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Femoral Neck Fractures: A New Risk Assessment Method Using CT Hounsfield Measurement

Femur Boyun Kırıkları: BT Hounsfield Ölçümü ile Yeni Bir Risk Değerlendirme Yöntemi

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Abstract

Objective: Hip fractures, which are a serious consequence of osteoporosis, lead to a decrease in life expectancy. Computed tomography (CT) Hounsfield unit (HU) measurements have been clinically utilized to assess fracture risk.
Materials and Methods: This retrospective study, conducted between 2020-2023, analyzed 99 patients with femoral neck fractures and 62 controls who underwent pelvic CT. Two radiologists conducted bone density measurements using CT, with specific measurements at the femoral head, fracture level, and lesser trochanter. Statistical analyses, including Mann-Whitney U tests, Wilcoxon tests, chi-square tests, ROC curve analysis, and logistic regression analysis, were performed using SPSS version 28.0.
Results: The study revealed significant differences in bone density measurements between the fractured and control groups. Proximal, middle, and distal values demonstrated significant differences in distinguishing between patients with and without fractures. The distal measurement was the most effective measure, with an area under the curve of 0.918.
Conclusion: This study emphasizes the potential of CT HU measurements for predicting femur fracture risk, particularly the distal measurement at the minor trochanter level. Further research with larger samples and comparisons with other methods, such as dual X-ray absorptiometry or quantitative CT, are needed to validate these findings and their clinical significance.
Keywords: Bone density, computed tomography, femur, Hounsfield unit, osteoporosis

Öz

Amaç: Osteoporozun ciddi bir sonucu olan kalça kırıkları, beklenen yaşam süresinde azalmaya yol açmaktadır. Bilgisayarlı tomografi (BT) Hounsfield ünitesi (HU) ölçümleri kırık riskini değerlendirmek için klinik olarak kullanılmaktadır.
Gereç ve Yöntem: 2020-2023 yılları arasında gerçekleştirilen bu retrospektif çalışmada, femur boynu kırığı olan 99 hasta ve pelvik BT çekilen 62 kontrol hastası analiz edildi. İki radyolog, BT taramalarını kullanarak femur başı, kırık seviyesi ve küçük trokanterde spesifik ölçümler ile kemik yoğunluğu ölçümleri yaptı. İstatistiksel analizler, Mann-Whitney U testleri, Wilcoxon testleri, ki-kare testleri, ROC eğrisi analizi ve lojistik regresyon analizi dahil olmak üzere, SPSS 28.0 sürümü kullanılarak gerçekleştirildi.
Bulgular: Çalışma, kırık ve kontrol grupları arasında kemik yoğunluğu ölçümlerinde anlamlı farklılıklar olduğunu ortaya koydu. Proksimal, orta ve distal değerler, kırığı olan ve olmayan hastaları ayırt etmede önemli etkiler göstermiştir. Distal ölçümün 0,918'lik eğri altındaki alan ile en etkili ölçüm olduğu kanıtlanmıştır.
Sonuç: Bu çalışma, BT HU ölçümlerinin femur kırığı riskini öngörmedeki potansiyelini, özellikle de minör trokanter seviyesindeki distal ölçümü vurgulamaktadır. Bu bulguların ve klinik önemlerinin doğrulanması için daha büyük örneklemlerle yapılacak araştırmalara ve dual X-ray absorbsiyometri veya kantitatif BT gibi diğer yöntemlerle karşılaştırmalara ihtiyaç vardır.
Anahtar kelimeler: Kemik yoğunluğu, bilgisayarlı tomografi, femur, Hounsfield ünitesi, osteoporoz

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Introduction

As the population ages, osteoporosis has become a global health problem, affecting more than 200 million people worldwide (1). Low bone mineral density is a disease of the skeletal system that leads to fractures as a result of deterioration in the microarchitecture of bone. It is silent until a fracture occurs. Osteoporotic hip fractures cause a 20% decrease in life expectancy and approximately half of the patients become dependent on walking in their later life (2,3). The rate of hospitalization due to hip fracture is high in the elderly population and the most common cause is low-energy trauma such as simple falls. Hip fractures and other accompanying comorbidities impose a great burden on both the patient and the healthcare system. Therefore, it is very important to detect osteoporosis before fracture and to take the appropriate precautions (4). Dual-energy x-ray absorptiometry (DXA) is currently considered the gold standard for quantifying bone mineral density and has been shown to have a strong correlation with fracture risk and the efficacy of therapeutic treatments (5). However, in patients over 65 years of age, DXA is performed in approximately 30% of women and approximately 4% of men. In addition, some of the fractures occur in the osteopenia stage. For this reason, computed tomography (CT), which is one of the alternative methods, can be seen as an opportunity for osteoporosis screening (6). CT value measurements have been used clinically to assess fracture risk for patients (7-9).

