Serial White Blood Cell Counts in Trauma: Do They Predict a Hollow Viscus Injury?

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Background: The significance of serial white blood cell (WBC) counts in trauma patients with a suspected hollow viscus injury (HVI) is unknown. The purpose of this study was to examine the role of serial WBC counts in the diagnosis of a HVI.

Methods: After institutional review board approval, all injured patients admitted to a Level I trauma center from January 2003 to December 2007 with at least one WBC measurement were included in a retrospective analysis. The WBC profiles for patients with a HVI were compared against those without HVI. All WBC counts are reported as [$\times 10^3/\mu$L].

Results: The mean WBC count of the overall study population (n = 5,950) on admission was 11.6 ± 5.3. Overall, 59.2% had an elevated WBC count on admission. A significant relationship between increasing Injury Severity Score and increasing WBC count on admission was found by linear regression. When comparing patients with HVI (n = 267) with patients without HVI (n = 5,683), no significant difference was found for admission WBC count. The highest WBC count within the first 24 hours for patients with HVI was 16.7 ± 4.7. This was significantly higher than that for the 4,520 patients without any intraabdominal injury (13.0 ± 5.2, adjusted $p < 0.001$). Penetrating injury, a concomitant severe thoracic trauma (chest Abbreviated Injury Scale value ≥3), and highest WBC count ≥20.0 in the first 24 hours were independent risk factors for HVI. A maximal WBC count ≤12.5 in the first 24 hours was independently associated with a lower incidence of HVI. The area under the receiver operating characteristic curve for the highest WBC count in the first 24 hours for predicting HVI was 0.723 (95% CI: 0.656–0.790).

Conclusion: Multiple variables likely impact the WBC count in trauma patients. WBC count elevation on admission is nonspecific and does not predict the presence of a HVI. With serial measurements, WBC counts ≥20.0 are independently associated with a HVI, whereas counts ≤12.5 rule against the presence of HVI. However, the sensitivity of these cutoff values to predict a HVI is poor. The diagnostic value of serial WBC counts for predicting a HVI within the first 24 hours after trauma is very limited.

Key Words: Hollow viscus injury, White blood cell count, Diagnosis, Trauma.

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An elevated white blood cell (WBC) count is a nonspecific indicator of stress, inducible by states of infection, inflammation, tissue necrosis, or hemorrhage. The demargination of leukocytes after major injury and surgical stress has led several investigators to examine the diagnostic value of the initial WBC count in trauma patients.[1–6]

The diagnosis of a hollow viscus injury (HVI) after blunt and penetrating trauma may be challenging, and delays in diagnosis may result in an increase in morbidity and mortality, independent of the site of perforation.[7–9] It is a common practice for patients who are at risk of having significant intraabdominal injury to be followed with serial clinical examination and WBC counts for at least 24 hours. However, the interpretation of serial WBC counts, particularly in patients with a questionable HVI, is difficult, because data supporting the ability of serial WBC measurements to predict the presence of a HVI is lacking. The purpose of this study was to investigate the ability of the admission WBC count and serial measurements within the first 24 hours to predict a HVI.

PATIENTS AND METHODS

After institutional review board approval, all trauma patients older than 16 years admitted from January 2003 to December 2007 (5 years) to the Los Angeles County + University of Southern California Medical Center, having at least one WBC count reported were identified. All WBC counts are reported as ($\times 10^3/\mu$L). A computerized spreadsheet (Microsoft Excel 2003; Microsoft, Redmond, WA) was created to abstract the following variables: age, gender, mechanism of injury, systolic blood pressure and Glasgow Coma Scale on admission, Abbreviated Injury Scale (AIS) for head, chest, abdomen, and extremities, Injury Severity Score (ISS), and WBC counts with dates and times. All injuries sustained by the patients were cataloged. For patients who underwent a laparotomy, the date and time of surgery were abstracted, and the findings were recorded. Data were subsequently analyzed using the Statistical Package for Social Sciences (SPSS Windows), version 16.0 (SPSS, Chicago, IL).

