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Incidence, characteristics, and treatments of traumatic open fractures in children and adolescents

A retrospective observational study

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Abstract

We aimed to investigate the incidence, characteristics, and treatments of open fractures in children and adolescents (≤18 years old).

We retrospectively reviewed the records of 2418 children and adolescents who presented with traumatic fractures and were admitted to our university-affiliated hospitals, among which 206 patients (8.5%) presented with open fractures. The patients' clinical and radiographic records were reviewed, and the age, gender, cause of injury, injury season, injury week, associated injuries and complications were collected.

This study enrolled 1789 males (74.0%) and 629 females (26.0%) with an average age of 11.2 ± 5.0 years. The patients were divided into an open fracture group (OF group, n = 206) and a group with no open fracture (No-OF group, n = 2212). There were 206 patients (8.5%) who presented with open fractures and the most common fracture sites were the tibia (31.1%, 64/206) and fibula (20.9%, 43/206). The patients in the OF group presented with higher frequency of emergency admission ($P < 0.001$), self-supporting medical insurance ($P < 0.001$), MVCs ($P < 0.001$), wounded by machine ($P < 0.001$), struck by object ($P < 0.001$), hurt/cut by others ($P < 0.001$), lower limb fractures ($P < 0.001$), multiple fractures ($P = 0.010$), associated injuries ($P < 0.001$) and wound infection ($P = 0.003$) then the patients in the No-OF group. The most common complication were wound infection (5.8%) and pneumonia (1.0%) in the OF group, wound infection (2.1%) and pressure sores (2.0%) in the No- OF group. Multivariate logistic regression analysis indicated that mechanical trauma (OR = 64.229, $P < 0.001$), being hurt/cut by others (OR = 26.757, $P < 0.001$), and being struck by an object (OR = 15.345, $P < 0.001$) were stronger risk factors for open fracture than were low falls; additionally, lower limb fractures (OR = 5.970, $P < 0.001$), upper limb fractures (OR = 5.865, $P < 0.001$) and multiple fractures (OR = 5.414, $P < 0.001$) were stronger risk factors than craniofacial fractures for open fractures. The frequency of surgical treatment for the patients with traumatic open fractures (87.9%, 181/206) was significantly higher than those without open fractures (72.2%, 1596/2212) ($P < 0.001$). The hospital stays and fees for surgical treatment for the patients with traumatic open fractures were significantly higher than those without open fractures ($P < 0.001$).

Etiology (especially being injured by a machine or being hurt/cut by others) and the fracture site (including lower limb fractures and upper limb fractures) were independent risk factors for open fractures. Traumatic open fractures presented with higher surgical treatment rate, hospital stays and fees.

Abbreviations: ASOIs = associated injuries, CFFs = craniofacial fractures, CT = computed tomography, LLFs = lower limb fractures, MFs = multiple fractures, MRI = magnetic resonance imaging, MVCs = motor vehicle collisions, NIs = nerve injuries, OFs = open fractures, RSFs = fractures of rib and sternum, SFs = spinal fractures, SD = standard deviation, TFs = traumatic fractures, ULFs = upper limb fractures, VIs = visceral injuries.

Keywords: adolescent, children, fracture, open fracture, traumatic

Hongwei Wang, Hong Yuan, and Lu Liu contributed equally to this work.

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1. Introduction

Fractures account for 10% to 25% of paediatric injuries.[1,2] The patterns of fractures vary between countries and even between regions within a country, depending on the local climate, culture, and leisure-time activities.[3–8] The epidemiology of paediatric open fractures (OFs) is still not completely understood. The incidence varies from centre to center, the OFs comprise 2% to 9% of all paediatric fractures.[9–12] Data about the incidence, characteristics and treatments of OFs in children and adolescents (≤18 years old) in China are scarce. It is very important to investigate the incidence, characteristics and treatments of OFs. At the same time, we discuss the associated injuries and complications, which is helpful for discussing the early, timely diagnosis and treatment. It is important for the allocation of public resources, the development of preventative strategies and efficient diagnosis and treatment.

