Clinical Neurology and Neurosurgery 217 (2022) 107258

Contents lists available at ScienceDirect

Clinical Neurology and Neurosurgery

journal homepage: www.elsevier.com/locate/clineuro

Determination of bleeding time by hounsfield unit values in computed tomography scans of patients diagnosed with intracranial hemorrhage: Evaluation results of computed tomography scans of 666 patients☆

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ARTICLE INFO

Keywords:
Head trauma
Hounsfield Unit
Intracranial hemorrhage
Computed tomography
HU value

ABSTRACT

Objective: Determining the bleeding time in intracranial hemorrhage patients is one of the most critical parameters in determining the surgical or medical treatment method. Since these are trauma patients, they are essential patients in forensic medicine. In patients where the bleeding time cannot be determined, HU value measurements in CT scans can provide quantitative data. In the radiological follow-up of the patients, only the follow-up of the bleeding volume may be misleading.
Methods: CT scans of patients diagnosed with epidural, acute subdural, and intracerebral hematoma between 2016 and 2021 were evaluated. CT scans were examined in the first 2 h, 2–6 h, 6–12 h, 12–24 h, 24–36 h, 36–48 h, 48–72 h, and 72–96 h. Each time interval obtained the lowest, highest, and average HU values. HU value ranges were defined as the heterogeneity index within the same CT scan.
Results: CT scans of 666 patients were evaluated. In patients with extra-axial hematoma, it was determined that the heterogeneity index increased over time. It was observed that the HU value decreased most slowly in the central part in intra-axial hemorrhages.
Conclusions: HU value measurements in CT imaging can provide quantitative bleeding time and process data. Evaluating only the volumetric increase of the hematoma radiologically may cause erroneous results. HU value measurements are the most rational indicator of new bleeding.

1. Introduction

Intracranial hemorrhages are common diagnoses in neurosurgery and neurology clinics. The time of bleeding is one of the most critical parameters in determining the treatment approach in a patient with intracranial hemorrhage. Acute hematomas are defined as hyperdense in computed tomography (CT) scans. Over time, the hematoma density decreases, and they are defined as hypodense in CT scans [1]. CT is almost always preferred as the first radiological diagnosis method in patients with intracranial hemorrhage [1,2]. Hounsfield Unit(HU) values are frequently used for differential diagnosis of tissues in CT scans. Differential diagnosis can be made between HU values measurements and tissues that are very similar in CT scans, such as adipose tissue and air [3].

HU value can provide quantitative data about the time of bleeding. The HU value quantifies the tissues defined as hyperdense and hypodense in CT scans. Since hematomas transform from hyperdense to hypodense form over time, HU value measurements can describe this transformation quantitatively.

A significant portion of the patients diagnosed with intracranial hemorrhage is diagnosed after forensic events. For this reason, these data can be used both clinically and as auxiliary data to clarify forensic events [4].

For the HU value to be evaluated correctly, the hematoma should be homogeneous and not contain other tissues. HU value measurements may cause incorrect evaluation in patients diagnosed with cerebral contusion or subarachnoid hemorrhage. Since the HU value is the pixel value of a texture, findings such as artifact and swirl sign may cause erroneous evaluation.

This study aimed to obtain the HU values of different bleeding types

Abbreviations: CT, computed tomography; HU, Hounsfield Unit; CSF, cerebrospinal fluid; PACS, Picture archiving and communication system.
☆ Previous Presentations: Any portion of the paper has not been published anywhere.

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https://doi.org/10.1016/j.clineuro.2022.107258
Received 9 February 2022; Received in revised form 15 April 2022; Accepted 17 April 2022
Available online 19 April 2022
0303-8467/