The data was analyzed in three parts. First, we examined the correlation between the WBC counts on admission with the injury severity (ISS) using linear regression. The admission WBC counts for patients who had a HVI were compared with those without HVI. The area under the re-

ceiver operating characteristic (ROC) curve was used to calculate the sensitivity and specificity of admission WBC counts.

In the second part of the analysis, the highest WBC counts in the first 24 hours (24-hour WBC) for patients with a HVI were compared with the highest 24-hour WBC of patients without any intraabdominal injury, defined as an AIS abdomen value = 0. The third part of the analysis compared the admission and last preoperative WBC count for patients who had a laparotomy to repair a HVI against patients who underwent a laparotomy for a reason other than a HVI.

Proportions and means were compared using Pearson's χ^2 and one-way analysis of variance. To adjust for differences between the study groups, all factors that were significant on bivariate analysis ($p < 0.05$) were included in a multivariable analysis to determine independent associations. To identify independent predictors for HVI, potential risk factors were examined in bivariate analysis. All risk factors ($p < 0.2$) were then entered in a stepwise logistic regression model.

RESULTS

During the 5-year study period, 5,950 trauma patients with a total of 49,522 WBC measurements were reviewed (Fig. 1). Mean age was 34.4 years ± 17.7 years, 77.0% were men, and 26.3% had a penetrating injury. The mean ISS was 9.8 ± 9.5.

Relationship of Admission WBC Counts to Injury Severity and Its Predictive Value for HVI

Overall, the mean WBC count on admission was 11.6 ± 5.3. A total of 3,523 (59.2%) patients had a WBC count >9.5 on admission. A relationship between increasing ISS and increasing WBC count on admission (Fig. 2) was confirmed by linear regression ($R^2 = 0.053$, $\beta = 0.127$, $p < 0.001$). Overall, 267 (4.5%) of these patients had a HVI. After adjusting for confounding variables (age, gender, penetrating injury, systolic blood pressure <90 mm Hg on admission, AIS head value ≥3, AIS chest value ≥3, AIS abdomen value ≥3, AIS extremity value ≥3, Glasgow Coma Scale, and ISS), the WBC count on admission for patients with a HVI was not

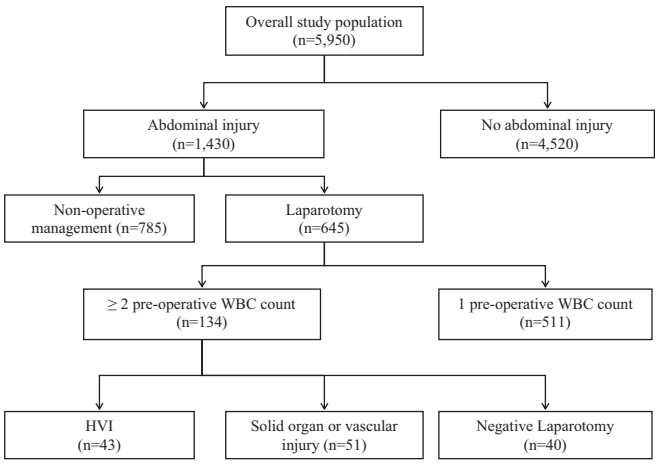

Figure 1. Stratification of the study population.