In the present study, we reviewed a multicentre (2 tertiary hospitals in Chongqing, China) database of TFs (traumatic fractures) in a population of children and adolescents ≤ 18 years of age to address these deficiencies and to provide comprehensive information on this important childhood public health problem in China. Three topics have been discussed in depth: (1) Incidence and characteristics (including associated injuries and complications) of traumatic OFs in children and adolescents (≤18 years old); (2) Risk factors for traumatic OFs in children and adolescents (≤18 years old); (3) Treatments of traumatic OFs (including treatment technique, intensive care unit stays, hospital stays and fees).

2. Materials and methods

2.1. Study population

We have searched 2505 patients from a population of children and adolescents (≤18 years old) who had TFs between January 2013 and December 2020 and who were admitted to our university-affiliated hospitals. We used X-rays, computed tomography (CT) and magnetic resonance imaging (MRI) to make definitive diagnoses of TFs in patients who were children or adolescents (≤18 years old). The medical records were reviewed and assessed by 2 independent persons who did not participate in treating any of the patients. The inclusion criteria for patients in this study were as follows: (i) patients who presented with fractures on X ray, CT, and/or MRI and (ii) hospitalization for the treatment of TFs between January 2013 and December 2020. The exclusion criteria were as follows: (i) patients with pathologic fractures and (ii) repeated hospitalizations due to injuries at the same fracture site. There were 73 cases with pathologic fracture and 14 cases with repeated hospitalizations due to injuries at the same fracture site were excluded. Finally, our study included 2418 patients who had TFs between January 2013 and December 2020.

2.2. General characteristics

The patients were classified into 3 age groups: ≤6 years old (neonatal period, infancy stage, toddler period, and preschool period), 6 to 12 years old (junior middle school stage) and 12 to 18 years old (senior high school stage). The patients were also classified into 7 groups based on the etiology of the trauma: motor vehicle collisions (MVCs), high fall (fall from a high height ≥2 m unrelated to MVCs), low fall (fall from a high height <2 m unrelated to MVCs), injured by a machine, struck by an object, hurt/cut by others and other etiologies. The sites of fractures included lower limb fractures (LLFs), upper limb fractures (ULFs), craniofacial fractures (CFFs), spinal fractures (SFs), fractures of rib and sternum (RSFs) and multiple fractures (MFs). The sites of the lower limb fractures (LLFs) were classified as the femur, tibia, fibula, pelvis and foot. The sites of the upper limb fractures (ULFs) were classified as the humerus, radius, ulna, clavicle, scapula and hand.

2.3. Associated injuries and complications

Associated injuries (ASOIs) include head injury, lung injury, renal injury, hemorrhagic shock, osteofascial compartment syndrome, retroperitoneal hematoma and so on. Complications included fracture malunion, fracture nonunion, delayed union, fracture site infection, decubitus ulcers, traumatic arthritis, deep vein thrombosis, and so on. Visceral injuries (VIs) included craniocerebral injury, intrathoracic injuries and intraabdominal injuries. Nerve injuries (NIs) included central nervous system injury (traumatic brain injury and spinal cord injury) and peripheral nerve injury (cranial nerve injury and spinal nerve injury). The study protocol and this manuscript were approved by the ethics committee and the institutional review board of our institution.

2.4. Statistical analysis

All statistical analyses were performed using SPSS version 22.0 (SPSS, Inc., Chicago, IL). We used Pearson chi-square tests to assess differences in age, sex distribution and clinical characteristics between the 2 groups of patients with and without open fractures. Continuous variables such as current age were examined using the 1-sample Kolmogorov-Smirnov test for normally distributed variables; these variables are expressed as the mean ± standard deviation (SD). Differences in the continuous variables between the 2 groups were evaluated using independent samples *t*-tests. Univariate and multivariate logistic regression analyses were used to evaluate associations between the clinicopathological features and the prevalence of open fractures.

3. Results

3.1. General characteristics of traumatic fracture

This study enrolled 1789 males (74.0%) and 629 females (26.0%) with an average age of 11.2 ± 5.0 years old. Overall, the most common etiologies were low falls (42.5%, 1027/2418), followed by MVCs (29.5%, 713/2418) and high falls (14.4%, 348/2418). Among all the patients, the most common fracture sites were ULFs (38.9%, 940/2418) and LLFs (31.3%, 758/2418), followed by CFFs (17.7%, 427/2418). A total of 645 (26.7%) patients sustained ASOIs, and 197 (8.1%) patients had experienced complications (Table 1).