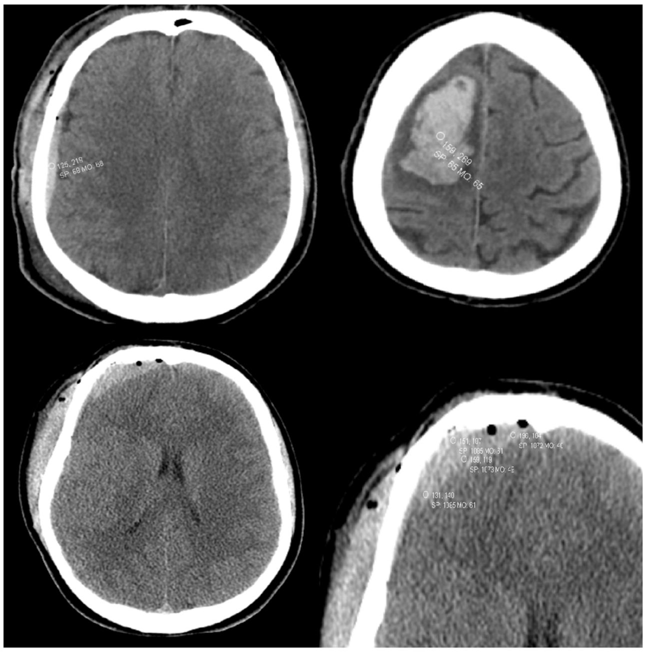

Fig. 1. HU value measurements in different bleeding types at the time of admission.

according to the hours as a table in patients of intracranial hemorrhage and serve as a reference.

2. Methods

Patients diagnosed with epidural, acute subdural, and intracerebral hematoma between 2016 and 2021 were evaluated retrospectively. Demographic data of the patients were obtained by examining the polyclinic and service records. A database file was created by saving the obtained data to an Excel file. In patients with spontaneous intracranial hemorrhage, the onset of symptoms was recorded as the time of onset. In trauma patients, the onset of bleeding at the time of trauma was recorded. Patients who could not obtain information about when intracranial bleeding occurred were excluded from the study.

CT scans of the patients were evaluated on Picture Archiving and Communication System (PACS). Since the HU value will have different values in different regions of the hematoma, HU values were recorded in the superior, inferior, medial, lateral, and central regions. The average sum of the obtained values was formulated in the Excel file, and the average HU value was calculated (Fig. 1).

CT scans were divided into groups as 0–2 h, 2–6 h, 6–12 h, 12–24 h, 24–36 h, 36–48 h, 48–72 h, and 72–96 h. The mean values of HU value measurements in each group were calculated. Among the HU values obtained from each CT scan, the difference between the highest and lowest HU values was calculated and recorded as the heterogeneity index.

Control CTs of these patients were excluded from the study since the HU value would increase in patients with an increase in hematoma size in control CT scans. In addition, patients with intratumoral hemorrhage were not evaluated in the study. Subarachnoid hemorrhage patients were also excluded from the study due to blood and cerebrospinal fluid (CSF) coexistence. In the CT scans of the patients with a cerebral contusion, the parenchymal structure is also included with the blood in the region where HU measurement is made. Therefore, cerebral contusion patients were also excluded from the study.

3. Statistics

After the database was created by saving the patients' data to the Excel file, the mathematical data required for statistical data were transferred to the SPSS22 software, and statistical analyses were carried out. A one-way ANOVA test was used to compare hourly HU values in each group, and $p < 0.05$ was considered statistically significant.

Winautomatization tool software was used to enter data into the database, transfer data to SPSS files, and speed up repetitive computer operations. With this software, macro files were created, data entries were automated, and their accuracy was confirmed by simultaneously checking data entries.

Ethics Committee Approval: Ethics committee application for the study obtained from Kirsehir Ahi Evran University Clinical Research Ethics Committee. Ethics committee Approval No: 2021–11/122.

4. Definition of heterogeneity index and limitations of the study

In patients diagnosed with intracranial bleeding, it is not always possible to know when the bleeding occurs with absolute certainty. It can be known for sure when bleeding occurs in trauma patients, but this is not always valid for patients diagnosed with spontaneous intracranial hemorrhage. There may be a tolerance period in patients with spontaneous intracranial bleeding until symptoms appear. Therefore, there may be a period between bleeding and the onset of symptoms in spontaneous intracranial hemorrhage.

The difference between HU values of different values in different regions of a hematoma indicates the homogeneity of the hematoma. The difference between the highest and lowest HU values in a hematoma was defined as the heterogeneity index. (Mean of highest HU value – Mean of lowest HU value = Heterogeneity index).

