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Relationship between surgeon volume and the risk of deep surgical site infection (DSSI) following open reduction and internal fixation of displaced intra-articular calcaneal fracture

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Abstract
It is well established that the postoperative results were affected by the surgeon
volume in a variety of elective and emergent orthopaedic surgeries; however,
by far, no evidences have been available as for surgically treated displaced
intra-articular calcaneal fractures (DIACFs). We aimed at investigating the
relationship between surgeon volume and deep surgical site infection (DSSI)
following open reduction and internal fixation (ORIF) of DIACFs. This was a
further analysis of prospectively collected data from a validated database.
Patients with DIACFs stabilised by ORIF between 2016 and 2019 were identi-
fied. Surgeon volume was defined as the number of surgically treated calcaneal
fractures within one calendar year and was dichotomised based on the optimal
cut-off value. The outcome measure was DSSI within 1 year postoperatively.
Multivariate logistics regression analyses were performed to examine the rela-
tionship, adjusting for confounders. Among 883 patients, 19 (2.2%) were found
to have a DSSI. The DSSI incidence was 6.5% in surgeons with a low volume
(<6/year), 5.5 times as that in those with a high volume (≥6/year) (incidence
rate, 1.2%; $P < 0.001$). The multivariate analyses showed a low volume <6/year
was associated with a 5.8-fold increased risk of DSSI (95% confidence interval,
2.2-16.5, $P < 0.001$). This value slightly increased after multiple sensitivity ana-
lyses, with statistical significances still unchanged (OR range, 6.6-6.9;
$P \leq 0.001$). The inverse relationship indicates a need for at least six cases/year
for a surgeon to substantially reduce the DSSIs following the ORIF of DIACFs.

KEYWORDS
annual case volume, calcaneal fracture, deep surgical site infection, inverse relationship

Shiji Qin and Yanbin Zhu contributed equally to this study.

Key Messages
- the incidence rate of deep surgical site infection following open reduction and internal fixation of closed displaced intra-articular calcaneal fracture was 2.2%
- an inverse relationship exists between the incidence rate of DSSI and the surgeon volume of surgical cases, with a 5.5-fold increased risk in high-volume as in low-volume surgeons
- there is a need for at least six cases of ORIF procedures per year for an orthopaedic surgeon to substantially reduce the DSSIs following closed DIACFs

1 | INTRODUCTION

Displaced intra-articular calcaneal fractures (DIACFs) are seen in approximately 30% of foot and ankle injury sufferers and have a major impact on the patient's quality of life.[1,2] Currently, open reduction and internal fixation (ORIF) remains the mainstay of treatment, but the operative results were seriously compromised by postoperative deep surgical site infection (DSSI) in 2.9%-15.4% of patients,[3-5] even though appropriate antibiotics are routinely administrated. Due to the fact that this procedure is technically demanding and has a steep learning curve, it is reasonably assumed that the surgeons' degree of surgical proficiency and skills in handling operative details regarding the accuracy of fracture reduction, blood vessel, or soft tissue will directly affect the risk of DSSI.

In fact, surgeon case volume has been identified as a risk factor for morbidity and mortality following a wide range of orthopaedic procedures, from osteosynthesis for stabilising fractures to total joint arthroplasty.[6-12] Most studies supported the lower rate of morbidity or mortality was significantly associated with increased case volume of one surgeon,[7,9,13,14] but not in other studies.[8,15] In a quantitative systematic review, Poeze et al[16] included 21 original studies with inclusion of 1656 cases of calcaneal fractures and concluded that significant inverse correlation was present between the institutional fracture volume and the DSSI rate ($r^2 = -0.5$) and subtalar arthrodesis rate ($r^2 = -0.7$), but they did not address the surgeon case volume. In a retrospective study by Court-Brown et al,[17] the authors found a fivefold increased risk of DSSI following operatively managed intra-articular calcaneal fractures by inexperienced surgeons vs most experienced surgeons (rate, 14.3% vs 2.8%). However, the limited sample size and absence of confounding factors for adjustment might affect drawing the definite conclusion. In the other studies seeking to identify the risk factors associated with overall infectious events or DSSIs, none noted or investigated the institutional or surgeon case volume.[5,18-22]