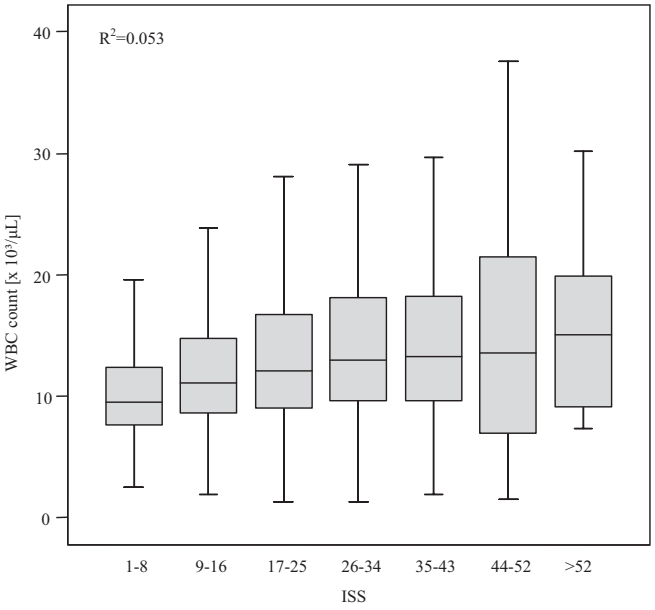

Figure 2. Mean WBC counts (95% CI) on admission in relation to the ISS (n = 5,950).

significantly higher than in patients without a HVI (12.3 ± 5.6 and 11.6 ± 5.3, respectively, adjusted $p = 0.183$). When comparing patients with a penetrating HVI injury to those with a blunt trauma mechanism, no difference was found for the admission WBC count (11.2 ± 6.3 vs. 12.3 ± 5.5, $p = 0.173$).

The area under the ROC for the WBC count on admission predicting a HVI was 0.553 (95% CI: 0.52–0.59; Fig. 3*A*). In addition, after adjusting for demographic variations, no significant difference in admission WBC count was found when comparing patients with a HVI with patients undergoing laparotomy but without a HVI or patients with intraabdominal injuries managed nonoperatively (12.3 ± 5.6, 12.5 ± 6.0, and 13.1 ± 6.1, respectively, adjusted $p = 0.094$; Table 1).

Comparison of the Highest WBC Count Within the First 24 Hours for Patients With and Without a HVI

A total of 645 (10.8%) patients underwent a laparotomy for various intraabdominal injuries. Of these patients, 511 (79.2%) had only 1 WBC count before laparotomy. Indications for these laparotomies were in 224 patients with a HVI and in 287 patients other intraabdominal findings. A total of 134 patients (20.8%) had at least 2 preoperative WBC counts (Fig. 1) and were included in this analysis. Forty-three of those patients had a hollow viscus perforation (17 small bowel, 19 colonic, 5 gastric, and 2 duodenal perforations). In these patients, the time to operation was 14.7 ± 22.2 hours because of a negative initial diagnostic workup (Table 4). Their maximal 24-hour WBC count was 16.7 ± 4.7. This was significantly higher than the 24-hour WBC count of the 4,520 patients without any intraabdominal injury (13.0 ± 5.2, adjusted $p < 0.001$). Figure 3*B* depicts the ROC for the

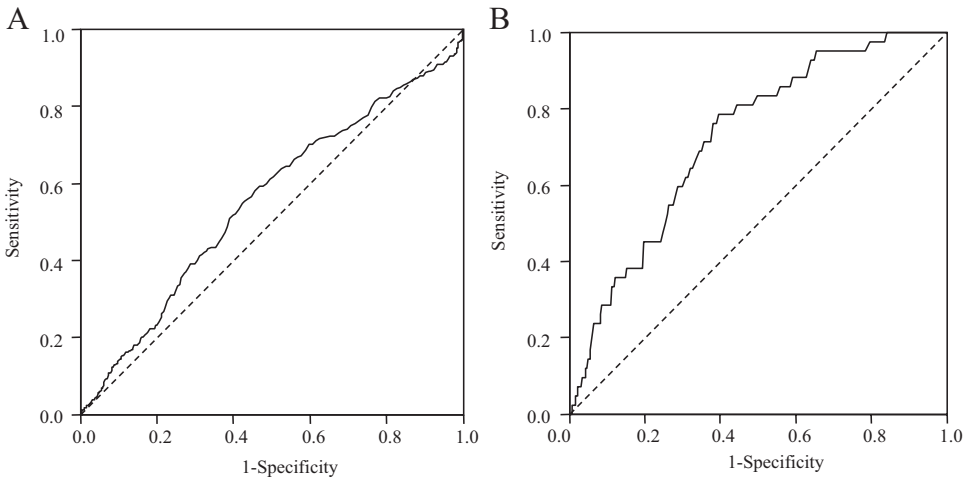

Figure 3. ROC curves for the WBC count on admission to predict a HVI (*A*) and the highest WBC count within 24 hours after admission to predict a HVI (*B*).

