Received: 23.05.2011 / **Accepted:** 09.06.2011
DOI: 10.5137/1019-5149.JTN.3570-10.2

Early and Delayed CT Findings in Patients with Mild-to-Moderate Head Trauma

Hafif-Orta Kafa Travmalı Hastaların Erken ve Geç BT Bulguları

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ABSTRACT

AIM: The aim of this study is to evaluate the changes between the initial and late cranial CT scans in patients with mild-to-moderate head trauma.

MATERIAL and METHODS: Of the two thousand six hundred and forty-four patients hospitalized for head trauma within a two-year period, 112 (4.24%) patients scored 8 or above in the Glasgow coma scale and there were changes between initial and late head CT.

RESULTS: Of these, 103 had worsening CT findings. Neurological status deteriorated in 30% of these cases. Forty-six patients required surgery based on findings seen on the delayed scans. Neurological status was stable in 50% of the cases. All the eight patients who expired had abnormal CT scans initially and had progression in their late scans.

CONCLUSION: In patients with mild-to-moderate head trauma, serial CT scanning may independently modify treatment decisions in a subgroup of patients. Judgment for delayed scans should be made on an individual basis by taking the risk factors into account.

KEYWORDS: Head trauma, Computed tomography, Intracranial hemorrhage, Glasgow coma scale

ÖZ

AMAÇ: Bu çalışmanın amacı, hafif-orta kafa travması olan hastalarda başlangıçtaki ve sonraki kraniyal BT taramalar arasındaki değişikliklerin değerlendirilmesidir.

YÖNTEM ve GEREÇLER: İki yıllık bir süre içinde kafa travması nedeniyle yatış yapılan 2,644 hastanın 112'sinde (%4,24) Glasgow koma ölçeğinde puan 8 ve üzerindeydi ve başlangıç ve geç BT bulgularında değişiklik görüldü.

BULGULAR: Bunların 103'ünde BT bulgularında kötüleşme vardı. Bu vakaların %30'unde nörolojik durum kötüleşti. Geç taramaların bulgularına göre 46 hastaya cerrahi yapılması gerekti. Bu vakaların %50'sinde nörolojik durum stabildi. Ölen 8 hastanın hepsinde başlangıç BT'leri anormaldi ve geç BT'lerinde progresyon vardı.

SONUÇ: Hafif-orta kafa travması olan hastalarda seri BT taramalar bir hasta alt grubunda tedavi kararlarını bağımsız olarak değiştirebilir. Geç tarama kararları risk faktörlerini hesaba katarak her hasta için ayrı ayrı verilmelidir.

ANAHTAR SÖZCÜKLER: Kafa travması, Bilgisayarlı tomografi, İntrakranyal kanama, Glascow koma skoru

INTRODUCTION

The neurosurgery literature is replete with studies and reviews on the use of computerized tomography (CT) scanning in the evaluation of the head trauma patient. Several papers focus on the difficult issue of selecting patients who require CT scans (10,26,38,49). No universal agreement has been reached on the routine use of head CT in cases of less severe head trauma (37,38,49). A number of investigators advocate routine sequential CT scans for follow-up of the head trauma patient (8,15,29,35,43). Relatively little has been published in the radiology literature regarding early and late changes in the head CT scans of trauma patients.

Our aim in this study is to share our observations in a relatively large number of head trauma patients with mild-moderate head injury and their serial CT findings displaying changes.

MATERIAL and METHODS

Two thousand six hundred and forty-four sequential cases admitted to our emergency service and treated with hospitalization with mild or moderate severity head traumas (Table I) within a period of two years were analyzed retrospectively. According to our protocol, CT scan was performed within the first one hour for all the cases according to the protocol of our hospital. Patients that surgery was performed according to the results of the initial CT result were not included in the study. A second CT scan was performed within the first 8 hours following admission for all the 2644 patients included in the study.

Cranial CT scans were performed using a third generation CT scanner within intravenous contrast substance. Sections were

Table I: Traumatic Brain Injuries (Tbi) Can be Classified into Mild, Moderate, and Severe Categories (33)

Severity of head trauma	Glascow Coma Score (GCS)
Mild	13-15
Moderate	9-12
Severe	3-8

taken as parallel to the orbitomeatal line, in 5mm thickness for the posterior fossa and 10mm thickness for the brain, and with 1mm intervals for all.

Of the 2644 patients, 2532 (95,76%) were stable according to CT findings, while for the remaining 112 (4,24%) patients, there were changes between the first and second scans (regardless of the initial CT findings or the direction of change).

Clinical and radiological follow-up data of all the cases were recorded. Initial and control CT findings were compared. Increasing or reducing intracranial pathologies were determined. Treatment modes were determined according to the control data. Reflections of the radiological changes in the neurological picture were analyzed.