Considering the serious consequence of DSSI that substantially increased healthcare cost, need for multiple surgical procedures, and possible long-term sequelae of limb dysfunction,[3,19] it is essential to elucidate the relationship between DSSI and surgeon case volume as such an important modifiable factor. The aim of this study was to investigate the relationship between surgeon volume and the risk of DSSI. We hypothesised that a lower volume was associated with increased risk of DSSI.

2 | METHODS

2.1 | Data resource

This was a single-centre, retrospective secondary analysis of data extracted from a prospected maintained and updated database of Surgical Site Infection in Orthopaedic Surgery (SSIOS) in the Third Hospital of Hebei Medical University, a 2000-bed tertiary and teaching hospital involving a variety of orthopaedic subspecialties (general orthopaedics trauma, spinal surgery, joint arthroplasty, hand surgery, paediatric orthopaedics, orthopaedic oncology, orthopaedic disorders, geriatric orthopaedics trauma, and foot and ankle surgery). During the past 5 years, approximately 48 000 cases of orthopaedic procedures were performed yearly in this institution. The SSIOS database was initiated on 1 October 2 014 and was updated yearly, with primary aim to investigate the incidence, epidemiologic characteristics, change in causative bacteria spectrum, and risk factors for postoperative surgical site infection (SSI). Data on patients undergoing any orthopaedic surgeries were manually entered and prospectively collected to maximise the data completeness and accuracy. During hospitalisation stay, wound surveillance was routinely implemented for the cases with signs of SSI, and then samples from wound secreta or deep tissue during surgical debridement were obtained for microbial culture and drug sensitivity. After discharge, patients were subjected to the protocolised surveillance of

infection at the outpatient clinic for the first 3 months and afterwards, telephone follow-up was conducted by our investigators through 1 year. The details about SSIOS had been described in our previous studies.[23-27]

2.2 | Participants and perioperative management

In this study, patients aged 18 years or above who underwent ORIF of acute closed calcaneal fractures between January 2016 and December 2019 with complete 1-year follow-up data were deemed to be eligible to be included. The exclusion criteria were open calcaneal fracture, bilateral calcaneal fractures, pathological (metastatic) fractures, old fractures (>28 days from injury), polytrauma, treatments other than ORIF, presence of infections or signs before index admission, wound-related issues other than DSSIs (eg superficial infection, wound edge necrosis), missing information for variables of interest, or insufficient 1-year follow-ups. This study was approved by the ethics committee of the Third Hospital of Hebei Medical University, which waived the need for informed consent due to its nature of secondary data analysis.

For ORIF procedure, extended lateral approach or sinus tarsi approach was used. Protocolised 1-2 g of second-generation cephalosporin on the basis of weight was administered 30 to 60 minutes prior to skin incision, and for cases lasting over 3 hours, another dose was given. Within 24 hours after *wound closure*, prophylactic antibiotic regimen per the protocol was routinely given. Tourniquets use, need of bone graft, or drainage use was at the attending surgeon's discretion, based on the specific circumstances encountered. Postoperatively, all patients were instructed to follow the institutional protocol regarding wound care and fracture union.

2.3 | Definition of DSSI

DSSI was defined, according to the criteria proposed by the US Centers of Disease Control (CDC), as an infection directly related to wound that involved the tissues surpassing the deep fascia. The following signs were considered: continuous pus discharging; dehiscence or separation; clinically proven infections requiring antibiotic therapy, surgical debridement, and/or removal of implants; presence of osteomyelitis; and wounds requiring construction of with skin grafts or tissue flaps. The microbial culture results of the sample were considered as auxiliary diagnosis, but were not dependent upon.