HU value measurements of hemorrhages are pixel value measurements. Each pixel can have a different HU value. It is expected that the heterogeneity index will be less in pixels in close neighborhoods. Artifact, swirl sign, parenchymal regions within hematoma may cause erroneous HU values. It is known that the HU value of acute hematomas is between 30 and 70 [3]. For this reason, HU values that are not detected in this range are considered inaccurate measurements and are not taken into account. In order to evaluate HU values within a certain standardization, the average of the highest HU values in 5 different regions was calculated and recorded.

Another method of evaluating HU values of hematoma or parenchymal structures with objective criteria can be considered as

Table 1
Mean HU values of different regions of hematoma according to hours in epidural hematoma patients (h= hours).

	0–2 h. (n = 87)	2–6 h. (n = 67)	6–12 h. (n = 59)	12–24 h. (n = 45)	24–36 h. (n = 38)	36–48 h. (n = 24)	48–72 h. (n = 21)	72–96 h. (n = 18)
Central	67,61 ± 1,74	66,45 ± 2,22	65,51 ± 2,42	64,49 ± 2,13	63,68 ± 2,55	61,50 ± 2,50	57,67 ± 2,08	53,11 ± 2,32
Medial	66,51 ± 1,82	64,91 ± 2,08	64,02 ± 2,03	62,64 ± 1,91	61,95 ± 2,24	60,21 ± 1,98	55,86 ± 1,88	52,44 ± 1,54
Lateral	65,39 ± 1,90	63,92 ± 2,04	62,80 ± 2,03	62,02 ± 1,96	60,66 ± 1,85	59,21 ± 1,79	55,24 ± 2,32	49,89 ± 1,99
Superior	63,61 ± 1,74	62,27 ± 1,65	61,46 ± 1,78	60,44 ± 1,87	59,53 ± 1,64	57,79 ± 1,61	53,33 ± 1,83	49,72 ± 1,41
İnferior	66,95 ± 3,49	67,61 ± 3,49	66,45 ± 3,84	64,89 ± 3,20	64,76 ± 3,67	62,25 ± 3,66	59,19 ± 3,11	54,89 ± 4,16
Heterogenity index	7,32 ± 2,51	7,31 ± 2,76	7,58 ± 2,40	6,67 ± 2,41	7,53 ± 2,23	6,75 ± 2,71	7,33 ± 2,94	7,83 ± 2,79
Mean values	66,23 ± 1,04	65,03 ± 1,06	64,05 ± 1,11	62,90 ± 1,16	62,12 ± 1,23	60,19 ± 1,15	56,26 ± 0,85	52,01 ± 0,84

Table 2
Mean HU values of different regions of hematoma according to hours in acute subdural hematoma patients (h=hours).

	0–2 h. (n = 284)	2–6 h. (n = 195)	6–12 h. (n = 180)	12–24 h. (n = 123)	24–36 h. (n = 97)	36–48 h. (n = 70)	48–72 h. (n = 56)	72–96 h. (n = 51)
Central	68,32 ± 2,29	66,31 ± 2,18	65,22 ± 2,32	64,56 ± 2,05	63,04 ± 2,55	61,29 ± 2,53	57,70 ± 2,10	52,75 ± 2,21
Medial	66,32 ± 1,68	64,74 ± 2,04	63,94 ± 1,83	62,46 ± 1,98	61,69 ± 2,16	60,60 ± 1,97	56,03 ± 1,96	52,39 ± 1,54
Lateral	65,99 ± 1,70	63,74 ± 1,93	62,36 ± 1,95	61,89 ± 1,97	60,80 ± 1,75	59,53 ± 1,67	54,57 ± 2,21	49,76 ± 1,89
Superior	63,43 ± 1,75	62,23 ± 1,61	61,42 ± 1,92	60,08 ± 1,79	59,68 ± 1,62	58,09 ± 1,54	53,34 ± 1,69	49,69 ± 1,39
Inferior	67,35 ± 3,53	67,71 ± 3,40	66,31 ± 3,67	64,98 ± 2,87	65,08 ± 2,91	62,37 ± 3,92	59,36 ± 3,36	54,96 ± 4,01
Heterogenity Index	7,08 ± 2,53	7,23 ± 2,75	7,55 ± 2,28	6,94 ± 2,32	6,90 ± 2,11	6,56 ± 2,97	7,79 ± 2,63	7,84 ± 2,59
Mean values	66,28 ± 0,92	64,95 ± 1,09	63,85 ± 1,03	62,80 ± 1,08	62,06 ± 1,21	60,37 ± 1,29	56,20 ± 0,90	51,90 ± 0,78

Table 3
Mean HU values of different regions of hematoma according to hours in intracerebral hematoma patients (h:hours).