Follow-up data for the weeks 2 and 6 following the discharge are present for all the patients.

FINDINGS

When we evaluated the CT scans of 2644 patients, 5 different causes of head trauma were identified: falls, traffic accidents, physical abuse (non-penetrating injury), penetrating injury and birth trauma (Table II). One hundred and twelve patients who were investigated in detail that changes were found between the initial and control CT scans constituted the 4.24% of the patients admitted to the emergency service within the study period with mild- to moderate head traumas. Of these, 75 (67%) were males and 37 (33%) were females. The range of age was between the neonatal period (first day of life) and 97 years of age, the mean age was 30.88 years.

There was mild trauma in 81 patients according to initial GCS scores (GCS scores between 13 and 15; 72.3%), and moderate-level trauma in 31 patients (GCS scores between 9 and 12; 27.7%). The initial GCS scores of 112 patients are given in Table III. The results of the initial CT scans are given in Table IV. Within 8 hours of admission, a second CT scan of head was obtained in all patients. Table V summarizes the distribution of patients with change from the initial study. Table VI shows the type of change in lesions detected by serial CT scanning for the lesion types seen.

Eight patients (7.1%) where changes were observed in the control CT findings died. All had initial abnormal CT studies with progression on the delayed scans. Seven of these patients (87.5%) were of 65 years or older age.

While the initial CT scans of the 91 patients out of 112 (81.3%) were abnormal, for the 21 (18.7%) normal initial CT scans were obtained. Fourteen patients out of 21 with normal initial CTs (66,7%) had mild traumas and 7 (33.3%) had moderate-level traumas. Surgery was required in four patients out of 14 in the mild trauma group with normal initial CT scores because of the lesions found in the second CT scan (two epidural hematomas and two intracerebral hematomas) (Figure 2A-C). Surgery was required in two patients out of the 7 in the moderate trauma group with normal initial CT scores because of the lesions found in the late scan.

Table II: The Distribution o 112 Patients According to the Cause of Head Trauma

Cause of head trauma	Number of patients
Fall	47
Car accident	45
Physical abuse (non-penetrating injury)	12
Penetrating injury	6
Birth trauma	2

Table III: The Distribution of 112 Patients According to the Initial GCS Scores

Initial GCS score	Number of patients
9-10	12 (10.7%)
11-12	19 (17.0%)
13-14	54 (48.2%)
15	27 (24.1)

Table IV: The Distribution of 112 Patients According to the Traumatic Pathology on the Initial CT Scan

Findings on the initial CT scan	Number of patients
Skull fracture	84 (74%)
Pneumocephalus	38 (34%)
Subarachnoid hemorrhage	18 (16%)
Epidural hemorrhage	17 (15.1%)
Subdural hemorrhage	12 (10.7%)
Intraaxial hemorrhage (ICH+HC)	47 (41.9%)

While the CT findings deteriorated in 103 of the patients out of 112 (91%) CT (with newly-appearing lesions or the increase in the size of the known lesion), late CT findings improved only in 9 (8%). Neurological deterioration was seen in 34 patients out of 103 (33%) with deteriorating CT findings. Surgery was required for 22 (64.7%) of these patients (Figure 1A-C).

Forty-six patients out of 112 (41.1%) required surgery according to the late CT findings. In these forty-six patients, the reason for surgery was deterioration in CT findings (Table VII). When compared to the total number of hospitalized patients (2,644), the rate of these 46 patients requiring surgery was 1.7%. The neurological status of the 24 patients with deteriorating CT findings (52.2%) was stable (Table VIII).

Table V: The Distribution of 112 Patients According to the Location and Type of Change on the Second CT Scan Compared to the Initial Scan

The change on the second CT scan from the initial	Location of pathology	Type of pathology	Number of patients	
New lesion on the second scan not present initially 21 patients (18.75%)	Intraaxial	ICH	15	
	extraaxial	EDH	5	6
		SDH	1	
Increase in size of the lesion present on the initial scan 82 patients (73.21%)	intraaxial	ICH	47	
	extraaxial	EDH	17	35
		SDH	12	
		pneumocephalus	6	
Decrease in size or disappearance of the initial lesion 9 patients (8%)	extraaxial	SDH	6	
		EDH	3	

ICH: *intracerebral hemorrhage,* ***EDH:*** *epidural hemorrhage,* ***SDH****: subdural hemorrhage.*

Table VI: The Type of Change on Serial Scanning According to Pathology

Lesion	Appeared with delay	Increased	Decreased
ICH	15	47	None
EDH	5	17	3
SDH	1	12	6
SAH	None	None	None
Pneumocephalus	None	6	

