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Detection of Midline Shift from CT Scans to Predict Outcome in Patients with Head Injuries

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Abstract

Background: The present study aimed to detect the degree of midline shift from CT scans and the clinical status of the patient, to evaluate the relationship between the degree of midline shift found by the CT scan and Glasgow Coma Scale (GCS) score as a predictor of clinical outcome in head injury patients. Furthermore, we aimed to assess the relationship between midline shift and age, sex, and causes.

Methods and Results: The study included 50 subjects (36 males and 14 females). The age range of the patients in this study was 18–95 years old (mean age of 48.34±17.02 years). The inclusion criteria were patients with traumatic brain injury (TBI) or patients evaluated for level of consciousness by a neurosurgeon. Toshiba 16 Slice CT Scanner (Toshiba Medical Systems, Nasu, Japan 2003) was used to scan all patients in the supine, head first position. Contiguous 2 mm slices were obtained using the Toshiba 16-slice machine spiral technique (pitch 1.25–1.5, 0.75 s rotation time, 120 KvP, 2 mm reconstruction interval).

The results indicated that the degree of midline shift in patients with brain injuries was statistically significant as a determinant of clinical outcome. It appeared that the probability of poor clinical outcome was higher when there was a combination of midline shift and other types of intracranial hemorrhage, clinical factors, such as sex, age, and GCS score, and associated injuries. The worst outcome was seen in patients with midline shift and subdural hematoma, when compared with other lesions in patients with brain injuries.

Conclusion: This study suggests that the degree of midline shift may be predictive of clinical outcome in patients with head injuries.(**International Journal of Biomedicine. 2021;11(1):18-23.**)

Key Words: brain midline shift • Glasgow Coma Scale • intracerebral hemorrhage • intracranial pressure • subdural hematoma

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Abbreviations

CT, computed tomography; **TBI**, traumatic brain injury; **GCS**, Glasgow Coma Scale; **SDH**, subdural hematoma; **EDH**, epidural hematoma; **ICH**, intracerebral hemorrhage; **H-MLS**, hemorrhage and midline deformation; **dML**, deformed midline; **iML**, ideal midline; **ICH,** intracerebral hematoma; **DAI**, diffuse axonal injury.

Introduction

Computed tomography (CT) scans are widely used for neurological diagnosis. CT scans of the brain are useful in tracing midline shift in traumatic brain injury and intracranial pathology. In intracranial pathological examination, brain midline shift is an important diagnostic feature to evaluate the severity of brain compression due to various pathologies.[1,2] Despite the functional difference of the brain hemispheres, the normal anatomic structure of the brain is symmetric and called the midsagittal plane, which is shown in a single CT slice as the brain midline.[3] Intracranial pathological changes, such as hemorrhage or tumor (Figures 1-3), may cause midline shift.[1,3]

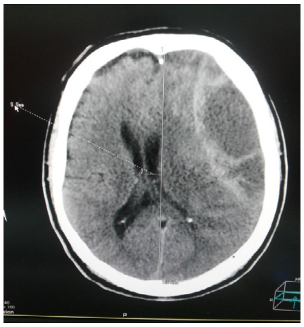

Fig. 1. *A 59-year-old male. SDH with midline shift of 9.9 mm, right-sided weakness, GCS score of 14.*