	0–2 h. (n = 295)	2–6 h. (n = 240)	6–12 h. (n = 187)	12–24 h. (n = 95)	24–36 h. (n = 65)	36–48 h. (n = 41)	48–72 h. (n = 28)	72–96 h. (n = 19)
Central	66,30 ± 2,33	64,38 ± 2,28	61,25 ± 2,37	56,38 ± 2,29	52,42 ± 2,24	49,34 ± 2,33	46,21 ± 2,33	43,29 ± 2,12
Medial	65,73 ± 1,74	63,70 ± 1,82	60,84 ± 1,61	55,30 ± 1,91	51,49 ± 1,90	48,24 ± 1,84	45,43 ± 2,15	42,94 ± 2,12
Lateral	64,26 ± 1,81	62,26 ± 1,89	59,27 ± 1,73	53,89 ± 2,01	50,03 ± 2,00	46,63 ± 1,89	44,25 ± 1,96	41,89 ± 1,94
Superior	62,75 ± 1,75	60,64 ± 1,77	57,80 ± 1,74	52,67 ± 1,68	48,60 ± 1,75	45,85 ± 1,64	42,57 ± 1,79	40,21 ± 1,23
Inferior	66,84 ± 4,21	64,93 ± 4,23	61,79 ± 4,17	57,10 ± 4,22	53,12 ± 4,27	50,44 ± 4,32	47,17 ± 4,18	43,37 ± 4,49
Heterogenity Index	7,34 ± 2,38	7,50 ± 2,39	7,19 ± 2,34	7,56 ± 2,45	7,68 ± 2,40	7,59 ± 2,57	7,86 ± 2,38	7,21 ± 2,53
Ortalama	65,18 ± 1,07	63,18 ± 1,07	60,19 ± 1,09	55,07 ± 1,08	51,13 ± 1,06	48,10 ± 1,15	45,13 ± 1,04	42,44 ± 0,93

Table 4
Distribution of mean HU values by the hour in all intracranial hemorrhage patients (h: hours).

	0–2 h. (n = 666)	2–6 h. (n = 502)	6–12 h. (n = 426)	12–24 h. (n = 263)	24–36 h. (n = 202)	36–48 h. (n = 135)	48–72 h. (n = 105)	72–96 h. (n = 88)
Central	67,47 ± 2,58	65,40 ± 2,44	63,52 ± 3,09	61,59 ± 4,47	59,74 ± 5,62	57,70 ± 6,06	53,86 ± 6,62	49,72 ± 5,57
Medial	66,09 ± 1,75	64,26 ± 2,01	62,59 ± 2,35	59,91 ± 3,97	58,46 ± 5,24	56,78 ± 5,98	52,44 ± 6,07	49,26 ± 5,47
Lateral	65,15 ± 1,95	63,06 ± 2,06	61,07 ± 2,45	59,03 ± 4,34	57,30 ± 5,35	55,56 ± 6,17	51,35 ± 6,16	47,18 ± 4,58
Superior	63,15 ± 1,78	61,47 ± 1,87	59,84 ± 2,56	57,47 ± 4,02	56,07 ± 5,42	54,32 ± 5,83	49,74 ± 6,22	46,54 ± 5,48
Inferior	67,07 ± 3,84	66,36 ± 4,06	64,34 ± 4,52	62,12 ± 5,12	61,18 ± 6,59	58,73 ± 6,78	55,24 ± 6,99	51,07 ± 6,67
Heterogenity Index	7,23 ± 2,45	7,37 ± 2,59	7,40 ± 2,33	7,11 ± 2,40	7,28 ± 2,26	6,90 ± 2,83	7,66 ± 2,88	7,62 ± 3,61
Mean Values	65,79 ± 1,14	64,11 ± 1,40	62,27 ± 2,13	60,02 ± 3,89	58,55 ± 5,25	58,61 ± 5,77	52,53 ± 6,41	48,78 ± 5,49

"calculating the histogram values of the hematoma area". However, the presence of parenchymal structures in the measurement areas, artifacts, and hypodense formations such as swirl signs may cause "inaccurate results" in calculating HU value as histogram value.