Table VII: The Distribution of 46 Patients Requiring Surgery due to Worsening CT Findings According to Type of Pathology and Severity of Head Trauma

Reason for surgery	Appeared with delay	Increased
EDH (19 patients: 1 mild, 18 moderate)	3 (2 mild, 1 moderate)	16 (all moderate)
SDH (12 patients: 4 mild, 8 moderate)	0	12 (4 mild, 8 moderate)
ICH (13 patients: 4 mild, 9 moderate)	3 (2 mild, 1 moderate)	10 (1 mild, 9 moderate)
Tension pneumocephalus (2 patients: both moderate)	0	2 (both moderate)

mild: *GCS score 13-15,* ***moderate:*** *GCS score 9-12.*

Table VIII: The Distribution of 82 Patients with Worsening CT Findings According to Change in Neurological Status and Necessity of Surgery

	Neurologically stable	Neurologically deteriorated
Underwent surgery	24	22
Surgery not required	24	12

While surgery was required in 28 patients out of 81 with mild traumas (34%), the same was required in 18 patients out of 31 with moderate-level traumas (58%). The reason for surgery according to control CT scans performed in 24 patients out of 28 (85.7%) patients with mild traumas, and in 16 patients out of 18 (88.9%) with moderate traumas was deterioration of the abnormality in the CT scan (Figure 3A,B). Surgery was required because of epidural hematoma (EDH) in two patients out of four who had mild traumas and that initial CT scans were normal, and because of intra cerebral hematoma (ICH) with delayed appearance in the remaining two. In these patients, neurological deterioration did not accompany the changes in CT findings.

The neurological picture in the four patients out of 18 that surgical treatment was applied according to the control CT scans was stable. Of these eighteen patients, no prominent intracranial pathologies were seen in the initial CT scans. One of these patients was operated because of ICH, and the other was operated for EDH.

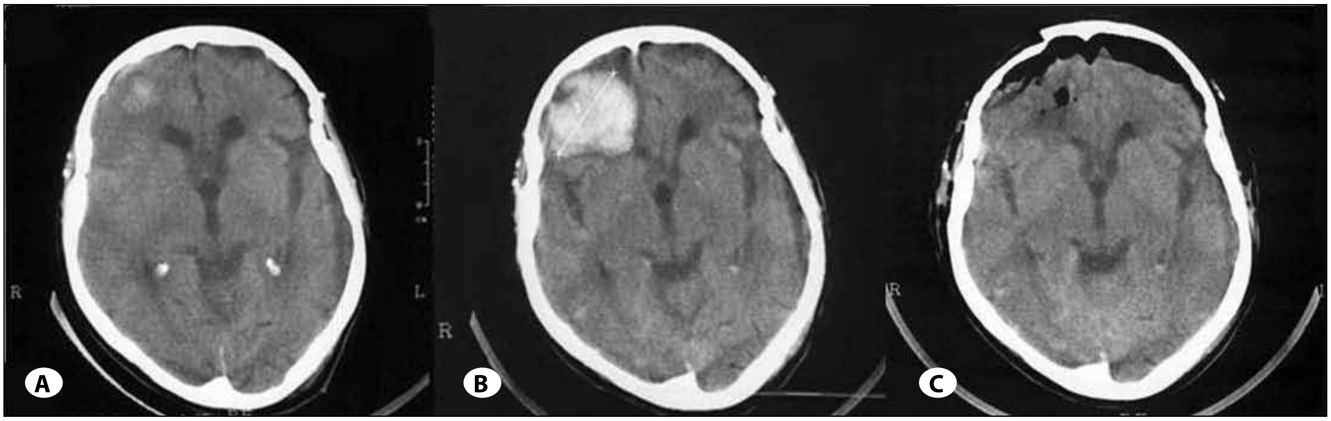

Figure 1: Non-enhanced cranial CT of 5 year-old male after a fall. Delayed epidural hemorrhage. **A)** Initial CT shows no evidence of hemorrhage. GCS score was 14. **B)** 6 hours later, late CT shows interval appearance of a right frontal epidural hematoma (arrow). GCS score remained unchanged. **C)** Postoperative CT shows right frontal craniotomy and evacuated hematoma.