Fig. 2. *A 36-year-old male. EDH with midline shift of 3.2 mm, GCS score of 10.*

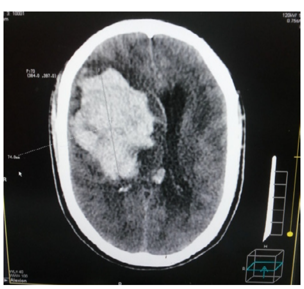

Fig. 3. *A 38-year-old male. ICH with midline shift of 13.3 mm, GCS score of 3.*

Patients presenting with midline shift may suffer from continual disequilibrium. Moreover, midline shift is often associated with high intracranial pressure, which can be fatal.[4,5] Furthermore, previous studies have shown that midline shift is significant in indicating the survival probability of patients.[6] Therefore, midline shift is used as a measurement of changes in brain symmetry and is an important indicator of the severity of pathology. The degree of midline shift after traumatic brain injury (TBI) is widely recognized as an important marker of severe injury.[6] Numerous reports[7-9] have described the association between extensive midline shift on CT scans and poor outcomes or other adverse sequelae of TBI.A study by Englander et al.[10] concluded that the presence of either a midline shift greater than 5 mm or subcortical concussion on acute CT scans is associated with a greater need for assistance with ambulation, activities of daily living, and global supervision at rehabilitation discharge. In addition to midline shift, other variables, such as age, Glasgow Coma Scale (GCS) score, abnormal motor responses, other CT findings, and episodes of hypoxia and hypertension, have been subsequently introduced to build more complex and accurate prognostic models. Given the significance of midline shift in diagnosis, automated detection and computation of midline shift on brain CT images using processing techniques is an important task.[1,2] A robust and efficient algorithm to compute midline shift is an essential component of a computer-aided neurology diagnostic system.[1] There is research in the literature that focuses on automated detection and computation of midline shift.[2,11,12] A generic algorithm was used to minimize the summed score of each point of deformed midline on symmetry maps.[3,11,13] This method was proven to be effective. However, it is mainly based on symmetry of the brain structure along the image's ventricle direction, which may be lost if there is a tumor, large hemorrhage, subdural hematoma (SDH), or epidural hematoma (EDH). This shortcoming often causes failure of the method in cases of intracerebral hemorrhage (ICH). Moreover, the use of a generic algorithm makes the method time inefficient.[3] In this study, a novel method of tracing brain midline shift on CT images in TBI was used to report the cause of midline shift instead of being based on symmetry information in the image. In TBI, hemorrhage is the main cause of brain midline shift. First, we modeled the relationship between hemorrhage and midline deformation (H-MLS) caused by hemorrhage using a linear regression model. Second, using the H-MLS model, the deformed midline (dML) was determined from the hemorrhage detected on the CT images. Finally, the dML was adjusted according to the visual symmetry information. Preliminary experimental results demonstrate the effectiveness of this method.

The present study aimed to detect the degree of midline shift from CT scans and the clinical status of the patient, to evaluate the relationship between the degree of midline shift found by the CT scan and GCS score as a predictor of clinical outcome in head injury patients. Furthermore, we aimed to assess the relationship between midline shift and age, sex, and causes.

Materials and Methods

This cross-sectional, descriptive study was performed in the department of radiology at the Al Gazira Traumatology center in Al Gazira State in Sudan during the period from February to July 2020. The study was conducted in accordance with ethical principles of the WMA Declaration of Helsinki (1964, ed. 2013). Written informed consent was obtained from all participants.

The study included 50 subjects (36 males and 14 females). The inclusion criteria were patients with TBI or patients evaluated for level of consciousness by a neurosurgeon. Adults with normal healthy brains were excluded from the study.

Toshiba 16 Slice CT Scanner (Toshiba Medical Systems, Nasu, Japan 2003) was used to scan all patients in the supine, head first position. Contiguous 2 mm slices were obtained using the Toshiba 16-slice machine spiral technique (pitch 1.25–1.5, 0.75 s rotation time, 120 KvP, 2 mm reconstruction interval).

Methods of midline shift measurement using CT scan

We considered revising the iML as the intersection of the CT scan and the midsagittal plane. When a large mass of pathology such as a hemorrhage emerges, the iML deforms and shifts to one side of the brain. The dML is defined as a curve that best fits the actual position of the original points on the iML, after deformation. The displacement of points from iML to dML during deformation is the amount of midline shift.

Hemorrhage is a common pathology in TBI, and it is the cause of most brain midline shifts, based on a large number of CT scans presenting with midline shifts. We have observed that, in general, the amount of midline shift caused by a hemorrhage is influenced by the following factors: the size of the hemorrhage (the larger the size, the larger the amount of midline shift), the distance between the hemorrhage and the iML (the longer the distance, the smaller the amount of midline shift), and the midline elastic property (points on the iML further apart from the skull are displaced more easily).