The primary aim of our study was to investigate the potential of CT density measurements to assess the risk of femur fracture in elderly patients and to investigate whether we can make a preliminary assessment of fracture risk.

Materials and Methods

Our study was retrospective and was approved by the University of Health Sciences Turkey, Ümraniye Training and Research Hospital, Clinical Research Ethics Committee (number: B.10.1.TKH.4.34.H.GP.0.0.01/462, date: 23.11.2023). Between January 2020 and August 2023, 99 patients with femoral neck fractures admitted to our hospital were included. Patients who were over 55 years of age, had femoral neck fractures secondary to low-energy trauma, and underwent CT scans in the acute period (first 24 hours) were included in the study. Patients with major trauma, endocrine and metabolic diseases affecting bone mineral density, pathological fractures (osteomyelitis or multiple myeloma), metal implants, and unilateral CT scans were excluded. As a control group, 62 patients who underwent pelvic CT for another reason and did not have a femur fracture were evaluated.

All CT scans were performed in the same 128-multidetector CT scanner, GE Healthcare, without using contrast media. All bilateral measurements in the patient and control groups were performed by two radiologist (10 and 21 years experience) independently. A 1.00 cm^2± 3.00 cm^2 elliptical ROI was used to assess bone mineral density. Measurements were taken at the level of the femoral head, fracture level, and lesser trochanter. The region of interest (ROI) was placed to include trabecular bone and marrow, avoiding cortical bone. The mean density for each measurement was recorded in Hounsfield units (HUs) (Figure 1-3). The measurement taken at the level of the femoral head is referred to as "proximal", measurement taken excluding the fracture site is labeled as "middle", and measurement taken at the level of the lesser trochanter is termed "distal".

Statistical Analysis

Mean, standard deviation, median, minimum, maximum value frequency, and percentage were used for descriptive statistics. The distribution of variables was checked with the Kolmogorov-Smirnov test. Mann-Whitney U test was used for the comparison of quantitative data. Wilcoxon test was used for the repeated measurement analysis. The chi-square test was used for the comparison of the comparison of qualitative data. We used the intraclass correlation efficient (ICC) test to evaluate the interrater reliability for the measurements of two reviewers. ROC analysis was used to show the effect level. Logistic regression analysis was used to show the effect level. SPSS 28.0 was used for statistical analysis.

