  
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26 234 monitoring of patients mild TBI and associated intracranial hemorrhage and/or skull fracture.  
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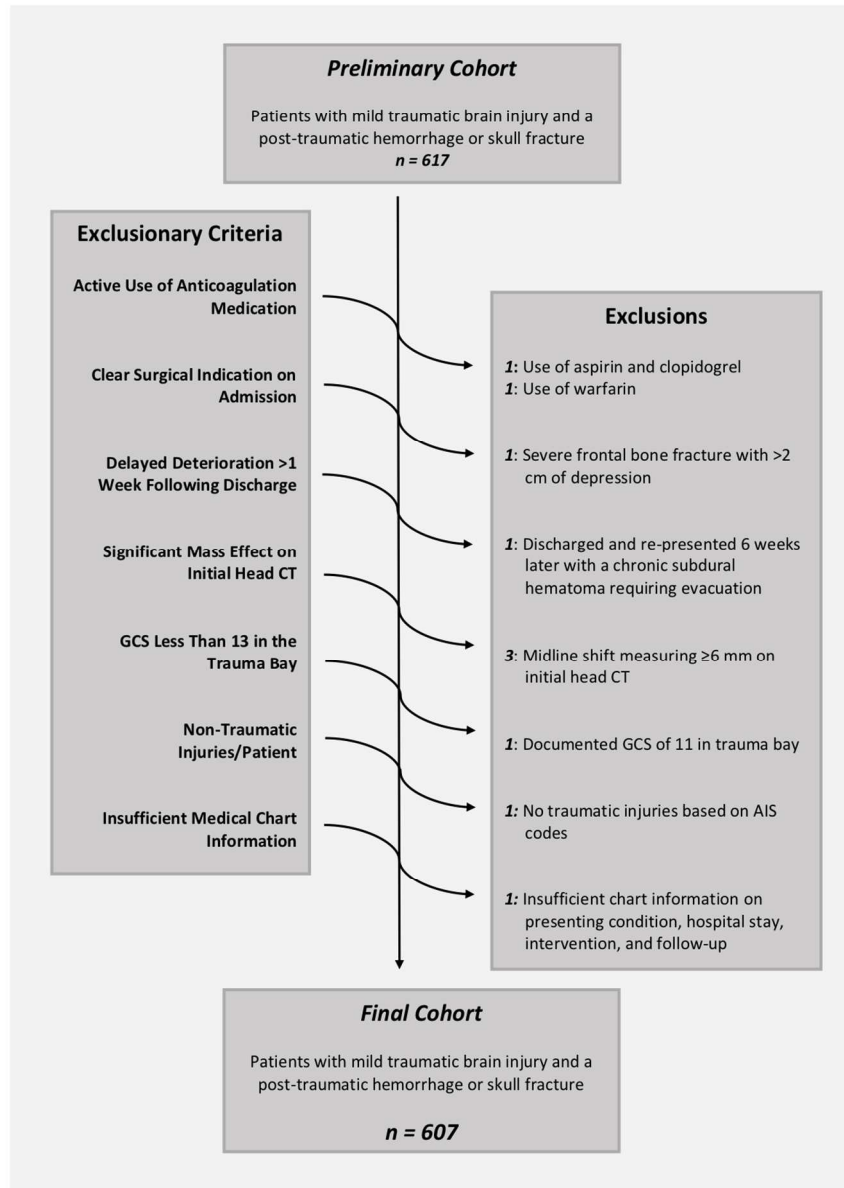
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Figure 1. Exclusion criteria for deriving final study cohort and number of patients excluded for each specific reason. AIS- Abbreviated Injury Scale, GCS- Glasgow Coma Scale, CT- Computed Tomography.

215x279mm (150 x 150 DPI)

**Table 1.** Baseline patient characteristics. IQR- Interquartile Range, ATV- All-Terrain Vehicle

<b>Patient Characteristics</b>	<b>Total Cohort (n = 607)</b>
Baseline characteristics	
Median age, year (IQR)	55 (37-70)
Male (%)	68.4
Mechanism of Injury (%)	
Fall	38.6
MVC Occupant	22.8
Pedestrian	18.3
Pedal cyclist	7.2
Assault (Blunt Trauma)	3.8
Motorcycle/ATV	3.8
Other	5.5
Isolated head injury (% of patients)	9.4
Concomitant other injuries (% of patients):	
Face + Neck	46.2
Thorax	39.6
Abdomen/Pelvis	10.0
Spine	30.7
Upper extremities	35.0
Lower extremities	27.6
External, burns, other injuries	3.1
Median injury severity score (IQR)	17 (14-24)
Total Injury Severity Score (%):	
1-15	32.4
16-25	45.2
>25	22.4
Initial Glasgow Coma Scale score (%):	
15	61.7
14	30.4
13	7.9
Alcohol Consumption <sup>A</sup> (%):	
No	80.6
Yes, beyond legal limit	15.3
Yes, trace limit	4.0

A- proportion of the 392 patients who were tested for serum alcohol levels;