2.4 | Definition of surgeon volume

Surgeon names were used to count the number of surgical procedures for calcaneal fractures for each surgeon in each calendar year. Thus, one surgeon was assigned to have a maximum of 4 numbers (from 2016 through 2019), and each procedure was corresponding to be assigned a number according to annual case volume of the index treating surgeon. Of note, calcaneal fracture for which the number was used for the definition of surgeon annual case volume not only involved the closed fracture but also involved other types of calcaneal fractures (open, bilateral as two cases, multiple, polytrauma, etc.). High or low volume was determined by the optimal cut-off value by means of constructing the receiver operating characteristic (ROC) curve described in detail in the statistical analysis section.

2.5 | Variables and data collection

Data were collected on demographics (age, sex, body weight, height, residence place, occupation), current smoking and alcohol drinking status, comorbid conditions (hypertension, diabetes mellitus, chronic heart disease (cardiovascular disease or heart failure), history of cerebrovascular accident, pulmonary disease (bronchial lesions or chronic obstructive pulmonary disease), liver disease (hepatitis or cirrhosis), renal insufficiency), injury (injury mechanism, fracture type based on Sanders' classification), and surgery (time from injury to surgery, surgical approach, surgical time, blood loss, allogeneic blood transfusion, anaesthesia mode, American Society of Anesthesiologists [ASA] grade, bone grafting, postoperative drainage use).

Comorbid conditions were reported by patients themselves after admission to hospital. Occupation was categorised as retirement, office work, manual work, professional work, and others. Body mass index (square of height divided by weight) was dichotomised into obesity ($\geq$28 kg/m^2) and non-obesity (<28 kg/m^2) in accordance with the criteria fit for Chinese people. Smoking or alcohol consumption was defined as self-reported smoking activity or alcohol drinking within 12 months of the index operation. A trauma from traffic accidents, fall from a height above 1 m, and other violent injuries were regarded as high-impact trauma, otherwise as the low- to medium-impact trauma.

2.6 | Statistical analysis

Data were presented as number with percentage, or as the mean and the standard deviation (SD). We

constructed the ROC curve by calculating the sensitivity and 1-specificity for the prediction of the DSSI rate for every possible value for the surgeon volume. When the combined sensitivity and specificity were maximised, the optimal cut-off value was determined. The validity of this cut-off value was evaluated by the size of area under the ROC curve, as was detailed in previous studies.[28] Based on this cut-off value, the surgeons were dichotomised into high-volume or low-volume category, with which the rate of DSSI and crude odds ratio (OR) were calculated.

The differences between patients operated by high-volume surgeons and those by low-volume surgeons were analysed. For continuous variables, the normality status was explored using the Kolmogorov–Smirnov test and between-groups differences were detected using the Student t-test or Mann–Whitney U-test, as appropriate. For categorical variables, the chi-square test or Fisher exact test were used, as appropriate.

In the multivariate logistics regression model, variables that were tested to be significant or approximately significant ($P < 0.10$) in the univariate analyses, along with the surgeon volume category, sex, and age, were entered for adjustment. The stepwise forward method was used, so as to obtain the precise effect estimate for surgeon volume as possible. For addressing the potential multicollinearity between the entered variables, we performed the linear regression analysis in stepwise backward manner, with DSSI as a dependent variable. The value of the variation inflation factor (VIF) ≥ 3 or tolerance $\leq 1/3$ signifies multicollinearity and thereby excludes the involved variables.[29] To address the potential for over-fitting of the logistics regression model, the Hosmer-Lemeshow test was performed, with $P < 0.05$ and adjusted Nagelkerke $R^2 > 0.750$, indicating the over-fitting.[29] Odds ratio (OR) and its 95% confidential interval indicated the magnitude of association effect.