From these observations, a heuristic model called H-MLS was established to model the influence of the various factors on the degree of midline shift (Figure 4).

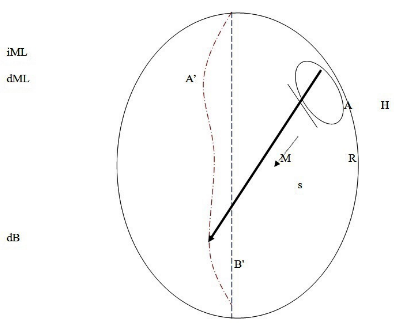

Fig. 4. *The H-MLS model.*

Tracing the deformed midline

Based on the H-MLS model, a scheme for tracing the dML, the algorithm first computes the hemorrhage information presented in the TBI CT scan. Then, it uses the H-MLS model to predict the possible dML. The predicted dML is adjusted according to visual symmetry information.

Step 1: Hemorrhage segmentation: In the CT image, the intracranial hemorrhage region has a higher intensity value than normal brain tissue. The simple thresholding method is used to segment out the image regions corresponding to hemorrhage (thresholding using 160<intensity value<230).

Step 2: Computation of hemorrhage information: An ellipse H is fitted to the boundary of the hemorrhage, and a ray R is shot from each point A on H. For each effective ray R, the corresponding point B on iML and the corresponding r, s, and f are computed.

Step 3: Predicting the deformed midline: The H-MLS model is used to compute the amount of midline shift d for each point B on iML, which is also on the effective ray. Thus, there is a corresponding point B', and a simple curve-smoothing process is applied to get the predicted dML.

Step 4: Symmetry adjusting: In this final step, the predicted dML is adjusted to best fit the visual symmetry information.

In our H-MLS model, each hemorrhage is represented as an ellipse H that best fits the hemorrhage boundary. For each point A on H, a ray R is shot from A along the normal direction N at A.

If ray R intersects the iML at point B, it is called an effective ray, which means it affects the deformation of the midline. The intersection of the effective ray R is denoted with the dML as B'. R is back extended to let it intersect with H at A'. Therefore, the amount of midline shift of point B is the image distance between B and B'. Depicted as D = (BB').

The amount of midline shift of each point B on the iML is affected by the effective ray R passing through it. On each effective ray R, we use e = (AA') to measure the size of the hemorrhage, and we use s = (AB) to measure the distance between the hemorrhage and the iML. M is considered the middle point of the iML, then f = (BM) measures the position of B on the iML. Then, the H-MLS model is constructed as a simple linear equation: $D = r + s + f$

Given a number of points B on the iML, the corresponding effective ray R, and the amount of midline shift D, the linear regression method is used. Therefore, the H-MLS model is a linear regression model that reveals the relationship between intracranial hemorrhage and the midline shift caused by it.

Data collection and analysis

The data collected in this study were obtained directly from CT images, and the information was sorted using data sheets for each patient. The ethics and research committee approved the study, and consent forms were obtained from all patients prior to procedures.

Statistical analysis was performed using the statistical software package SPSS version 22.0 (IBM Corp., Armonk, N.Y., USA). Continuous variables were presented as mean±standard deviation (SD). Student's unpaired t-test was used to compare two groups for data with normal distribution. The frequencies of categorical variables were compared using Pearson's chi-squared test. A value of $P<0.05$ was considered significant.

Results

In this study, males accounted for 72% (n=36) of the study population, and females accounted for 28% (n=14) (Figure 5). The age range of the patients in this study was 18–95 years old (mean age of 48.34±17.02 years). Most of the patients affected by brain injuries were between 36 and 75 years of age (Table 1).

We found that 28 patients with mild GCS scores had midline shifts up to 10mm, and only five patients had midline shifts greater than 10 mm (Table 2). The distribution of patients according to characteristics of brain injury includes SDH, EDH, ICH, and DAI. Midline shifts are presented in Table 3. Seventeen patients had midline shifts up to 10mm due to SDH, nine patients due to EDH, and six patients due to

ICH. Of these patients, 31 improved. In addition, the results show that 13 patients with midline shifts greater than 10mm improved and six died (Table 3).