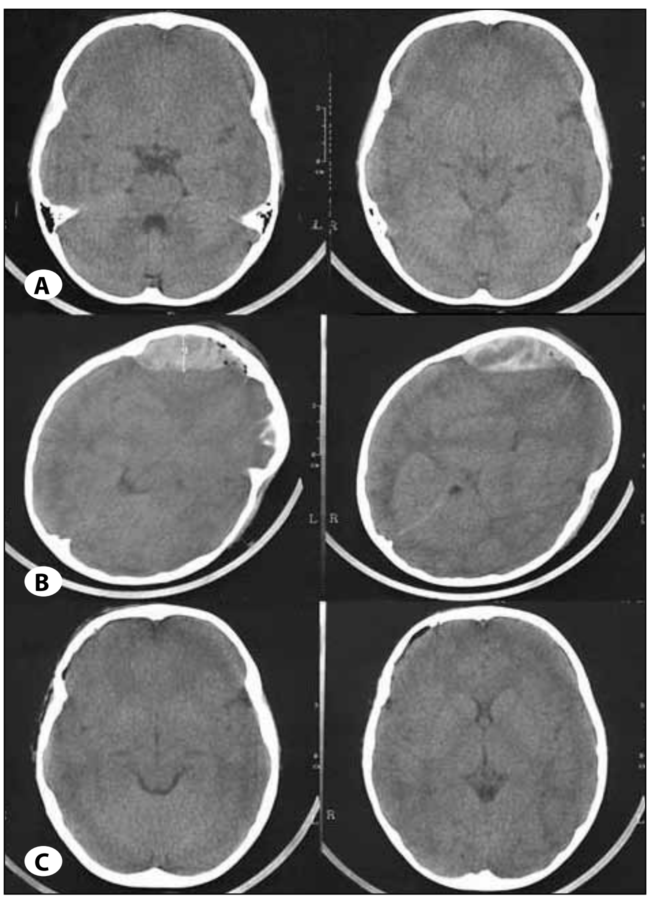

Figure 2: Non-enhanced cranial CT of 97 year-old male who was brought to the emergency department after a fall from the stairs. Increasing intracranial hemorrhage necessiating surgical evacuation. **A)** CT scan at admission shows hemorrhagic contusion in the right frontal lobe (arrow). GCS score was 15 at this time. **B)** Late CT shows significant interval increase in size of the hematoma. GCS score was 14 at this time. **C)** Postoperative CT. Right frontal craniotomy was performed and hematoma was evacuated.

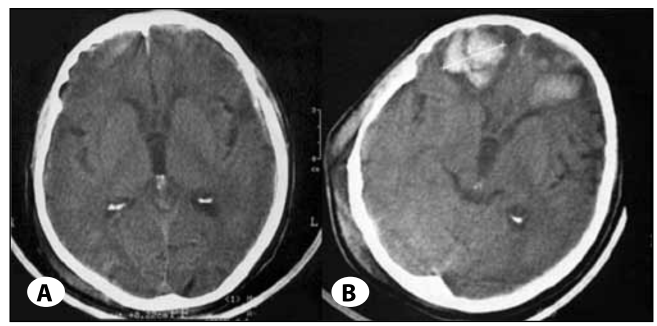

Figure 3: Delayed appearance of hemorrhagic contusion. Seventy-eight year-old male was seen in the emergency department after a fall. **A)** CT within the first hour of admission shows thin subdural hematoma on the left (straight arrow) and minimal subarachnoid hemorrhage on the right (curved arrow). GCS was 14. **B)** Late CT shows interval appearance of bilateral frontal hemorrhagic contusion (arrows) and interval disappearance of thin subdural hematoma on the left. GCS was 13.

Disappearance of the abnormality in the initial CT scan after the interval was the most frequent in subdural hematomas (SDH) (Figure 4A,B) followed by EDH (Table V).

DISCUSSION

The goal of emergency CT scanning in head trauma patients is to depict lesions that need neurosurgical treatment or that can need alternative medical therapy. There is wide agreement on the use of CT in head trauma patients with moderate or severe head injury according to the GCS scores (24). In mild head injury there can also be life-threatening complications that can need further treatment (5). There are some guidelines published regarding the use of CT in patients with mild head trauma (5,6,24,40,45).

In our group of patients hospitalized with mild to moderate trauma and changes in serial CT findings, 27.7% had moderate head injury. Majority (78%) of these patients had

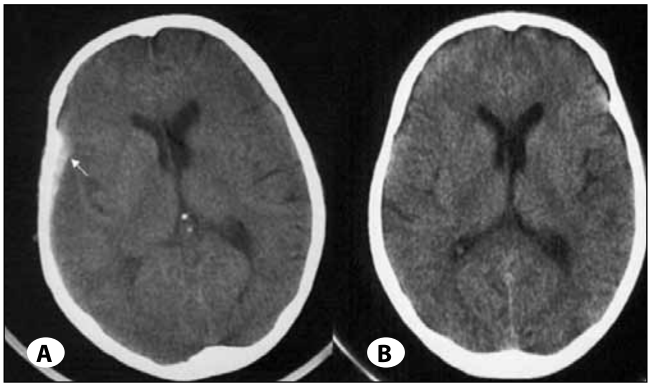

Figure 4: Disappearance of subdural hematoma. Sixty five year-old female was brought to the emergency department after a fall from height. **A)** Initial CT shows a right-sided subdural hematoma (arrow). GCS was 14. **B)** Late CT shows disappearance of subdural hematoma. GCS remained unchanged.