We performed several sensitivity analyses by repeating the multivariate logistics analyses restricted to patients aged ≤ 45 years and ≤ 60 years, those receiving procedure within 2 weeks after injury, those with an isolated calcaneal fracture (namely without multi-fractures or polytrauma), and those without comorbidities listed above, to explore the potential effects of unmeasured confounders. That is because the age-related frailty and the delayed surgery that arises from patient, institutional or surgeon factors, multi-fractures or polytrauma (possibly, prioritisation for systematic stabilisation) are likely to affect the operative procedure assignment.

To explore the potential dose-effect relationship between annual case volume and the DSSI incidence, we performed the multivariate analysis using multiple linear regression, with the completely same covariables entered

into the logistics regression model for adjustment. The results were presented with standardised regression coefficient (beta) with standard error (SE).

The statistical significance was set as $P < 0.05$, and all the analyses were performed using SPSS24.0 (IBM corporation, New York).

3 | RESULTS

Initially, 1508 patients with a discharge diagnosis of calcaneal fracture were identified. Seventy-two patients were excluded for age <18 years, 70 for open fracture, 178 for bilateral fractures, 12 for pathological (metastatic) fractures, 22 for old fractures (>28 days from injury), 29 for polytrauma, 116 for treatments other than ORIF, 6 for the presence of infections or signs before index admission, 58 for wound-related issues other than DSSIs, and 62 for missing information on variables of interest or follow-ups, leaving 883 patients for data analysis (Figure 1).

Among them, most were male patients (90.0, 795/883), the mean age was 42.2 ± 11.1 years, and 56.1% were aged <45 years. All of the ORIF procedures were performed by 64 surgeons. The median and mean case volume for one surgeon in a calendar year were 14 (rang, 1-40) and 16.3 (SD, 10.5), respectively. During the postoperative 1-year follow-up, 19 DSSI were found, indicating an accumulated incidence rate of 2.2%. These 19 DSSIs were distributed in 16 surgeons, with 3 and 2 in one and another surgeon, and 1 in the remaining 14 surgeons,
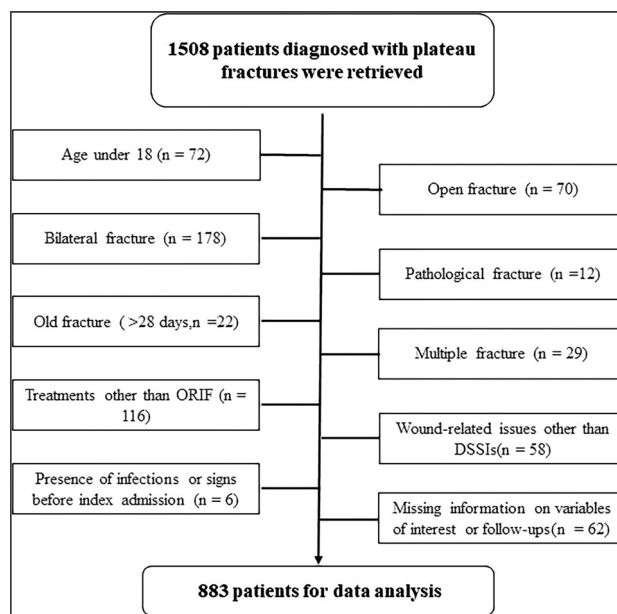

FIGURE 1 The flowchart showing the exclusion process, with finally 883 patients for data analysis
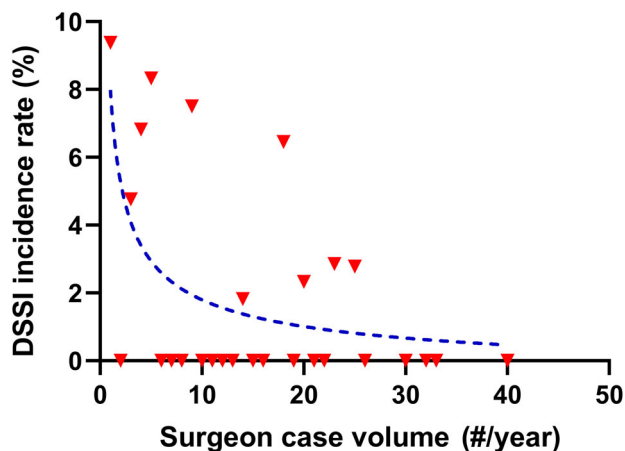
FIGURE 2 Graph showing the relationship between DSSI incidence rate and the number of procedures of surgical management displaced intra-articular calcaneal fracture. As the surgeon case volume increased, the DSSI rate seems decreased