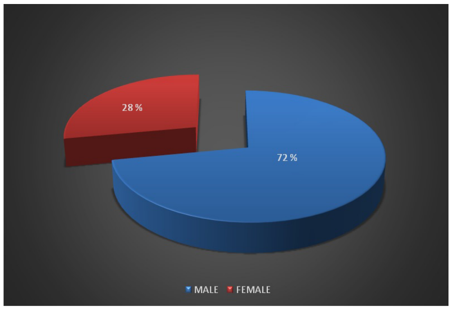

Fig. 5. *Gender distribution.*

Table 1.
Distribution of patients according to age

Age group (years)	Frequency	n (%)
18–35	8	16
36–55	17	34
56–75	19	38
76–95	6	12
Total	50	100%
Mean±SD	48.34±17.02	
Age range (years)	18–95	

Table 2.
The distribution of patients according to midline shift severity and GCS score

Midline shift classification	GCS severity		
	Mild	Moderate	Severe
Shift up to 10 mm	28	6	3
Shift greater than 10 mm	5	3	5
Total	33	9	8

Table 3.
Distribution of patients according to characteristics of brain injury with midline shift

Cause of midline shift	Midline shift up to 10 mm	Midline shift more than 10 mm
SDH	17	8
EDH	9	6
ICH	6	3
DAI	-	1
Final outcome		
Improvement	31	13
Death	-	6

The relationship between GCS severity and age groups is illustrated in Table 4 and Figure 6. Sixteen percent of patients were between 15 and 35 years of age, and their GCS scores—according to classification as mild, moderate, and severe—were 21.2%, 12.5%, and 0%, respectively. For patients between 36 and 55 years of age (34%), their GCS scores were 39.4%, 33.3%, and 12.5%, respectively. Thirty-eight percent of patients were aged between 56 and 75 years of age, and their GCS scores were 30.3%, 55.6%, and 50.0%, respectively. Twelve percent of patients were between 76 and 95 years of age, and their GCS scores were 9.1%, 0%, and 37.5%, respectively.

Table 4.
Correlation between GCS severity and age

Age	GCS severity					
	Mild	%	Moderate	%	Severe	%
18–35	7	21.2	1	11.1	0	0
36–55	13	39.4	3	33.3	1	12.5
56–75	10	30.3	5	55.6	4	50.0
76–95	3	9.1	0	0	3	37.5
Total	33	100%	9	100%	8	100%

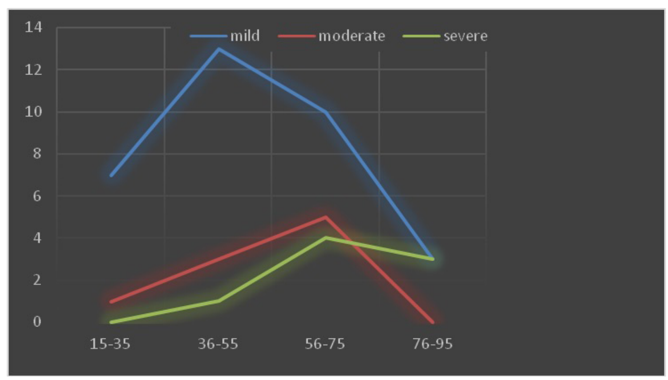

Fig. 6. *Relationship between GCS severity and age group.*

Table 5 and Figure 7 illustrate a significant correlation between GCS severity and gender (P<0.05). Similarly, there was a significant relationship between midline shift and age (Table 6).