initial CT scan abnormalities. Fifty-eight percent of these patients required surgery due to worsening CT findings or deteriorating neurological status. Two patients (0.06%) were operated due to lesions that were not present on initial CT scans. The majority (72.3%) of our patients had mild head trauma according to the GCS scores. This class constitutes a more heterogenous group of patients regarding the diagnostic and therapeutic needs as well as the prognosis (9,12,46,48). Due to the increasingly evident inadequacy of GCS scoring system in diagnostic and therapeutic decision making in this group, the definition of mild head injury has been questioned in the neurosurgery literature (46,47). Attempts have been made to further divide this class into high and low risk subgroups by the use of additional clinical data such as loss of consciousness, presence of amnesia, nausea-vomiting, old age, depressed skull fracture, and basal fracture (10,26,37,38,46,48). Hence the term "minor or minimal head injury" describing patients with GCS scores of 13-15, normal neurological examination, and a history of loss of consciousness / amnesia. Efforts have concentrated on separating patients with GCS scores of 13-14 from those with 15 (9,12). Most of these attempts aimed at selecting patients who require CT scanning and / or hospitalization. Although no combination of clinical data could consistently predict CT findings (thereby eliminate the need for CT in a subgroup of patients), debate still continues regarding the benefit of routine CT scanning in patients with minor head injury. The authors who argue against the routine admission CT refer to the fact that only a small percentage of patients with low risk factors will harbor intracranial lesions requiring surgery (37). Objections to this point of view come from those who argue that, especially in the pediatric population, missing this minority who require surgery has severe implications (38,49). The risk factors identified in the literature to be associated with a greater percentage of positive CT findings in head trauma patients are: presence of coagulopathy (34), loss of consciousness (1,14,28), amnesia (1,38), skull fracture (14,26), basilar skull fracture (2,17), old age (2,17,38), white race (12), type of trauma (being a pedestrian or cyclist hit by a vehicle, or being an assault victim) (2,17), severe headache, nausea / vomiting (26), type of SAH, DAI, edema (31), cranial soft tissue injury (2), focal neurological deficit, initial low GCS and decreased GCS after appearance in the emergency department (28) and ethanol intoxication (13). Compagnone et al (7) found that when admission CT showed diffuse injury, the risk of progression to a mass lesion is 23%, and 22% of these patients need an emergency craniotomy. Investigators found that when GCS score was 9 or 10 the predictor of the worst outcome was a low motor GCS score but when GCS score was 11 to 13 the factors that associated with worst outcome were neurological worsening, seizures and medical complications (7). Although it was not our aim to evaluate the risk factors, the old age stood out in addition to the initial GCS score as a risk factor for both injury requiring surgery and poor prognosis in our study.

A growing number of observations on delayed injury after head trauma have been published (8,15,16,18,29,35,36,43,44). In some studies, early progressive head injury was documented in up to 50% of patients without initial warning of clinical symptoms or CT scan findings (22,29,43). Broderick et al (3) revealed doubling in volume of intracranial hematomas within 12 hours in 40% of patients. Changes from the initial CT have been detected up to 2 weeks after trauma. Nearly all of these observations were made on patients with moderate to severe head trauma.

Imhof et al (15) reported worsening of CT findings in 45% of cases up to 2 weeks after trauma regardless of the initial GCS scores on patients with mild-to-moderate head injury. Livingston et al (21) concluded that patients with minimal head trauma could be safely discharged if their initial helical CT of head was negative. In that study, only 5 of the 1,788 patients those with initially negative CT required surgery later. In our study, of the 21 patients whose initial CT scans were normal, 5 required surgery because of the delayed appearance of CT findings. This constitutes 0.2% of the patients hospitalized within the study period. In this group two patients had mild trauma (1 EDH, 1 ICH-HC). This constituted 0.06% of the hospitalized patients.

Several investigators have made an effort to correlate poor prognosis after head trauma with the initial CT findings. Recently Smits et al (41) investigated outcome for minor head trauma patients and found that diffuse axonal injury was associated with higher grades of functional disability on all outcome scales, where intraparenchymal contusions and subdural hematoma were associated with poor outcome according to Glascow Outcome Scale and Barthel Index. Maas et al (23) studied moderate to severe head trauma and advised a prognostic CT scale for probability of mortality but they did not assess patients with mild trauma. In the pediatric age, the presence of SAH, DAI or edema has been reported to indicate a worse prognosis (31). Presence of SAH, along with a higher grade of initial scan severity using an overall grading system from normal to severe diffuse injury correlated with worse prognosis in another study (50). Edema, intraventricular hemorrhage and greater midline shift were associated with poorer outcome in another study (11). In our study, most (87.5%) of the expired patients were of age 61 and above.