5. Results

A total of 666 patients matching the study criteria were identified. The mean age of all patients was calculated as 46.39 ± 20.06 years. Four hundred twenty-three patients were male, and 243 patients were female. Eighty-seven patients of epidural hematoma, 284 patients of acute subdural hematoma, 295 patients of intracerebral hematoma, were recorded.

A total of 359 CT scans of 87 patients diagnosed with epidural hematoma were evaluated. In the CT scans evaluated within the first 2 h, the mean HU value was calculated as 66.23 ± 1.04. The mean HU value was higher in the central part of the hematoma (Table 1). The mean HU value decreased over time ($p:<0001$).

A total of 1056 CT scans of 284 patients diagnosed with acute subdural hematoma were evaluated. In the CT scans evaluated within the first 2 h, the mean HU value was calculated as 66.28 ± 0.92. In the first CT scans, the mean HU value was higher in the central part of the hematoma. As time passed, it was determined that the HU value inferior to the hematoma was higher than the other regions. The mean HU value decreased over time ($p:<0001$) (Tables 2 and 3).

A total of 970 CT scans of 295 patients diagnosed with intracerebral hematoma were evaluated. In the CT scans evaluated within the first 2 h, the mean HU value was calculated as 65.18 ± 1.07. In the first CT scans, the mean HU value was higher in the central part of the hematoma. As time passed, it was determined that the HU value in the central part of the hematoma was higher than in the other regions. The mean HU value decreased over time ($p:<0001$).

The distributions of the mean HU values in all intracranial hemorrhage patients according to the hour intervals are shown in Table 4.

6. Discussion

Knowing when bleeding occurs in patients with intracranial hemorrhage is essential for determining the type of treatment. Careful selection of patients eligible for surgery is mandatory. Minimal invasive techniques are valuable surgical options for patients with a poor Glasgow Coma Scale score or harboring large deep-seated hemorrhages [5].

As a general approach, the onset of symptoms is considered to be when bleeding begins. Although this approach is valid for trauma patients, it is not always valid for patients with spontaneous intracranial hemorrhage. The tolerance of intracranial dynamics can have an impact on when symptoms begin. Especially hematomas distant from eloquent areas may prevent the occurrence of symptoms [6,7] Cerebral atrophy may delay the onset of symptoms associated with increased intracranial pressure.

The terms hyperdense, isodense, and hypodense are qualitative definitions in CT scans. However, HU values are quantitative data describing the densities. As a general approach, as hematomas transform into a chronic form, HU values decrease in CT scans [1,3,8].

Fig. 2. Although air and adipose tissue are defined as hypodense on CT, differential diagnosis can be made with HU value measurements.

An essential part of the patients diagnosed with intracranial hemorrhage is related to trauma, accident, or assault. Along with determining the type of treatment, the events also have forensic significance. A direct relationship is established between the time when the intracranial bleeding occurs and the period when the forensic event occurs. For this reason, quantitative evaluation of bleeding values according to time is also important in terms of forensic identification of the event.

The Hounsfield Unit value provides quantitative data to identify tissues, lesions, and even differential diagnoses [9,10] The ranges of these values of the tissues are known. With these values, differential diagnoses of structures of similar density can be made in CT scans [3,11–14] The most typical example is that air and adipose tissue are hypodense on CT scans, but HU values are significantly different. (Fig. 2). The HU value ranges from 1000 for bone, − 1000 for air, 15 for cerebrospinal fluid, and 25–40 for cerebral parenchyma [3].

Intracranial hemorrhages can be evaluated in 2 main groups as intra-axial and extra-axial hematomas. Epidural and subdural hematomas are more homogeneous than intra-axial hemorrhages because they contain only blood components. In intra-axial hemorrhages, parenchymal structures are also present, even though they cannot be detected visually in CT images. For this reason, these value measurements are expected to be more heterogeneous. The most obvious example of this is cerebral contusions [1,15–18]. HU values belonging to the cerebral parenchyma outside the hemorrhage foci may cause erroneous evaluation. The same rationale applies to subarachnoid hemorrhages. Blood mixed with CSF has a more hypodense appearance, resulting in erroneous HU measurement. HU value measurements are the point color value measurement of the pixel evaluated depending on the resolution on the computer. Therefore, measuring one or more HU values of a heterogeneous structure may cause erroneous interpretation. Figs. 3 and 4.