Table 5.
Correlation between GCS severity and gender

Gender	GCS severity						*P*-value
	Mild	%	Moderate	%	Severe	%	
Male	25	69.4	6	16.7	5	13.9	0.001
Female	8	57.1	3	21.4	3	21.4	0.01
Total	33	66.0	9	18.0	8	16.0	0.01

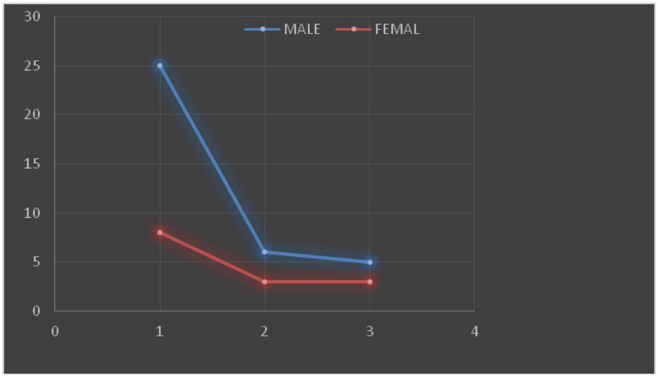

Fig. 7. *Correlation between GCS severity and age (1- mild, 2 - moderate, 3 - severe).*

Table 6.
Correlation between midline shift and age group

Midline shift	Age group (years)				*P*-value
	18–35	36–55	56–75	76–95	
Shift up to 10 mm	8	14	8	3	0.01
Shift greater than 10 mm	0	3	11	3	0.02
Total	8	17	19	6	0.013

Discussion

This study aimed to measure the degree of midline shift using CT scan images, and to use that measurement to predict outcomes in patients with head injuries. Of the 50 patients with head injuries, 72% were male and 28% were female. GCS has been widely used to classify severity in head injury patients.

In a previous study by Chiewvit et al.,[14] which included 216 consecutive cases of traumatic head injury, 96 of 216 patients had midline shifts. Of these patients, 53 of 96 had CT scan midline shifting <10mm, whereas 37 of 96 had CT scan midline shifting >10mm. The present study revealed that lower GCS (<12), which indicates severity of head injury, was correlated with a larger degree of midline shift (shift up to 10mm and shift greater than 10mm) and poor clinical outcomes, such as death. This is consistent with previous research. They found that the greater degree of midline shift in patients with brain injuries was statistically significantly correlated with poor final clinical outcomes.[14] It appeared that the probability of a poor outcome was higher when there was a combination of midline shift and other types of intracranial hemorrhage, clinical factors, such as sex, age, and GCS score, and associated injury.

Similar results were demonstrated by Gennarelli et al.[15] and Lobato et al[16], who pointed out that the type of lesion is an important factor in determining the outcome of severity of injury assessed by GCS. In the present study, the degree of midline shift was found to be significantly correlated with GCS score, sex, and age group. This indicates that a larger midline shift tends to be associated with a lower GCS score, male sex, and advanced age.

The results of our study reveal the clinical importance of midline shift with SDH. The outcome is poorest when there is midline shift together with SDH, compared to other lesions in patients with TBI. Reviews by Valadka et al.[6] indicated that treatment of SDH with midline shift was possible in certain cases. It could be successful with smaller hematomas for patients in satisfactory clinical condition, but also for less midline shift in comatose patients where the midline shift was most likely caused by brain edema and there is minimal contribution of brain compression. Another study by Selladurai et al.[17] noticed that the degree of midline shift did not prove to be a significant predictor for all patients with midline shift. Twenty-nine patients (30%) had a GCS score between 12 and 15, while 68 patients (70%) had a GCS score <12, which was the unfavorable group. This indicates that the degree of midline shift did not prove to be of predictive significance for all patients with midline shift.

Conclusion

The present study concluded that increased midline shift based on CT scans in patients with head injuries is related to the severity of head injury (GCS=3–12) and is significantly related to poor final clinical outcome. This is consistent with the results of previous studies. This study also found that greater midline shift tends to be associated with lower GCS scores, and the type of lesion is an important factor in determining the outcome of the severity of injury assessed by GCS. In addition, the degree of midline shift in a patient's brain injury was statistically significant as a determinant of outcome. It appears that the probability of poor outcome is higher when there is a combination of midline shift with other types of intracranial hemorrhage, clinical factors, such as sex, age, GCS score, and associated injury. Ultimately, the outcome was the poorest if there was midline shift with SDH compared to other lesions in patients with brain injuries.

Acknowledgments

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Competing Interests

The authors declare that they have no competing interests.

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