respectively. The DSSI rate with surgeon case volume was presented in Figure 2. Seventeen (89.5%) patients underwent at least one surgical procedure for treatment of DSSI, and the mean number was 1.8 ± 1.6. No amputation was performed.

The optimal cut-off value for surgeon volume was determined as 6, greater than or equal to which the corresponding rate of DSSI was 6.5% (10/755), significantly higher than that for low volume (1.2%, 9/724, for volume less than 6 cases) ($P < 0.001$). The crude OR was 5.5 (95%CI, 2.2-13.8). The univariate analyses showed that patients operated on by low-volume surgeons were more likely to be residing in urban areas (40.0% vs 30.9%, $P = 0.005$), have comorbid diabetes mellitus (7.7% vs 4.0%, $P = 0.043$), have surgical incision level of II (6.5% vs 1.9%, $P = 0.002$), and were less likely to have bone grafting (3.9% vs 9.3%, $P = 0.026$). Also, a trend to a greater proportion of high-impact trauma mechanism was found in patients operated on by low-volume surgeons, but not approaching to significance level (72.9% vs 65.7%, $P = 0.082$) (Table 1).

The multiple linear regression analyses did not detect the multicollinearity between either of the independent variables (surgeon volume, age, sex, residential area, comorbid diabetes mellitus, bone grafting, surgical incision) (VIF, 1.01-1.03; tolerance, 0.97-0.99;). The multivariate logistics regression analysis showed low- vs high-volume surgeon was associated with a substantially higher risk of DSSI (OR, 5.8; 95%CI, 2.1-15.7, $P = 0.001$). However, other variables were not found to be statistically significant, except bone grafting for which a trend to a higher risk of DSSI was observed (OR, 3.4; 95%CI, 0.9-12.9; $P = 0.075$) (Table 2). The Hosmer-Lemeshow test ($P = 0.813$) and the adjusted Nagelkerke R^2 (value, 0.131) demonstrated the acceptable fitting of the model.

In the sensitivity analyses restricted to some specific populations, the statistical significance was not altered and the association magnitude of surgeon volume with risk of DSSI was slightly increased. The adjusted OR was 6.9 (95%CI, 2.0-23.5, $P = 0.002$), 6.7 (95%CI, 2.4-18.6; $P < 0.001$), 6.9 (95%CI, 95%CI, 2.4-19.3; $P < 0.001$), 6.6 (95%CI, 2.3-19.0; $P < 0.001$), and 6.6 (95%CI, 2.4-17.9; $P < 0.001$), when sensitivity analyses were restricted to patients aged ≤45 years (12/524), aged ≤60 years (n = 16/770), operated on within 2 weeks after injury (n = 16/816), with an isolated and unilateral calcaneal fracture (n = 16/785), and without comorbidities listed above (18/749), respectively. No over-fitting was found in the multivariate model for any sensitivity analysis ($P = 903$, $R^2 = 0.192$; $P = 720$, $R^2 = 0.103$; $P = 978$, $R^2 = 0.108$; $P = 0.736$, $R^2 = 0.113$; $P = 0.0585$, $R^2 = 0.134$).

The multiple linear regression showed significant reverse volume-outcome relationship (Beta, −0.094; SE, 0; $P = 0.006$).