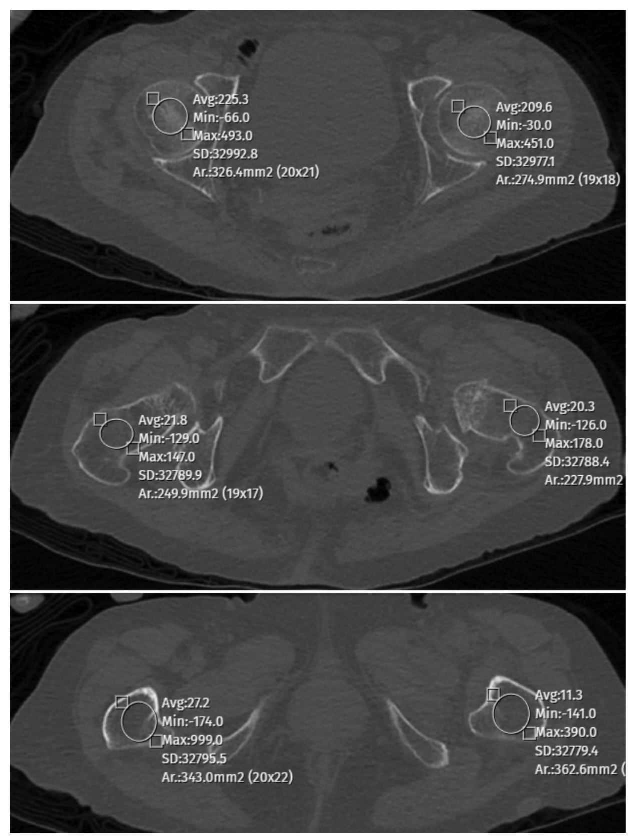

Figure 1-3. Examples of ROI, each 1.00-3.00 cm^2 in size and elliptical in shape, were outlined at three locations: proximally in the femoral head (proximal), at the site of the fracture (middle), and distally at the level of the lesser trochanter (distal). It's important to note that similar analyses were performed on the contralateral, non-fractured side, as well as bilaterally on the control patients

Results

The analysis of our study revealed intriguing findings regarding femur density measurements and their association with fracture risk. The ICC values showed high reliability at all measured levels, indicating strong agreement between the two graders. Specifically, the ICC for the proximal level was 0.852 (95% CI: 0.820 to 0.880, p<0.001), for the mid level was 0.869 (95% CI: 0.840 to 0.895, p<0.001), and for the distal level was 0.883 (95% CI: 0.860 to 0.904, p<0.001). The average ICC across all levels was 0.868 (95% CI: 0.845 to 0.890, p<0.001), demonstrating the reliability and repeatability of the measurements in assessing bone quality.

When comparing patients with and without fractures, there were no significant differences in age and gender distribution (p>0.05) (Table 1). In the fractured group, the proximal value was significantly lower than the control group (p<0.05), and it was also lower than the non-fractured side (p<0.05). Similarly, in the fractured group, the middle and distal values were significantly lower than the control group (p<0.05) and the non-fractured side (p<0.05) (Table 1). The results of logistic regression analysis show that decreased density values in the proximal, middle and distal regions of the femur are statistically significant in the assessment of femur fracture risk. Proximal and middle density values had similar effects [odds ratio (OR)=0.980 and OR=0.976, respectively; p<0.001], whereas distal density values were associated with a more significant decrease (OR=0.959; p<0.001). Especially the decrease in distal zone density value has a critical importance in predicting fracture risk (Table 2).

In the ROC curve analysis, the area under the curve (AUC) value obtained for the distal femur showed the highest accuracy in relation to fracture risk with 0.918 (95% CI: 0.875-0.961; p<0.001). On the other hand, the AUC values of the proximal and middle regions were calculated as 0.836 and 0.765, respectively, and although these measurements contribute to the assessment of risk, they are not as decisive as the distal measurement. Specifically, the distal value demonstrated significant independent effectiveness (p<0.05) in distinguishing between patients with and without fractures (Table 3). These results demonstrate the importance of the distal region in predicting the risk of femur fracture.

Analysis based on cut-off values revealed that the distal femur region, with a cutoff value >83.5, demonstrated a sensitivity of 82.8%, positive predictive value (PPV) of 92.1%, specificity of 88.7%, and negative predictive value (NPV) of 76.4%, marking it as the most accurate predicting the risk of femur fractures. In the proximal region, with a cutoff >282, sensitivity was 74.7% and specificity was 79.0%; whereas in the middle region, with a cut-off >93.5, sensitivity reached 87.9% but specificity was at 53.2%. The high PPV and NPV values in the distal region underscore its reliability in assessing fracture risk. (Table 4).

Discussion

Osteoporosis, a condition characterized by decreased bone mass and structural deterioration, poses a significant public health concern globally due to its association with an increased risk of fractures, particularly in weight-bearing bones like the femur (10).

Table 1. The results obtained from the fixed region of interest (ROI) measurements are presented in this table, showing the mean and standard deviation values for the average Hounsfield unit (HU) densities measured both proximal, middle and distal on both sides in both the case and control groups