**Table 2.** Imaging and interventions. CT- Computed Tomography, ICU- Intensive Care Unit.

<b>Imaging/Intervention</b>	<b>Total Cohort (n = 607)</b>
Number of head CT scans, median (IQR)	2 (2-3)
Total number of head CT scans (%):	
1	16.6
2	50.1
3	19.4
≥4	13.9
Indication for repeat CT head (%) <sup>A</sup> :	
Routine <sup>B</sup>	76.1
Neurologic deterioration	5.9
Rule out vascular injury	17.6
Other	0.4
Disposition after Emergency Department (%)	
Trauma/General Surgery	46.5
Neurosurgery	26.4
Medicine	12.8
Orthopedic Surgery	8.4
Plastic Surgery	0.5
Discharged	4.7
Length of stay in days, median (IQR)	7 (3-13.25)
Total length of stay (%):	
≤7 days	52.3
8-14 days	25.7
>14 days	22.0
Patients requiring ICU stay (%)	63.0
Length of ICU stay in days, median (IQR):	3 (1-6)
Total length of ICU stay (%):	
≤7 days	80.5
8-14 days	10.2
>14 days	9.3
Required neurosurgical intervention (%):	
No	99.2
Yes	0.8
Indication for surgery (n = 5)	
Clinical deterioration within 72 hours	5
Type of operation (n = 5)	
Decompressive craniectomy	3
Craniotomy	2

<sup>A</sup>Proportion of the 506 patients who received a repeat CT head, <sup>B</sup>Repeat CT head done in the absence of any documented neurological change

**Supplementary Table 1.** Patients who underwent neurosurgical intervention. GCS- Glasgow Coma Scale, aSDH- Acute Subdural Hematoma, SAH- Subarachnoid Hemorrhage, CT- Computed Tomography, EVD- External Ventricular Drain, ICP- Intracranial Pressure, EDH- epidural hematoma, OR- Operation.

Patient ID	Age	Initial GCS	Trauma	Initial head CT	# of head CTs	OR	Indication for operation	Discharge disposition
1	55	15	Fall from one flight of stairs	Left frontotemporal contusion, aSDH and traumatic SAH	7	Left decompressive hemicraniectomy for evacuation of aSDH, frontal + temporal contusion, EVD	Decline in GCS on same day as admission, repeat scan showed increase in contusion size	Inpatient Rehab
2	60	13	Fall off a ladder	Right 5 mm aSDH, traumatic SAH, small right frontal + temporal contusions	6	Right hemicraniectomy for evacuation of ICH, subdural ICP monitor	Decline in GCS on same day as admission, repeat CT: increase in size of contusions	Repatriation to home hospital
3	64	13	Fall down stairs while intoxicated	Bilateral aSDH hematoma, left temporoparietal contusion	3	Left craniotomy for evacuation of temporoparietal contusion, aSDH, EVD	Decline in GCS morning after admission, repeat CT: enlarged left parietal contusion	Inpatient rehab
4	47	15	Pedestrian struck by train	Right frontal + temporal contusions, traumatic SAH	8	Right decompressive hemicraniectomy, evacuation of right frontal + temporal ICH, aSDH, EVD	Decline in GCS, repeat CT: expansion of right frontal + temporal contusions	Deceased
5	84	15	Fall from standing height	Left convexity and tentorial aSDH	3	Left posterior craniotomy for evacuation of tentorial SDH	Decline in GCS 72h after admission, repeat CT: enlargement of SDH	Inpatient rehab

Supplementary Table 2. ICD-10 Codes of included patients.

S066, S02200, S02890, S02480, S82400, S000, S8180
S065, T110
S065, S508
S065, S066
S02100, S0685, S02200, S02890, S0150, S0140
S22400, S060, S061, S065, S066, S02100, S0635, S008, S000
S065, S02000, S02100, S066, S0685, S02890, S02480, S02200, S12210, S27000, S27100, S27300, S22400, S22200, S32010, S42180, S081, S42020
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S065
S43090, S22400, S065, S0635, S066, S36800, S000, S408
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S0100, S066, S202, S708
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S066, T130, S060
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S066, S065, S22010, S22010, S000
S42020, S22410, S0100
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S065
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S065, S066, S0635, S52500
S065, S0180, S0100
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S065, S0100
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S02430, S065, S066, S0685, S0685, S608, S0180, S008
S0635, S0180, S008

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9	S066, S000, S6180, S5100
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14	S12100, S0635, S066, S000
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16	S065, S0635, S060, S32500, S32500, S32100
17	S02200, S02100, S22490, S065, S066, S27200, S001, S800
18	S066, S27000, S22400, S22000, S42180, S62390, S3088
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20	S065, S42010, S27200, S27890, S22500, S5100
21	S22400, S0635, S202
22	S060, S065, S000
23	S066, S22400, S36090, S32010, S32030, S000
24	S065, S02000, S0635, S066, S22300, S62690, S0100, S301, T008
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17	S0180, S066, S0110
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