The etiologies such as being injured by a machine, being hurt/cut by others and being struck by object accounted for 2.0% (48/2418), 3.1% (74/2418), 4.2% (101/2418). Among the patients injured by a machine, 30 persons (62.5%, 30/48) injured during working. Among the patients struck by object, 22 persons (21.8%, 22/101) injured during working. Among the patients hurt/cut by others, 24 persons (32.4%, 24/74) were cut by others (Table 2).

3.2. Incidence and characteristics of traumatic open fracture

There were 206 patients (8.5%) who presented with an open fracture: 94 patients had an open fracture on the left side (45.6%), 105 patients had an open fracture on the right side (51.0%), and 7 patients had open fractures on both sides (3.4%). Overall, the most common etiologies were MVCs (45.6%, 94/206), followed by being injured by a machine (13.1%, 27/206). The most common fracture sites were lower extremity fractures (55.3%, 114/206) and upper extremity fractures (44.7%, 92/206). The most common fracture sites were

Table 1

General characteristics of traumatic fractures and open fracture.

	Total	OF group	No-OF group	χ^2	*P*
Total	2418	206	2212		
Gender					
Male	1789(74.0)	148(71.8)	1641(74.2)	0.537	0.464
Female	629(26.0)	58(28.2)	571(25.8)		
Admission to hospital					
Emergency admission	1098(45.4)	147(71.4)	951(43.0)	60.032	<0.001
Outpatient admission	1320(54.6)	59(28.6)	1261(57.0)		
Medical insurance					
Self-supporting	1376(56.9)	149(72.3)	1227(55.5)	21.162	<0.001
Medicare	1042(43.1)	57(27.7)	985(44.5)		
Age	11.2 ± 5.0	11.8 ± 5.2	11.1 ± 5.0		
0–6	550(22.7)	45(21.8)	505(22.8)	3.448	0.178
6–12	764(31.6)	55(26.7)	709(32.1)		
12–18	1104(45.7)	106(51.5)	998(45.1)		
Injury season					
Spring	608(25.1)	49(23.8)	559(25.3)	0.354	0.949
Summer	657(27.2)	59(28.6)	598(27.0)		
Autumn	629(26.0)	53(25.7)	576(26.0)		
Winter	524(21.7)	45(21.8)	479(21.7)		
Injury week					
Monday	353(14.6)	26(12.6)	327(14.8)	6.419	0.378
Tuesday	358(14.8)	36(17.5)	322(14.6)		
Wednesday	346(14.3)	30(14.6)	316(14.3)		
Thursday	330(13.6)	22(10.7)	308(13.9)		
Friday	348(14.4)	29(14.1)	319(14.4)		
Saturday	345(14.3)	38(18.4)	307(13.9)		
Sunday	336(13.9)	25(12.1)	311(14.1)		
Injury cause					
MVCs	713(29.5)	94(45.6)	619(28.0)	27.384	<0.001
Wounded by machine	48(2.0)	27(13.1)	21(0.9)	136.974	<0.001
High fall (≥2m)	348(14.4)	23(11.2)	325(14.7)	1.628	0.202
Low fall (<2m)	1027(42.5)	21(10.2)	1006(45.5)	94.588	<0.001
Struck by object	101(4.2)	20(9.7)	81(3.7)	15.738	<0.001
Hurt/cut by others	74(3.1)	17(8.3)	57(2.6)	18.593	<0.001
Others	107(4.4)	4(1.9)	103(4.7)	2.673	0.102
ASOIs -fracture					
LLFs	758(31.3)	90(43.7)	668(30.2)	15.315	<0.001
ULFs	940(38.9)	75(36.4)	865(39.1)	0.469	0.493
CFFs	427(17.7)	13(6.3)	414(18.7)	19.101	<0.001
SFs	78(3.2)	0(0)	78(3.5)	6.419	0.011
RSFs	8(0.3)	0(0)	8(0.4)	0.053	0.818
MFs	207(8.6)	28(13.6)	179(8.1)	6.597	0.010
ASOIs -VIs					
Craniocerebral injury	293(12.1)	18(8.7)	275(12.4)	2.081	0.149
intrathoracic injuries	76(3.1)	5(2.4)	71(3.2)	0.166	0.684
intraabdominal injuries	45(1.9)	4(1.9)	41(1.9)	0.008	0.929
ASOIs -NIs					
Craniocerebral injury	293(12.1)	18(8.7)	275(12.4)	2.081	0.149
Spinal cord injury	45(1.9)	2(1.0)	43(1.9)	0.517	0.472
Cranial nerve	25(1.0)	0	25(1.1)	1.378	0.241
Spinal nerve	127(5.3)	33(16.0)	94(4.2)	50.121	<0.001
Coma after injury	224(9.3)	16(7.8)	208(9.4)	0.421	0.516
ASOIs	645(26.7)	88(42.7)	557(25.2)	29.633	<0.001
Main complications					
Deep venous thrombosis	1(0.04)	0	1(0.04)	0.000	1.000
Pneumonia	15(0.6)	2(1.0)	13(0.6)	0.042	0.837
Pressure sores	5(0.2)	0	5(2.0)	0.000	1.000
Wound infection	60(2.5)	12(5.8)	48(2.1)	8.949	0.003
Complications	197(8.1)	17(8.3)	180(8.1)	0.003	0.954