		Fracture (+)			**Fracture (-)**			
		Mean ± SD / n%		**Median**	**Mean ± SD / n%**		**Median**	**p-value**
Age		77.1±12.7		80.0	75.1±8.6		78.0	0.081[m]
Gender	Female	69	69.7%		35	56.5%		0.087[X2]
	Male	30	30.3%		27	43.5%		
Proximal								
Fracture side		232.3±67.2		229.0	324.6±67.4		332.0	**0.000**[m]
Other side		267.5±66.4		264.0				**0.000**[m]
Intra group p		**0.000**[w]						
Middle								
Fracture side		57.1±35.8		50.0	97.6±44.2		99.0	**0.000**[m]
Other side		44.7±32.9		41.0				**0.000**[m]
Intra group p		**0.002**[w]						
Distal								
Fracture side		49.9±37.3		40.0	138.5±52.7		136.5	**0.000**[m]
Other side		70.3±43.5		65.0				**0.000**[m]
Intra group p		**0.000**		[w]				

[m]Mann-whitney u test, [X2]Chisquare test, [w]Wilcoxon test

Table 2. Univariate and multivariate models showing odds ratios (OR), 95% confidence intervals (CI), and p values for proximal, middle, and distal regions in logistic regression analysis

	Univariate model				Multivariate model		
	OR	%95 CI	p-value		OR	%95 CI	p-value
Proximal	0.980	0.974-0.987	**0.000**				
Middle	0.976	0.967-0.985	**0.000**				
Distal	0.959	0.948-0.971	**0.000**		0.959	0.948-0.971	**0.000**

Logistic Regression (Forward LR)

Table 3. Area under the curve (AUC) values with 95% confidence intervals (CI) and p values for the distal, proximal and middle regions in the ROC curve analysis

	AUC	% 95 CI	p-value
Distal	0.918	0.875-0.961	**0.000**
Proximal	0.836	0.771-0.901	**0.000**
Middle	0.765	0.689-0.841	**0.000**

ROC Curve

Table 4. Sensitivity, positive predictive value (PPV), specificity and negative predictive value (NPV) for the distal, proximal and middle regions in the fracture (-) and fracture (+) groups based on a comparison of cut-off values

		Fracture (-)	Fracture (+)	Sensitivity	PPV	Specificity	NPV
Distal	>83.5	**55**	17	82.8%	92.1%	88.7%	76.4%
	≤83.5	7	**82**				
Proximal	>282	**49**	25	74.7%	85.1%	79.0%	66.2%
	≤282	13	**74**				
Middle	>93.5	**33**	12	87.9%	75.0%	53.2%	73.3%
	≤93.5	29	**87**				

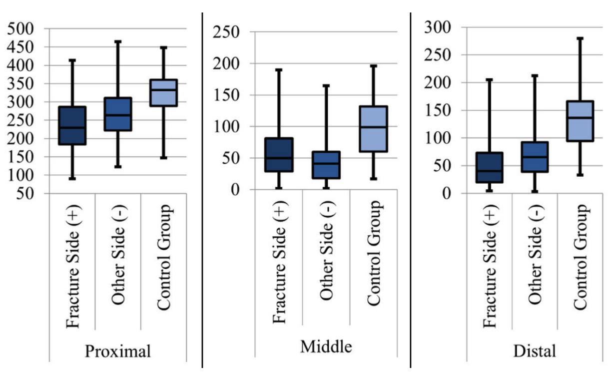

Figure 4. Box-and-whisker plots illustrating the Hounsfield Unit (HU) densities of both the case and control groups are provided, depicting the distributions of these densities, including any outliers, in the regions proximal, middle, and distal

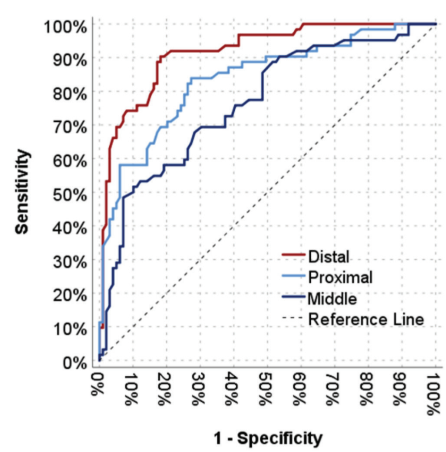

Figure 5. Sensitivity, specificity and PPV/NPV for fractures and anatomcal areas

Femoral neck fractures, which occur with minor trauma in the elderly population, are a major problem for both the patient and the healthcare system. Although DXA is the gold standard for diagnosis and screening, it is still not common enough. In CT taken for any other reason, radiologists can determine which patients are at high risk of femur fracture and benefit from DXA scanning by measuring bone density with the HU. This allows clinicians to diagnose osteoporosis earlier and treat it more effectively (11-13). In the field of radiology, the term opportunistic imaging refers to an application that is not related to clinical symptoms, but is usually performed for the purpose of preventing a disease and creating a risk profile or detecting the relevant disease without symptoms by utilising the imaging data