MRI has been shown to detect traumatic intraaxial CNS lesions more sensitively than CT (19,27). In patients with mild head trauma and normal initial CT scans, MRI detected DAI in 30% (30). With the advent and wider availability of faster scanning techniques, MRI will probably be performed more frequently, especially on patients with less severe trauma who do not require life support equipment. MR spectroscopy and diffusion-weighted MRI are other promising applications with theoretical capability of detecting trauma-induced changes in normal appearing tissue (4,32,39,42). The impact of these novel techniques on treatment decisions remains to be seen.

In our population of patients with mild-to-moderate head trauma and serial CT changes, initial neurological status or changes in neurological status during follow-up were not helpful in predicting the requirement for surgery. Fifty-two percent of patients requiring surgery for evolving CT scan abnormalities remained neurologically stable. Half of the patients with stable neurological status required surgery. Of those with deteriorating neurological status, 33% did not require surgery.

In our study, all studies were reviewed using hardcopy films. Digital reading which permits adjustment of window level and width of images on digital screen could theoretically allow us detect additional patients with more subtle findings on initial or late scans. Such manoeuvres have been documented to allow detection of cerebral infarcts more sensitively (20). The use of a spiral CT scanner could theoretically increase the sensitivity for smaller lesions. However, the surgical treatment decision would be unlikely to be altered.

CONCLUSION

In mild-to-moderate head trauma, late CT scanning of head identifies a subgroup of patients who will benefit from surgical intervention that would otherwise be delayed or missed. Although the number of such patients seem to be relatively low this can be the recommended way especially for patients who have additional risks such as pediatric or old age, coagulopathy and severe neurological symptoms etc.

The decision on the necessity of follow-up CT scans should be made on individual patient basis. Further studies correlating risk factors and prognosis in head trauma may result in more effective use of CT scanning. Radiologists interpreting head CT scans of trauma patients should be aware of the time of trauma as well as factors associated with increased risk of progressive injury and recommend serial studies when they consider necessary.

REFERENCES

1. Benito Fernandez J, Mintegui Raso S, Sanchez Echaniz J, Martinez Gonzalez MJ, Fernandez Cuesta MA: Head injuries in children: Can clinical features identify patients with high or low risk for intracranial injury? An Esp Pediatr 48(2):122-126, 1998
2. Borczuk P: Predictors of intracranial injury in patients with mild head trauma. Ann Emerg Med 25(6):731-736, 1995
3. Broderick JP, Brott TG, Tomsick T, Barsan W, Spilker J: Ultra-early evaluation of intracerebral hemorrhage. J Neurosurg 72(2):195-199, 1990
4. Brooks WM, Friedman SD, Gasparovic C: Magnetic resonance spectroscopy in traumatic brain injury. J Head Trauma Rehabil 16(2):149-164, 2001
5. Carroll LJ, Cassidy JD, Holm L, et al: Methodological issues and research recommendations for mild traumatic brain injury: The WHO Collaborating Centre Task Force on Mild Traumatic Brain Injury. J Rehabil Med 43:113–125, 2004
6. Cassidy J, Carroll L, Peloso P, et al: Incidence, risk factors and prevention of mild traumatic brain injury: Results of the WHO Collaborating Centre Task Force on Mild Traumatic Brain Injury. J Rehabil Med 28–60, 2004
7. Compagnone C, d'Avella D, Servadei F, Angileri FF, Brambilla G, Conti C, Cristofori L: Patients With Moderate Head Injury: A Prospective Multicenter Study of 315 Patients. Neurosurgery: 64(4): 690-697, 2009
8. Cooper PR, Maravilla K, Moody S, Clark WK: Serial computerized tomographic scanning and the prognosis of severe head injury. Neurosurgery 5(5):566-569, 1979
9. Culotta VP, Sementilli ME, Gerold K, Watts CC: Clinicopathological heterogeneity in the classification of mild head injury. Neurosurgery 38(2):245-250, 1996
10. Davis RL, Mullen N, Makela M, Taylor JA, Cohen W, Rivara FP: Cranial computed tomography scans in children after minimal head injury with loss of consciousness. Ann Emerg Med 24(4):640-645, 1994
11. Fearnside MR, Cook RJ, McDougall P, McNeil RJ: The Westmead Head Injury Project outcome in severe head injury. A comparative analysis of pre-hospital, clinical and CT variables. Br J Neurosurg 7(3):267-279, 1993
12. Gomez PA, Lobato RD, Ortega JM, De La Cruz J: Mild head injury: Differences in prognosis among patients with a Glasgow Coma Scale score of 13 to 15 and analysis of factors associated with abnormal CT findings. Br J Neurosurg 10(5):453-460, 1996
13. Holmes JF, Baier ME, Derlet RW: Failure of the Miller criteria to predict significant intracranial injury in patients with a Glasgow Coma Scale score of 14 after minor head trauma. Acad Emerg Med 4(8):788-792, 1997
14. Hung CC, Chiu WT, Lee LS, Lin LS, Shih CJ: Risk factors predicting surgically significant intracranial hematomas in patients with head injuries. J Formos Med Assoc 95(4): 294-297, 1996
15. Imhof HG, Wacker J, Kach K, Platz A, Trentz O: Computerized tomography follow-up in the acute phase after craniocerebral trauma. Helv Chir Acta 60(1-2):195-200, 1993
16. Jaimovich R, Monges JA: Delayed posttraumatic intracranial lesions in children. Pediatr Neurosurg 17(1):25-29, 1991
17. Jeret JS, Mandell M, Anziska B, Lipitz M, Vilceus AP, Ware JA, Zesiewicz TA: Clinical predictors of abnormality disclosed by computed tomography after mild head trauma. Neurosurgery 32(1):9-15, 1993