Theoretically, in intra-axial hemorrhages, the bleeding focus is expected to be in the center, and the bleeding is expected to progress circularly towards the periphery. However, the heavy components of the blood are displaced posteriorly, that is, towards the parietal area, since the patients are bedridden due to the effect of gravity. Therefore, the thickest point of the hematoma is usually in the inferior region. For this reason, the HU value at a single point of the hematoma can be interpreted incorrectly. The average HU value measurements in different regions provide a more objective assessment. The difference between HU values obtained from different regions of a hematoma is an indicator of heterogeneity and was defined as the heterogeneity index by the author.

This theory is different for extra-axial hematomas. In extra-axial hematomas, the heavy components of the blood do not spread to the periphery. The heavy components of the blood are more in the inferior due to gravity. The serum component of the blood, which does not contain heavy components, is located superiorly. For this reason, the difference between HU values in the frontal and parietal (superior and inferior) regions is higher. This finding is most typically seen on CT scans of chronic subdural hematomas with an acute component.

The heterogeneity index detected on CT scans in intra-axial hemorrhages increases with time. Less blood remains in the periphery after the hematoma spreads in a circular form. Intra-axial hematomas are resorbed starting from the peripheral region. The central point of the hematoma is usually the last to resorb in intra-axial hemorrhages. For this reason, the heterogeneity index increases as time pass in intra-axial hemorrhages.

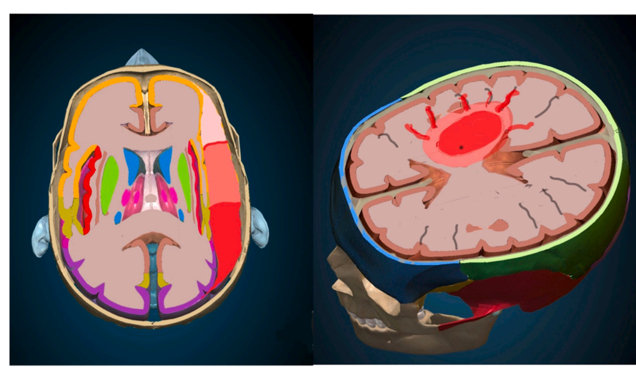

Fig. 4. It has been schematized that peripheral blood resorption is faster in intra-axial hematomas. For this reason, the HU value is higher in the center.

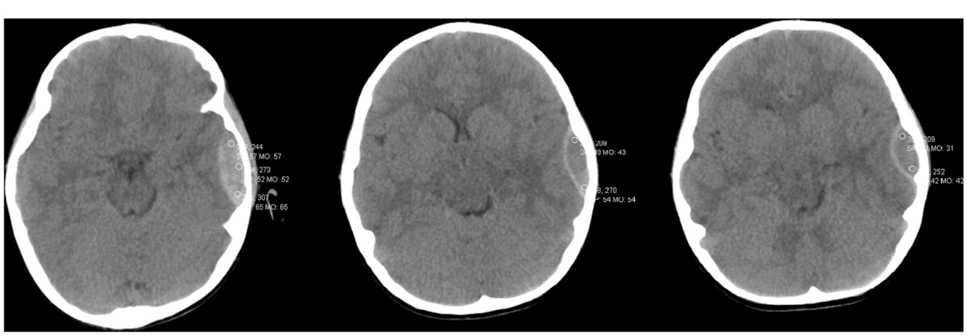

Fig. 3. HU changes in epidural hematoma transforming to the subacute stage. As the hematoma becomes chronic, the HU value in the superior decreases more.

7. Conclusions

Detection of when intracranial hemorrhages occur is one of the most critical markers in determining the treatment approach. It is possible to know when bleeding occurs with Hounsfield Unit measurements. Together with the medical approach, these data can provide quantitative data to determine the bleeding time in forensic patients. In radiological follow-ups, the course of bleeding can be followed quantitatively with Hounsfield Unit measurements.

Conflict of interest

No potential conflict of interest was reported by the author.

Acknowledgments

I would like to thank Omer Asan and Nurhale Asan for their assistance in editing and proofreading the article, and Oznur Tekin and Ayla Avsar, who contributed to the data collection and statistical stages.

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