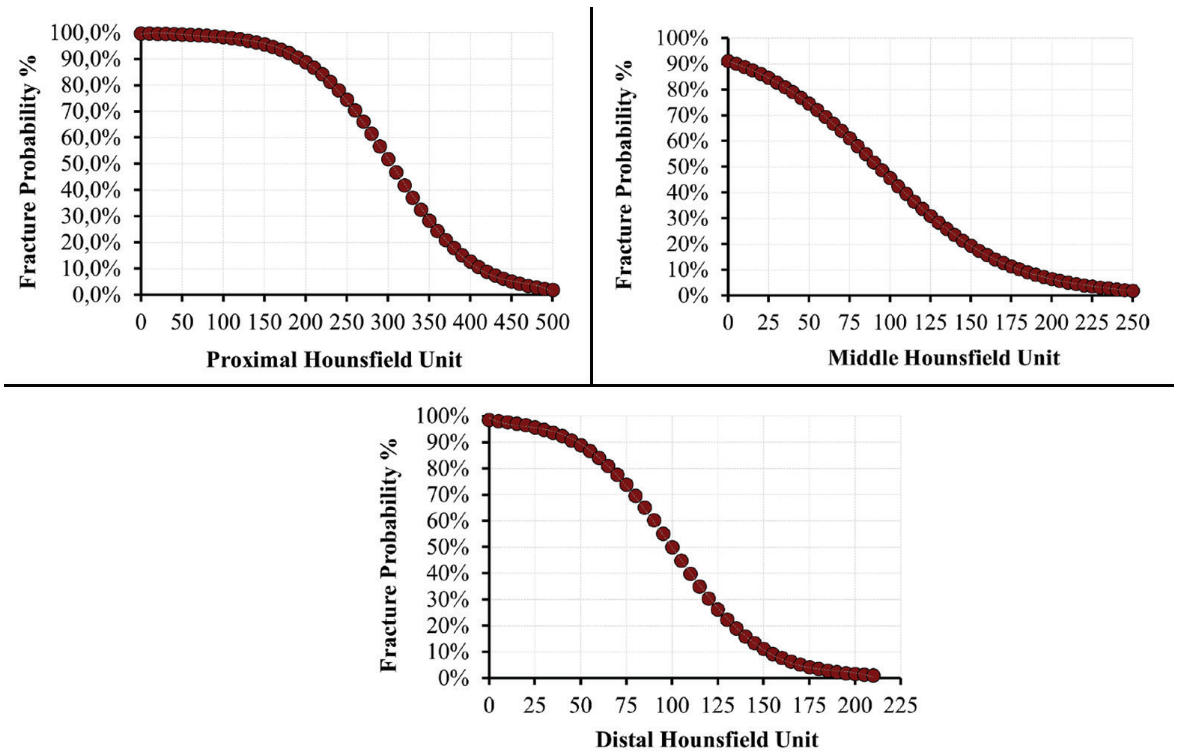

Figure 6-8. Relationship between the density values of the proximal, middle and distal femur and the probability of fracture

obtained. In this context, most studies have been conducted in the field of osteoporosis screening.

There are many studies that evaluate the risk of bone fracture with opportunistic BT. These studies are mainly related to vertebral bone and compression fractures (14-20). Numerous studies have shown that proximal femur density measurements correlate strongly with the femoral neck T-score. This measurement shows that patients with osteoporosis can be detected by opportunistic imaging and CT density assessment can be used in clinical practice.

Our study investigates the direct correlation between neck fractures and bone density by analyzing CT HU values and their crucial role in fracture risk assessment.

The absence of significant differences in age and gender distribution between fractured and non-fractured groups underscores the specificity of our findings, emphasizing the unique relevance of femur density measurements in fracture risk assessment.

The proximal measurement, notably lower in the fractured group, signifies the vulnerability of the femoral head, a region crucial for weight-bearing and mobility. The middle measurement, reflecting density in the femoral neck, further accentuates the complexity of fracture risk assessment. However, it is the distal measurement showcasing remarkable effectiveness in distinguishing between fractured and non-fractured patients.