TABLE 1. Comparison of Basic Demographics and WBC Counts on Admission of Patients With Intraabdominal Injury

	Overall Patients With Abdominal Injury (n = 1,430)	Laparotomy, With HVI (n = 267)	Laparotomy, No HVI (n = 378)	Nonoperative Management (n = 785)	Unadjusted *p**	
Demographic data						
Age (yr), mean ± SD	33.1 ± 16.2	29.6 ± 12.4	32.1 ± 15.5	34.8 ± 17.4	<0.001	
Male, % (n)	78.0 (1,116)	86.9 (232)	81.2 (307)	73.5 (577)	<0.001	
Penetrating injury, % (n)	34.8 (498)	71.2 (190)	56.9 (215)	11.8 (93)	<0.001	
GCS value, mean ± SD	13.9 ± 2.8	13.8 ± 3.0	13.6 ± 3.0	14.0 ± 2.7	0.174	
Hypotension (SBP <90 mm Hg) on admission, % (n)	7.4 (106)	12.0 (32)	10.6 (40)	4.3 (34)	<0.001	
Head AIS value ≥3, % (n)	12.6 (174)	7.1 (19)	13.8 (52)	13.1 (103)	0.012	
Chest AIS value ≥3, % (n)	32.4 (464)	27.0 (72)	41.3 (156)	30.0 (236)	<0.001	
Abdomen AIS value ≥3, % (n)	40.0 (572)	80.9 (216)	40.5 (153)	25.9 (203)	<0.001	
Extremity AIS value ≥3, % (n)	18.6 (267)	15.0 (40)	23.6 (89)	17.6 (138)	0.012	
ISS, mean ± SD	15.7 ± 11.6	17.6 ± 11.5	17.3 ± 12.3	14.4 ± 11.1	<0.001	
					Unadjusted *p**	Adjusted *p*†
WBC data						
WBC on admission, mean ± SD	12.8 ± 6.0	12.3 ± 5.6	12.5 ± 6.0	13.1 ± 6.1	0.113	0.094
WBC on admission >9.5, % (n)	67.6 (967)	68.5 (183)	64.0 (242)	69.0 (542)	0.216	0.104

SD, standard deviation; GCS, Glasgow Coma Scale; SBP, systolic blood pressure.

* *p* for categorical variables were abstracted from Pearson χ^2 test and for continuous variables were calculated by one-way ANOVA.

† Multivariable analysis adjusted for age, gender, penetrating injury, SBP <90 mm Hg, AIS head value ≥3, AIS chest value ≥3, AIS abdomen value ≥3, AIS extremity value ≥3, GCS, and ISS.

ability of the maximal 24-hour WBC count to predict a HVI (0.723 [95%CI: 0.656–0.790]). Table 2 summarizes the sensitivity and specificity, as well as the positive and negative predictive values, for selected 24-hour WBC counts to predict a HVI, represented by coordinates of the ROC in Figure 3*B*. Stepwise logistic regression analysis identified four independent predictors for a HVI within the first 24 hours after admission (Table 3). The presence of a penetrating injury, a concomitant severe chest injury (chest AIS value ≥3), and a highest 24-hour WBC count ≥20.0 were independent risk factors for a HVI. A maximal 24-hour WBC count ≤12.5 was independently associated with a lower incidence of a HVI.