18. Kobayashi S, Nakazawa S, Otsuka T: Clinical value of serial computed tomography with severe head injury. Surg Neurol 20(1):25-29, 1983
19. Lee H, Wintermark M, Gean AD, Ghajar J, Manley GT, Mukherjee P: Focal lesions in acute mild traumatic brain injury and neurocognitive outcome: CT versus 3T MRI. J Neurotrauma 25:1049–1056, 2008
20. Lev MH, Farkas J, Gemmete JJ, Hossain ST, Hunter GJ, Koroshetz WJ, Gonzalez RG: Acute stroke: Improved nonenhanced CTdetection--benefits of soft-copy interpretation by using variable window width and center level settings. Radiology 213(1):150-155, 1999
21. Livingston DH, Lavery RF, Passannante MR, Skurnick JH, Baker S, Fabian TC, Fry DE, Malangoni MA: Emergency department discharge of patients with a negative cranial computed tomography scan after minimal head injury. Ann Surg 232(1):126-132, 2000
22. Lobato RD, Sarabia R, Rivas JJ, Cordobes F, Castro S, Munoz MJ, Cabrera A, Barcena A, Lamas E: Normal computerized tomography scans in severe head injury. Prognostic and clinical management implications. J Neurosurg 65(6): 784-789, 1986
23. Maas AI, Hukkelhoven CW, Marshall LF, Steyerberg EW: Prediction of outcome in traumatic brain injury with computed tomographic characteristics: A comparison between the computed tomographic classification and combinations of computed tomographic predictors. Neurosurgery 57: 1173–1182, 2005
24. Maas AIR, Stocchetti N, Bullock R: Moderate and severe traumatic brain injury in adults. Lancet Neurol 7:728-741, 2008
25. Miller EC, Derlet RW, Kinser D: Minor head trauma: Is computed tomography always necessary? Ann Emerg Med 27(3):290-294, 1996
26. Miller EC, Holmes JF, Derlet RW: Utilizing clinical factors to reduce head CT scan ordering for minor head trauma patients. J Emerg Med 15(4):453-457, 1997
27. Mittl RL, Grossman RI, Hiehle JF, Hurst RW, Kauder DR, Gennarelli TA, Alburger GW: Prevalence of MR evidence of diffuse axonal injury in patients with mild head injury and normal head CT findings. AJNR Am J Neuroradiol 15(8): 1583-1589, 1994
28. Moran SG, McCarthy MC, Uddin DE, Poelstra RJ: Predictors of positive CT scans in the trauma patient with minor head injury. Am Surg 60(7):533-535, 1994
29. Oertel M, Kelly DF, McArthur D, Boscardin WJ, Glenn TC, Lee JH, Gravori T, Obukhov D, McBride DQ, Martin NA: Progressive hemorrhage after head trauma: Predictors and consequences of the evolving injury. J Neurosurg 96(1):109-116, 2002
30. Ogawa T, Sekino H, Uzura M, Sakamoto T, Taguchi Y, Yamaguchi Y, Hayashi T, Yamanaka I, Oohama N, Imaki S: Comparative study of magnetic resonance and CT scan imaging in cases of severe head injury. Acta Neurochir Suppl (Wien) 55:8-10, 1992
31. Ong L, Selladurai BM, Dhillon MK, Atan M, Lye MS: The prognostic value of the Glasgow Coma Scale, hypoxia and computerised tomography in outcome prediction of pediatric head injury. Pediatr Neurosurg 24(6):285-291, 1996
32. Provenzale JM: Imaging of traumatic brain injury: A Review of the recent medical literature. AJR 194:16–19, 2010
33. Saatman KE, Duhaime AC et al: Workshop Scientific Team and Advisory Panel Members. "Classification of traumatic brain injury for targeted therapies". Journal of Neurotrauma 25 (7): 719–738, 2008 doi:10.1089/neu.2008
34. Sawauchi S, Yuhki K, Abe T:The relationship between delayed traumatic intracerebral hematoma and coagulopathy in patients diagnosed with a traumatic subarachnoid hemorrhage. No Shinkei Geka 29(2):131-137, 2001
35. Servadei F, Murray GD, Penny K, Teasdale GM, Dearden M, Iannotti F, Lapierre F, Maas AJ, Karimi A, Ohman J, Persson L, Stocchetti N, Trojanowski T, Unterberg A: The value of the "worst" computed tomographic scan in clinical studies of moderate and severe head injury. European Brain Injury Consortium. Neurosurgery 46(1):70-75, 2000
36. Servadei F, Nanni A, Nasi MT, Zappi D, Vergoni G, Giuliani G, Arista A: Evolving brain lesions in the first 12 hours after head injury: Analysis of 37 comatose patients. Neurosurgery 37(5):899-906, 1995
37. Servadei F, Teasdale G, Merry G: Defining acute mild head injury in adults: A proposal based on prognostic factors, diagnosis, and management. J Neurotrauma 18(7):657-664, 2001
38. Simon B, Letourneau P, Vitorino E, McCall J: Pediatric minor head trauma: Indications for computed tomographic scanning revisited. J Trauma 51(2):231-237, 2001
39. Sinson G, Bagley LJ, Cecil KM, Torchia M, McGowan JC, Lenkinski RE, McIntosh TK, Grossman RI: Magnetization transfer imaging and proton MR spectroscopy in the evaluation of axonal injury: Correlation with clinical outcome after traumatic brain injury. AJNR Am J Neuroradiol 22(1): 143-151, 2001
40. Smits M, Dippel DW, de Haan GG, et al: Minor head injury: Guidelines for the use of CT—a multicenter validation study. Radiology 245: 831 – 838, 2007
41. Smits M, Hunink MG, van Rijssel DA, et al: Outcome after complicated minor head injury. AJNR 29:506–513, 2008
42. Son BC, Park CK, Choi BG, Kim EN, Choe BY, Lee KS, Kim MC, Kang JK: Metabolic changes in pericontusional oedematous areas in mild head injury evaluated by 1H MRS. Acta Neurochir Suppl 76:13-16, 2000
43. Stein SC, Spettell C, Young G, Ross SE: Delayed and progressive brain injury in closed-head trauma: Radiological demonstration. Neurosurgery 32(1):25-30, 1993
44. Stein SC, Spettell CM: Delayed and progressive brain injury in children and adolescents with head trauma. Pediatr Neurosurg 23(6):299-304, 1995
45. Stiell IG, Wells GA, Vandemheen K, et al: The Canadian CT head rule for patients with minor head injury. Lancet 357: 1391 –1396, 2001