4 | DISCUSSION

DSSI following the ORIF of displaced intra-articular calcaneal fractures seriously affects the operative outcome, and the identification of factors related to the patient and the care providers provides a most cost-effective choice in the improvement of the management of such complication. By far as we know, this is the first study that has investigated the DSSI incidence following the ORIF of displaced intra-articular calcaneal fractures in relation to the surgeon case volume. This study showed that annual low volume (< 6 cases/year) was associated with a 5.8-fold increased risk of DSSI compared with high volume (≥ 6 cases/year). The multiple sensitivity analyses restricted to several subgroups of patients showed a slight increase in the OR value (6.6-6.9 vs 5.8) and the constantly unchanged statistical significance ($P ≤ 0.001$).

The major advantages were the large sample size, use of the prospectively collected data from a database manually updated yearly, and performance of multiple sensitivity analyses, ensuring the accuracy of the data and the robustness of the primary analysis. There were some limitations to this study. First, the actual DSSI rate might have been underrepresented, even if we used the different strategies, for example wound surveillance during index hospitalisation, telephone follow-up after discharge, outpatient visit records, and looking into readmission records, to identify the cases. There still exists a possibility that patients might have sought for the treatment of DSSI outside our institution, for example in secondary hospitals (higher reimbursement rate), hospitals specialised for infection events, or traditional Chinese medicine hospitals (fearing secondary or more

TABLE 1 Comparisons of patient- and surgery-related factors between high- and low-volume surgeons

Variable	High volume (n = 728)	Low volume (n = 155)	*P* value
Age	42.0 ± 11.0	43.7 ± 11.9	0.095
Sex (male)	657 (90.2)	138 (89.0)	0.647
BMI (Kg/m²)	25.1 ± 3.1	25.5 ± 3.2	0.195
Obesity (≥28)	95 (13.0)	25 (20.8)	0.310
Residence			0.028
Rural	503 (69.1)	93 (60.0)	
Urban	225 (30.9)	62 (40)	
Occupation			0.641
Retirement	58 (8.0)	8 (5.2)	
Office work	94 (12.9)	17 (11.0)	
Manual work	437 (60.0)	102 (65.8)	
Professional work	106 (14.6)	21 (13.5)	
Others	33 (4.5)	7 (4.5)	
Hypertension	54 (7.4)	15 (9.7)	0.341
Diabetes	29 (4.0)	12 (7.7)	0.043
Cerebrovascular accident	8 (1.1)	1 (0.6)	0.610
Heart disease	19 (2.6)	3 (1.9)	0.625
Hepatopathy	12 (1.6)	2 (1.3)	0.746
Nephropathy	1 (0.1)	1 (0.6)	0.227
History of any surgery	31 (4.3)	7 (4.5)	0.886
ASA			0.888
I	126 (17.3)	29 (18.7)	
II	555 (76.2)	117 (75.5)	
III	47 (6.5)	9 (5.8)	
Smoking	123 (16.9)	29 (18.7)	0.587
Alcohol drinking	76 (10.4)	14 (9.0)	0.599
Time from injury to operation	7.7 ± 4.5	8.0 ± 4.4	0.536
Hospital stays	15.9 ± 10.9	16.7 ± 11.3	0.408
Injury mechanism			0.082
High-impact trauma	478 (65.7)	113 (72.9)	
Low- to medium-impact trauma	250 (34.3)	42 (27.1)	
Fracture type classified as Sanders' classification			0.354
II	389 (53.4)	92 (59.4)	
III	248 (34.1)	44 (28.4)	
IV	91 (12.5)	19 (12.3)	
Concurrent other fractures	82 (11.3)	16 (10.3)	0.735
Surgical approach			0.940
STA	425 (58.4)	91 (58.7)	
ELA	303 (41.6)	64 (64)	
Anaesthesia mode			0.314
General	143 (19.6)	36 (23.2)	
Regional	585 (80.4)	119 (76.8)	

(Continues)

TABLE 1 (Continued)