TABLE 2. Selected Values of the Highest WBC Count Within 24 hr After Admission to Predict a HVI Injury

WBC Count	Sensitivity (%)	Specificity (%)	Positive Predictive Value (%)	Negative Predictive Value (%)	Accuracy (%)
10.0	95	31	58	86	63
12.5	83	48	61	74	66
15.0	60	71	67	64	66
17.5	38	84	70	58	61
20.0	29	91	76	56	60

Patients sustaining penetrating and blunt trauma were also analyzed separately. A highest 24-hour WBC count ≥20.0 and a maximal 24-hour WBC count ≤12.5 were again independently associated with the presence and absence of a HVI in both groups of patients.

Comparison of the Admission and the Last Preoperative WBC Counts Between Patients With a HVI and Patients Who Underwent Laparotomy for Reasons Other Than a HVI

The ability of serial WBC counts to distinguish patients with HVI preoperatively was also tested. For patients undergoing delayed laparotomy with at least two preoperative WBC counts, the following three groups were compared: (1) patients with HVI (n = 43), (2) patients with solid organ or vascular injury (n = 51), and (3) patients with negative laparotomy (n = 40; Fig. 1). The demographics and vital signs on admission of these three groups are given in Table 4. The last WBC count before surgery was significantly higher in patients who had a HVI compared with patients who had no intraabdominal injuries (15.8 ± 1.00, 11.5 ± 1.00, adjusted $p = 0.008$; Table 5). This comparison was adjusted for the head AIS and the time from admission to the last preoperative WBC count (hours), because these variables were significantly different between the groups (Table 4). When comparing the amplitude of the increase of the WBC count (delta WBC = last preoperative WBC count − WBC count on admission), no significant difference was found (Table 5). Overall, 5 patients (3.7%) of these 134 patients died. Four patients died because of concomitant severe head and chest injuries, and one died because of severe recurrent bleeding from an associated blunt grade IV liver injury.

TABLE 3. Variables Independently Associated With HVI

Independent Variables	*p*	OR (95% CI)	R^2
AIS chest value ≥3	0.026	2.32 (1.10–4.88)	0.023
Highest WBC within 24 hr ≥20.0	0.039	2.23 (1.04–4.75)	0.030
Penetrating injury	0.023	2.19 (1.12–4.31)	0.012
Highest WBC within 24 hr ≤12.5	0.005	0.29 (0.12–0.68)	0.023

Risk factors selected into the equation: AIS chest value ≥3, AIS extremity value ≥3, AIS head value ≥3, SBP <90 mm Hg, GCS value ≤8, age <15 yr, age <30 yr, age <35 yr, age <40 yr, AGE >40 yr, WBC ≤12.5, WBC: 12.6–14.9, WBC: 15.0–17.4, WBC: 17.5–19.9, WBC ≥20, gender, and mechanism of injury (blunt or penetrating).

OR, odds ratio; GCS, Glasgow Coma Scale; SBP, systolic blood pressure.

DISCUSSION

Relationship of Admission WBC Counts to Injury Severity and Its Predictive Value for HVI

A significant relationship between increasing ISS and WBC count on admission was found. A similar association was documented in 1993 by Morell et al.[3] These authors also found that patients with an abnormally elevated WBC count (≥10.5) had a significantly higher ISS than those with normal WBC counts (11.4 and 7.1, respectively). The present study demonstrated a significant increase in WBC counts with increasing ISS. However, only 5.3% of the variation of the WBC count was explained by the ISS ($R^2 = 0.053$). This finding emphasizes the multifactorial impact of injury on the initial burst of leukocytes in trauma patients.

The WBC count was not significantly elevated on admission in patients with a HVI when compared with the rest of the trauma population. This stands in agreement with Fakhry and coworkers,[7,8] who also found no difference in admission WBC counts in 275,557 trauma patients with and without small bowel injury and colonic injury. Poletti et al.,[10] who tried to rule out intraabdominal injuries without an abdominal computed tomography scan, came to a similar conclusion. Based on our findings, we agree that the WBC count on admission is unreliable for the diagnosis of a HVI and is not helpful in the diagnostic workup. The presence of a HVI did not result in an increased admission WBC count,