46. Stiell IG, Lesiuk H, Wells GA, McKnight RD, Brison R, Clement C, Eisenhauer MA, Greenberg GH, MacPhail I, Reardon M, Worthington J, Verbeek R, Rowe B, Cass D, Dreyer J, Holroyd B,Morrison L, Schull M, Laupacis A: The Canadian CT Head Rule Study for patients with minor head injury: Rationale, objectives, and methodology for phase I (derivation). Ann Emerg Med 38(2):160-169, 2001
47. Tellier A, Della Malva LC, Cwinn A, Grahovac S, Morrish W, Brennan-Barnes M: Mild head injury: A misnomer. Brain Inj 13(7):463-475, 1999
48. Uchino Y, Okimura Y, Tanaka M, Saeki N, Yamaura A: Computed tomography and magnetic resonance imaging of mild head injury--is it appropriate to classify patients with Glasgow Coma Scale score of 13 to 15 as "mild injury"? Acta Neurochir (Wien) 143(10):1031-1037, 2001
49. Wang MY, Griffith P, Sterling J, McComb JG, Levy ML: A prospective population-based study of pediatric trauma patients with mild alterations in consciousness (Glasgow Coma Scale score of 13-14). Neurosurgery 46(5):1093-1099, 2000
50. Wardlaw JM, Easton VJ, Statham P: Which CT features help predict outcome after head injury? J Neurol Neurosurg Psychiatry 72(2):188-192, 2002