Variable	High volume (n = 728)	Low volume (n = 155)	P value
Incision level			0.002
I	714 (98.1)	145 (93.5)	
II	14 (1.9)	10 (6.5)	
Surgical time (minutes)	120.2 ± 59.3	123.3 ± 103.7	0.615
Intraoperative blood loss (ml)	174.6 ± 247.3	170.3 ± 247.4	0.846
Allogeneic blood transfusion	28 (3.8)	4 (2.6)	0.444
Bone grafting			0.026
Yes	68 (9.3)	6 (3.9)	
No	660 (90.7)	149 (96.1)	
Postoperative drainage use			
Yes			
No			
Operation timing			0.302
Daytime	715 (98.2)	154 (99.4)	
Night	13 (1.8)	1 (0.6)	

TABLE 2 Multivariate analysis of risk factors for postoperative DSSI[a]

Variables	Beta	Standard error	OR	95% CI Lower limit	95% CI Upper limit	P value
Surgeon volume (<6/year)	1.76	0.51	5.8	2.1	15.7	0.001
Residence place (urban vs rural)	0.57	0.48	1.8	0.7	4.5	0.235
Diabetes mellitus (yes vs no)	−0.14	1.07	0.9	0.1	7.1	0.896
Incision level (II vs I)	1.19	0.82	3.3	0.7	16.4	0.144
Injury mechanism (low-to medium- vs high-impact trauma)	−0.65	0.58	0.5	0.2	1.6	0.263
Age (increment in each year)	−0.02	0.02	1.0	0.9	1.0	0.422
Sex (male vs female)	−0.15	0.78	0.9	0.2	4.0	0.852
Bone grafting (yes vs no)	1.02	0.61	2.8	0.8	9.2	0.096
Constant	−5.59	1.66	0.0			0.001

[a]Nagelkerke R^2 = 0.115; Hosmer-Lemeshow test, X^2 = 10.336, P = 0.242.

operations). Second, this was a tertiary referral, university-affiliated, orthopaedics-specialised hospital, and thus, selection bias may have occurred. The findings may not be representative of the orthopaedic surgeon and hospitals in general. However, the selected population based on more stringent criteria and further the sensitivity analyses restricted to several specific subgroups would partly compensate for this bias. Third, some well-established factors in literature (eg diabetes mellitus, obesity, renal insufficiency) were not re-identified and hence not included for adjustment. It was not surprising that the very low prevalence in such injured population and the limited number of DSSI cases made them difficult to be statistically significant. Fourth, residual confounding effects remain due to the observational nature of this study; this is why we performed multiple sensitivity analyses to detect the magnitude of change of the primary result. In addition, the extent of soft-tissue trauma at the time of fracture and from the index procedure, quality of wound care, and patient compliance with rehabilitation protocol, among others are hard to concretise and quantify. We made the assumption that such heterogeneity would be randomly distributed across the cohorts. Fifth, despite the finding of the DSSI-surgeon volume relationship, we did not ignore the role of the experience and proficiency of operative assistants and scrub nurses in the

surgical management of fractures or the experience of ward nurses in perceiving the risk of wound infection. For these operations, a large number of different combinations from surgeons, operative assistants, scrub nurses, and ward nurses were actually formed, and the confounding effects would therefore have existed. On the other hand, the surgeon volume relationship was indeed relationship involving all participants. It is a pity that the relevant data had not been captured and their respective role was unable to adjust. Sixth, we used calendar year rather than practical cases within the preceding year to define the surgeon operative case, which might have biased the result. Considering less possibility that there may be a big fluctuation of operative case volume during adjacent years, the use of calendar year is accepted. Finally, we only assessed a single outcome, although a most serious one, and hence the conclusion could not be generalised to other postoperative outcomes or complications.