Narayanan et al. (21)'s study showed that the patient group's density measurement at the level of the fractures was significantly higher than that of the non-fractured side. This is thought to be caused by trauma-related hemorrhage and an increase in trabecular bone density associated with a fracture. In our study, the density measurement on the fractured side was significantly lower than on the opposite side. This finding may be associated with the time that has passed from the fracture to the CT. In our study, CT was performed during the acute period (the first 24 hours). Therefore, the density increase may not be high.

Ye et al. (22) analysed 680 patients and proved that the proximal femur CT HU value correlated well with the femoral neck t-score and the lower the density value on CT, the worse the bone quantity. Based on this evidence, we have demonstrated the difference in CT density in the fracture and non-fracture groups and suggest that CT HU values may also play an important role in predicting osteoporosis and fracture risk. In addition to this study, we wanted to investigate which femur level density measurements would be more instructive.

Christensen et al. (23) similarly investigate the potential of opportunistic screening to address the increasing problem of osteoporosis. They demonstrate that proximal femur CT HU measurement correlates positively with DXA results regardless of age and time difference between scans. These findings support the wide applicability of HU measurements in osteoporosis screening.

In the context of osteoporosis, our study's findings gain heightened relevance. Osteoporotic fractures, often linked to diminished bone mineral density, lead to substantial morbidity and mortality, imposing a considerable burden on healthcare systems. The efficacy of femur density measurements, particularly the distal value, in predicting fractures could revolutionize osteoporosis management. Our study shows that the density of 83.5 HU at the lesser trochanter level has high sensitivity and specificity in determining the risk of fractures. Ye et al. gave a cut-off value of 67 HU, Christensen et al. (23) did not give a cut-off but stated the mean density as 56±29 HU. These values are similar to our results.

Our study has several important limitations. First, the study was retrospective and performed in a single centre. Second, HU measurements could not be compared with DXA or QCT because CT examinations performed under emergency conditions were evaluated. This limits the opportunity to verify the accuracy of the measurements. Thirdly, as the patients did not have regular follow-up imaging, changes in the interval period could not be analysed. This prevents us from obtaining information about long-term results and changes in bone density. Fourth, the number of patients is small and limited due to our current inclusion criteria. This may raise questions about its applicability to the general population. Although HU values were lower in patients with fractures than in patients without fractures in our study, it should be taken into consideration that the measurements obtained from different CT devices may be different. Therefore, studies using different CT devices, larger patient population and collecting data from different centres group may improve the accuracy and applicability of our results.

In conclusion; our study suggests a low attenuation value associated with the femoral fracture in elderly patients. Our findings may be integrated into existing osteoporosis diagnostic protocols and the HU values obtained from CT scans may allow the identification of patients at high risk of fracture. This may be considered as a complement to DXA scans. In addition, evaluation of CT imaging obtained during emergency department visits in this respect offers a proactive screening opportunity especially for elderly patients at high risk for osteoporotic fractures. In conclusion, the results of our study provide valuable information that will support clinical decision-making processes and provide opportunities for further research in the field of osteoporosis screening and management.

Conclusion

In conclusion, this study highlights the potential for the use of opportunistic CT imaging in the early diagnosis and management of osteoporosis. Our findings suggest that HU values obtained on CT examinations may be a valuable tool to rapidly and practically identify elderly patients, especially those at high risk of fracture, thus contributing to the reduction of fracture-related morbidity and mortality.

Ethics

Ethics Committee Approval: Our study was retrospective and was approved by the Ministry of Health Istanbul Health Sciences University Umraniye Training and Research Hospital Clinical Research Ethics Committee (number: B.10.1.TKH.4.34.H.GP.0.0.01/462, date: 23.11.2023).

Informed Consent: Since this study was retrospective, patient consent was not required.

Footnotes

Authorship Contributions

Surgical and Medical Practices: S.N.E., S.S.D.B., Concept: S.N.E., S.S.D.B., Design: S.N.E., Data Collection or Processing: S.N.E., S.S.D.B., Analysis or Interpretation: S.N.E., S.S.D.B., Literature Search: S.N.E., S.S.D.B., Writing: S.N.E.

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