ASOIs = associated injuries, CFFs = craniofacial fractures, LLFs = lower limb fractures, MFs = multiple fractures, MVCs = motor vehicle collisions, NI = nerve injuries, RSFs = fractures of rib and sternum, SFs = spinal fractures, ULFs = upper limb fractures, VI = visceral injuries.

tibial fractures (31.6%, 65/206), fibular fractures (22.8%, 47/206), radial fractures (13.6%, 28/206), ulnar fractures (13.1%, 27/206), humeral fractures (13.1%, 27/206), and femoral fractures (12.6%, 26/206). The most common complication were wound infection (5.8%) and pneumonia (1.0%) in the OF group, wound infection (2.1%) and pressure sores (2.0%) in the No-OF group (Table 1).

3.3. Risk factors for traumatic open fracture

The patients in the OF group presented with higher frequency of emergency admission ($P < 0.001$), self-supporting medical insurance ($P < 0.001$), MVCs ($P < 0.001$), wounded by machine ($P < 0.001$), struck by object ($P < 0.001$), hurt/cut by others ($P < 0.001$), lower limb fractures ($P < 0.001$), multiple

Table 2

Fractures wounded by machine, hurt/cut by others, struck by object.

Age groups		0-6	6-12	12-18	Total
Wounded by machine	Total	10	4	34	48
	Male/ female	6/4	2/2	32/2	40/8
	Wound environment				
	Playing/daily life	10(100%)	4(100%)	4(11.8%)	18(37.5%)
	Working	0	0	30(88.2%)	30(62.5%)
Struck by object	Total	18	40	43	101
	Male/female	14/4	33/7	41/2	88/13
	Wound environment				
	Playing/daily life	18(100%)	40(100%)	21(48.8%)	79(78.2%)
	Working	0	0	22(51.2%)	22(21.8%)
Hurt/cut by others	Total	1	11	62	74
	Male/female	0/1	10/1	58/4	68/5
	Mechanism				
	Hurt by others	1(100%)	5(45.5%)	31(50%)	37(50.0%)
	Hurt by blunt object	0	5(45.5%)	8(12.9%)	13(17.6%)
	Cut by others	0	1(9.1%)	23(37.1%)	24(32.4%)

fractures ($P = 0.010$), associated injuries ($P < 0.001$) and wound infection ($P = 0.003$) then the patients in the No-OF group. Multivariate logistic regression analysis indicated that mechanical trauma (OR = 64.229, $P < 0.001$), being hurt/cut by others (OR = 26.757, $P < 0.001$), and being struck by an object (OR = 15.345, $P < 0.001$) were stronger independent risk factors for open fracture than low fall; moreover, lower limb fracture (OR = 5.970, $P < 0.001$), upper limb fracture (OR = 5.865, $P < 0.001$) and multiple fractures (OR = 5.414, $P < 0.001$) were stronger independent risk factors for open fracture than craniofacial fractures (Table 3).

Table 3

Multivariate analysis of risk factors for open fracture.