The case volume of surgeon has been demonstrated to have a significant effect on postoperative outcome or morbidity for a wide range of surgical procedures, for example closed reduction and percutaneous pinning of displaced supracondylar humeral fracture,[9] osteosynthesis or arthroplasty for hip fracture, and[6,10] elective arthroplasty for end-staged hip, knee, or shoulder joint degenerative diseases.[7,11,12] However, the inverse surgeon volume-outcome relationship was not always consistent.[8,30] It is presumed that the basic pathophysiological conditions (age, fragility, comorbidities, etc.), systematic inflammatory/immune stress response to regional trauma or surgery and the target outcome measures are primarily responsible for these inconsistent observations. In this study, our results supported that the calcaneal fracture ORIF procedure can be performed by high-volume surgeons to reduce the incidence of DSSI. The strong association magnitude (OR, 5.8) indicated that patients could benefit from surgical decision shift from low- to high-volume surgeons, at least regarding DSSI incidence. Furthermore, the robust significant results from multiple sensitivity analyses and the exponential dose-effect relationship added to this association.

Despite with significant inverse volume-outcome relationship, we did not observe the differences in procedure-directly-related measures between both surgeon groups, like approach (STA, 58.4% vs 58.7%), surgical duration (120.2 vs 123.3 minutes), surgical timing (daytime, 98.2% vs 99.4%), intraoperative blood loss (174.6 vs 170.3 mL), or blood transfusion (3.8% vs 2.6%). That means these intuitive surgical measures are even completely unable to account for the relationship. Interestingly, we found the greater variation in surgical duration in low-volume surgeons than in high-volume surgeons (confidence interval, 103.7 vs 59.3 minutes), reflecting the former being lack of

proficiency with the procedure. Therefore, it is reasonably inferred that appropriate and proficient handling of surgical details relating to soft-tissue sharp or blunt dissection, vascular integrity or tiny fracture fragment removal or preservation, are far more important than surgical duration itself.[31] The substantial difference in the use of autologous/allograft bone (3.9% vs 9.3% $P = 0.026$) may reflect that the low-volume surgeon was subjected to neglecting or inadequate to handle the residual space after fracture is reduced, although it demonstrated not to increase the risk of DSSI.

This reverse volume-DSSI relationship identified in this study supported the theory of 'practice-makes-perfect'; that is, as surgeon case volume increases, the skills, proficiency, and confidence in handing complex cases will increase, leading to improved postoperative overall outcomes, including reduced DSSI incidence. Poeze et al[16] deduced from his study that approximately five ORIF procedures for displaced intra-articular calcaneal fractures per year for an individual surgeon could allow maintaining the adequate skill level, similar to our finding ($\geq$ six cases/year). Sanders et al[32] demonstrated a learning curve of 35 to 50 calcaneal fractures to achieve a significantly improved operative results, also providing the evidence for this, but that seemed not applicable to complex type IV fractures classified as by Sanders' classification. Limited by the number of the type IV fractures, we could not make a further analysis.

In conclusion, the rate of DSSI following ORIF of DIACFs was significantly associated with annual surgeon volume and in dose-dependent manner to a certain extent. Keeping an annual case volume $\geq$ 6 per year is necessary for an orthopaedic surgeon to reduce the rate of DSSI. Our findings should be treated in the context of specific or general limitations, and the reverse volume-DSSI relationship should be verified by the multicentre studies with a larger sample size.

CONFLICT OF INTEREST

The authors declared no potential conflict of interest with respect to the research, authorship, and/or publication of this article. ICMJE forms for all authors are available online.

AUTHOR CONTRIBUTIONS

Yingze Zhang and Wei Chen conceived the idea and designed the study. Kuo Zhao, Junzhe Zhang, Hongyu Meng, and Junyong Li collected the relevant data.

Junyong Li and Kuo Zhao prepared the figures and tables. Yanbin Zhu performed the statistical analyses. All the authors interpreted the data and contributed to the preparation of the manuscript. Shiji Qin and Yanbin Zhu wrote the manuscript and contributed equally.

ETHICAL APPROVAL AND INFORMED CONSENT

The study protocol was approved by the ethics committee of the Third Hospital of Hebei Medical University, which waived the need for informed consent due to its nature of secondary data analysis.

DATA AVAILABILITY STATEMENT

Peer review of empirical data will be conducted to confirm that the data reproduce the analytic results reported in the article.

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