TABLE 4. Clinical and Demographic Characteristics of Patients With at Least 2 WBC Counts Before Laparotomy

	HVI (n = 43)	Positive Laparotomy Without HVI (n = 51)	Negative Laparotomy (n = 40)	*p*
Age (yr), mean ± SD	31.7 ± 11.6	29.6 ± 13.4	34.2 ± 19.0	0.347
Male, % (n)	83.7 (36)	88.2 (6)	90.0 (36)	0.670
Penetrating, % (n)	48.8 (21)	49.0 (25)	45.0 (18)	0.916
GCS value, mean ± SD	14.1 ± 2.6	14.4 ± 1.8	14.0 ± 2.6	0.651
Hypotension (SBP <90 mm Hg) on admission, % (n)	2.3 (1)	6.7 (4/60)	3.0 (2)	0.264
Head AIS value ≥3, % (n)	2.3 (1)	11.8 (6)	40.0 (16)	<0.001
Chest AIS value ≥3, % (n)	32.6 (14)	56.9 (29)	42.5 (17)	0.058
Abdomen AIS value ≥3, % (n)	67.4 (29)	51.0 (26)	0 (0)	<0.001
Extremity AIS value ≥3, % (n)	20.9 (9)	13.7 (7)	15.0 (6)	0.617
ISS, mean ± SD	16.6 ± 10.6	18.4 ± 13.0	16.2 ± 10.6	0.618
ISS ≥16, % (n)	46.5 (20)	43.1 (22)	42.5 (17)	0.922
Presurgical WBC follow-up (hr), mean ± SD	10.6 ± 20.9	18.7 ± 30.3	37.3 ± 40.3	0.001
Time to laparotomy (hr), mean ± SD	14.7 ± 22.2	21.7 ± 29.6	43.1 ± 38.4	0.001
WBC presurgery >9.5, % (n)	81.4 (35)	78.4 (40)	62.5 (25)	0.103
No. WBC counts presurgery	2.8 ± 1.3	3.4 ± 2.0	4.4 ± 2.2	0.001

GCS, Glasgow Coma Scale; SBP, systolic blood pressure.

TABLE 5. Comparison of the Preoperative WBC Follow-Up in Patients With HVI (n = 43), Positive Laparotomy Without HVI (n = 51), and Negative Laparotomy (n = 40)

Outcome	Laparotomy Group	Mean ± SD	Unadjusted *p*	Adjusted Mean ± SE (95% CI)	Adjusted *p**
WBC on admission	HVI	13.4 ± 5.3	1.000	14.1 ± 0.93 (12.3–16.0)	0.074
	Positive without HVI	13.3 ± 5.7	1.000	13.8 ± 0.81 (12.2–15.4)	0.088
	Negative	12.2 ± 6.0	—	11.5 ± 0.98 (9.5–13.4)	—
Last preoperative WBC	HVI	16.0 ± 6.5	0.001	15.8 ± 1.00 (13.8–17.8)	0.008
	Positive without HVI	13.6 ± 5.7	0.168	13.3 ± 0.80 (11.7–15.0)	0.213
	Negative	11.4 ± 5.2	—	11.5 ± 1.00 (9.4–13.8)	—
Delta WBC	HVI	2.5 ± 7.0	0.097	1.7 ± 1.2 (−0.5–4.0)	0.366
	Positive without HVI	0.3 ± 7.4	1.000	−0.5 ± 1.0 (−2.5–1.5)	0.686
	Negative	−0.8 ± 6.9	—	0.1 ± 1.1 (−2.1–2.4)	—
Outcome	**Laparotomy Group**	**% (n)**	**Unadjusted *p* (χ^2)**	**Adjusted OR (95% CI)**	**Adjusted *p****
Increase of WBC count	HVI	74.4 (32/43)	0.006	2.04 (0.67–6.25)	0.213
	Positive without HVI	57.0 (29/51)	0.261	1.06 (0.40–2.78)	0.901
	Negative	45.0 (18/40)	—	1.00	—
No. WBC presurgery >9.5	HVI	81.4 (35/43)	0.055	3.45 (1.08–11.11)	0.038
	Positive without HVI	78.4 (40/51)	0.095	2.29 (0.86–6.14)	0.099
	Negative	62.5 (25/40)	—	1.00	—

* Adjusted for head AIS and WBC follow-up time (hr). The negative laparotomy group was used as reference for comparison.
Delta WBC = last preoperative WBC count − WBC count on admission.

but rather, a high variation in WBC counts was noted. Even patients with a low ISS[1–8] and those with no HVI may present with an elevated WBC count on admission.