			95% *OR*	
	P	*OR*	Lower	Upper
Etiologies				
MVCs	<0.001	8.802	5.141	15.071
Wounded by machine	<0.001	64.229	30.731	134.24
High fall (≥2 m)	<0.001	4.670	2.455	8.885
Struck by object	<0.001	15.345	7.763	30.333
Hurt/cut by others	<0.001	26.757	12.598	56.829
Others	0.289	1.819	0.601	5.503
Low fall (<2 m)	–	–	–	–
Fracture site				
LLFs	<0.001	5.970	3.196	11.150
ULFs	<0.001	5.865	3.069	11.211
SFs	0.997	0.000	0.000	–
RSFs	0.999	0.000	0.000	–
MFs	<0.001	5.414	2.657	11.030
CFFs	–	–	–	–

ASOIs = associated injuries, CFFs = craniofacial fractures, LLFs = lower limb fractures, MFs = multiple fractures, MVCs = motor vehicle collisions, NI = nerve injury, RSFs = fractures of rib and sternum, SFs = spinal fractures, ULFs = upper limb fractures, VI = visceral injury.

3.4. Treatments of traumatic open fracture

The frequency of surgical treatment (ST) among the patients who presented with traumatic open fractures (87.9%, 181/206) was significantly higher than the frequency among patients without open fractures (72.2%, 1596/2212). The hospital stays and fees for surgical treatment for the patients who presented with traumatic open fractures were significantly higher than those for the patients without open fractures (Table 4).

4. Discussion

4.1. Incidence and characteristics of traumatic open fracture

The incidence of traumatic open fracture varies from center to center, the open fractures comprise 2% to 9% of all pediatric fractures.[9–12] In the current study, the incidence of traumatic open fracture was 8.5%. Consistent with previous studies showing that most cases of pediatric open fractures are a result of high-velocity trauma, including motor accidents and falls from a height,[13] the most common etiologies in the current study were MVCs (45.6%), being injured by a machine (13.1%) and high fall (11.2%). Open fractures are more common in boys (71.8%). Most open fractures involve the forearm and tibia. In a retrospective multicentric analysis of pediatric fractures, researchers reported that 34% of open fractures involved the tibia/fibula and 32% involved the forearm, followed by the hand (10%), femur (6.7%) and humerus (6.5%).[14] In the current study, the most common open fracture sites were the tibia (31.6%), fibula (22.8%), radius (13.6%), ulna (13.1%) and humerus (13.1%). We believe that the pattern of traumatic fractures among children is partly explained by differences in the activity patterns of children.

Children around the world are routinely engaged in paid and unpaid forms of work that are not harmful to them. However, they are classified as child laborers when they are either too young to work or are involved in hazardous activities that may compromise their physical, mental, social or educational development. In China, child labor refers to children or young workers under the age of 16. Among the patients injured by a machine, 30 persons (62.5%) injured during working. Among the patients struck by object, 22 persons (21.8%) injured during working. We presume that the main causes of child labor are high level poverty and lack of access to good education. Among the patients hurt/cut by others, 24 persons (32.4%) were cut by others. We should tighten up law enforcement to crack down on all kinds of violations and protect the children.

4.2. Associated injuries and complications

The frequency of ASOIs in the patients who presented with traumatic open fractures (42.7%) was significantly higher than those in the patients without open fractures (25.2%) but there was no significant difference in the frequency of complications. The most common complication were wound infection

Table 4

Treatment for traumatic fractures in children and adolescents.

	OF group	No-OF group	χ^2 or *Z*	*P*
Total	206	2212		
Treatment				
ST	181(87.9)	1596(72.2)	23.880	<0.001
CT	25(12.1)	616(27.8)		
Complications				
ST	12(6.6)	153(9.6)	1.687	0.194
CT	5(20.0)	27(4.4)	12.354	<0.001
ICU stays (days)				
ST	1.0(0.0–4.5)	1.0(0.0–3.0)	–0.550	0.602
CT	8.0(5.0–13.5)	7.0(3.0–13.0)	–0.431	0.667
Hospital stays (days)				
ST	17.0(9.0–29.0)	11.0(8.0–17.0)	–5.418	<0.001
CT	0.0(0.0–1.0)	0.0(0.0–1.0)	–1.150	0.250
Hospital fees (CNYs)				
ST	33261.4(19564.8–49375.7)	24017.2(14594.5–42346.1)	–3.163	0.002
CT	4812.6(2964.4–8124.0)	4074.2(1902.3–7691.1)	–1.236	0.216

CNYs = Chinese yuans, CT = conservative treatment, ICU = intensive care unit, ST = surgical treatment.

(5.8%) and pneumonia (1.0%) in the OF group, wound infection (2.1%) and pressure sores (2.0%) in the No-OF group. The frequencies of associated injuries and wound infection in the OF group were significantly higher than the No-OF group. The hospital stays and fees for surgical treatment of traumatic open fractures were significantly higher than those without open fractures. Therefore, it is clear that open fracture was an important associated with high frequencies of ASOIs and high hospital costs. The similarities and differences between managing open fractures for younger patients and older patients have been investigated in previous studies.[15–19] Further research may help to identify and take preventive measures to reduce the number of open fractures, treatment costs and patient distress.

4.3. Risk factors for traumatic open fracture

Previous study demonstrates the difference between adult and pediatric open fractures in hospitalized road traffic accidents, and showed that adults had a greater risk for open ULFs compared to children, and the adult pedestrian group particularly had a significantly higher risk for open ULFs than the pediatric group.[20] So, open fractures in pediatric group have its specific characteristics. In the current study, multivariate logistic regression analysis indicated that mechanical trauma, being hurt/cut by others, and being struck by an object were independent risk factors for open fracture. Multivariate logistic regression analysis indicated that lower/upper limb fractures and multiple fractures were independent risk factors for open fractures. Therefore, we should maintain and enhance a safe work environment for younger adolescents and provide a safe and comfortable place for children to rest and play to avoid mechanical trauma and being struck by objects. We should also strengthen school-based moral education to effectively prevent crimes such as being hurt/cut by others.

4.4. Treatment of traumatic open fracture

Considering the frequent association of open fractures with other potentially life-threatening injuries in children, stabilizing the patient condition is the first priority. Orthopedic evaluation and management should follow after immediate life-threatening conditions of the patient are stabilized. Information about the nature and mechanism of injury is essential for the trauma surgeon to assess the injuries with respect to severity and other associated injuries. The patients in the OF group presented with higher frequency of multiple fractures, associated injuries and wound infection then the patients in the No-OF group. The frequency of surgical treatment for the patients with traumatic open fractures (87.9%) was significantly higher than those without open fractures (72.2%). The hospital stays and fees for surgical treatment for the patients with traumatic open fractures were significantly higher than those without open fractures. In China, medical insurance is mainly managed by the government; most low-income people and disadvantaged people have to pay out of their own pockets because the rate of medical insurance coverage is low. We advocate aggressive initial wound debridement in theater with early definitive combined orthopedic and plastic surgery in order to obtain skeletal stabilization and soft tissue cover,[21] timely and comprehensive orthoplastic care,[22] vacuum assisted dressing,[23] rapid rehabilitation[24] and we should pay much attention to the medical insurance coverage to the nation's uninsured.

5. Limitations

There were many limitations in the current study. First, the retrospective design and small sample size of the study may have led to selection bias. Second, the lack of information about bone mineral density, serum calcium and vitamin D levels are important limitations of this study. Despite these limitations, we believe that the study can be used as guidance for the prevention and treatment of traumatic open fractures in children and adolescents.

6. Conclusions

Etiology (especially being injured by a machine or being hurt/cut by others) and the fracture site (including lower limb fractures, upper limb fractures and multiple fractures) were independent risk factors for open fractures. The patients in the OF group presented with higher frequency of multiple fractures, associated injuries, wound infection, surgical treatment, hospital stays and fees then the patients in the No-OF group. This study provides unique information on epidemiological characteristics of open fractures, pertinent both to medical care providers and to health policy makers allocating resources and formulating prevention strategies in the attempt to deal with the burden of family and society, and future prospective long-term multicenter studies are likely to provide answers to the optimal treatment for traumatic open fractures over the next few years.

Author contributions

Hongwei Wang, Hong Yuan, Lu Liu: Conceptualization, Methodology, Software, Data curation, Validation, Writing - Original draft preparation. Deluo Wu, Lan Ou, Changqing Li: Formal analysis, Visualization, Investigation, Writing - Original draft preparation. Hailong Yu: Supervision, Data curation, Writing - Reviewing and Editing.

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