Comparison of the Highest WBC Count Within the First 24 Hours for Patients With and Without a HVI

The literature examining serial preoperative WBC counts in trauma patients with HVI is scarce. In a review of 15 cases, Coleman and Dietz[11] concluded that serial WBC counts were not helpful in predicting a bowel injury. Nevertheless, serial WBC counts are widely used to evaluate trauma patients with questionable intraabdominal injuries. To examine the reliability of this practice, we compared the highest WBC counts within the first 24 hours for 4,520 patients without intraabdominal injuries with 43 patients with delayed laparotomy for a HVI. After adjusting for differences, a significantly higher WBC count was found for patients with a HVI (16.7 ± 4.7 and 13.0 ± 5.2, respectively). In addition, a maximal 24-hour WBC count ≥20 was found to be independently associated with a HVI. On the other hand, a maximal 24-hour WBC count ≤12.5 was independently associated with a lower risk of having a HVI. The clinical relevance of this finding is questionable as most of the WBC counts are within this range, resulting in a poor sensitivity of 29% in our series. The negative predictive value of a 24-hour WBC count of ≤12.5 for a positive laparotomy with HVI was 74%. Using this lower cutoff in isolation would have resulted in the failure to detect a HVI in 26% of patients. This emphasizes the high variability of WBC counts in trauma patients with a HVI and its unreliability in predicting those who require laparotomy. One possible explanation for the high variability in preoperative WBC counts may be differences in the sites of perforation. Unfortunately, the number of injuries in each group was too low to allow for any meaningful statistical analysis (n = 43: 17 small bowel, 19 colonic, 5 gastric, and 2 duodenal perforations).

Comparison of the Admission and the Last Preoperative WBC Counts Between Patients With a HVI and Patients Who Underwent Laparotomy for Reasons Other Than a HVI

The purpose of this comparison was to examine the predictive value of the preoperative WBC counts in detecting patients with a HVI requiring laparotomy. For this evaluation, we had two different control groups: patients who underwent laparotomy without HVI but with other positive findings and those with a negative laparotomy. We found that patients with a HVI had a significantly higher preoperative WBC count than all other patients who were subjected to laparotomy for other reasons. It is difficult, however, to make firm conclusions regarding the clinical applicability of the highest preoperative WBC counts for three reasons. First, the delta WBC count, calculated as the difference between the WBC count on admission and the very last preoperative count, did not differ significantly between the groups. Second, 45% of patients with a negative laparotomy also had increasing preoperative WBC counts. Third, a quarter (11 of 43) of patients with a HVI had a stable or even a decreasing WBC count before surgery. Therefore, again, a wide range of variability was seen in the admission to final preoperative WBC counts in these patients requiring laparotomy for HVI, making it a clinically unreliable value.

CONCLUSIONS

Multiple variables contribute to the initial burst of leukocytes in trauma patients. This leukocytosis on admission is nonspecific and unreliable as a diagnostic tool for HVI. Serial WBC counts demonstrate an increasing tendency in patients with a HVI; however, there is a high rate of variability. A highest WBC count within the first 24 hours of ≥ 20 is independently associated with a HVI, and a WBC count that remained ≤ 12.5 is associated with a lower risk of having a HVI. However, the sensitivity of these cutoff values for predicting a HVI is low. The diagnostic value of serial WBC counts for predicting a HVI within the first 24 hours after trauma is very limited.

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