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The Influence of Inhalation Injury and Pneumonia on Burn Mortality

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In order to assess the specific effects of inhalation injury and pneumonia on mortality in burn patients, the records of 1058 patients treated at a single institution over a five-year period, 1980–1984, were reviewed. Of these patients, 373 (35%) had inhalation injury diagnosed by bronchoscopy and/or ventilation perfusion lung scan. Of the 373 patients, 141 (38%) had subsequent pneumonia. Among the patients without inhalation injury, pneumonia occurred in 60 of 685 (8.8%). A multiple logistic equation was developed to estimate expected mortality at any age and burn size for patients without either inhalation injury or pneumonia, with either alone, or with both. Subtraction of the expected mortality without either inhalation injury or pneumonia from the expected mortality in the presence of either or both permitted the estimation of additional mortality attributable to these complications. Inhalation injury alone increased mortality by a maximum of 20% and pneumonia by a maximum of 40%, with a maximum increase of approximately 60% when both were present. The influence on mortality was maximal in the midrange of expected mortality without these complications for any age group. These data indicate that inhalation injury and pneumonia have significant, independent, additive effects on burn mortality and that these effects vary with age and burn size in a predictable manner.

IT IS GENERALLY RECOGNIZED that pulmonary complications adversely affect the outcome of patients with burn injury. In an autopsy study, 70% of all fire victims who died within 12 hours of burns had inhalation injury,[1] indicating that toxic gases and products of incomplete combustion contribute significantly to early postburn death. Cutaneous burns activate the complement cascade and induce intrapulmonary leukocyte aggregation, release of free radicals of oxygen, and pulmonary damage, possibly adding further respiratory insult to patients with inhalation injury. In addition, global immunosuppression accompanies, and is proportional to, the extent of burn injury. As a consequence, respiratory tract infection is the most common complication of burns.[2] Although both inhalation injury and pneumonia reduce patient survival, the specific contributions of these complications to age and burn size-dependent patient mortality have not been completely determined. We attempt to define, in explicit terms, the contributions of inhalation injury and pneumonia to patient mortality.

Materials and Methods

The records of 1058 consecutive burn patients treated at this institute during the five-year period between January 1980 and December 1984 were reviewed. The records were complete for all patients. Data were gathered on the status of inhalation injury on admission and on development of pneumonia during hospitalization. Patient survival was also noted. All patients received uniform care. Fluid resuscitation was performed according to a modified Brooke formula.[3] Burn wounds were treated with applications of silver sulfadiazine[4] and mafenide acetate cream alternated every 12 hours.[5] Nutritional support was provided to meet increased metabolic demands. Excision and grafting of the burn wound usually began during the first postburn week.

Inhalation injury was suspected in patients with facial burns and patients involved in structural fires or burned in a closed space. Patients were also considered at risk if they were mentally or physically impaired at the time of the accident. All patients at risk were investigated by

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bronchoscopy, ^{133}Xenon lung scan, or both.[6] Bronchoscopic diagnosis of inhalation injury in these individuals was made by demonstration of inflammatory changes in the respiratory tract. These changes included mucosal erythema, edema, or ulceration and submucosal hemorrhages with or without carbon deposition in the tracheobronchial tree.[7] Patients with an abnormal ^{133}Xenon lung scan independent of bronchoscopic findings were also considered to have inhalation injury. An abnormal lung scan consisted of ventilation perfusion mismatch or isotope retention exceeding 90 seconds.[8]

Of the 1058 patients, 487 patients were considered at risk for inhalation injury and were further studied. Bronchoscopy alone was performed in 140 patients, ^{133}Xenon lung scan alone was done in 106 patients, and both procedures were done in 241 patients. In patients with purulent sputum and physical findings suggestive of pneumonia, a chest roentgenogram was obtained and sputum or endotracheal secretions were examined by Gram-stained smears and by culture. Patients who had clinical signs and symptoms of respiratory tract infection and characteristic pneumonia infiltrates on chest roentgenograms received antibiotics. Initial antibiotic therapy for pneumonia was modified, if needed, when final culture and sensitivity results became available.[9]

Statistical differences between groups of patients with and without inhalation injury were assessed using the Student's t-test. Multiple logistic regression technique was used to develop a predictor of the occurrence of inhalation injury. A basic age and burn size-specific index, based on our experience in the treatment of over 6,000 burn patients at this institute over the past 3 decades, was used to assess severity of injury. In addition, the current group of 1058 patients was analyzed separately to assess specific contributions of inhalation injury and pneumonia to mortality.

Results

A diagnosis of inhalation injury was made in 373 patients (35.3%). Pertinent demographic data on the patients are shown in Figure 1 and Table 1. Twenty-one per cent of patients without inhalation injury and 73% of those with inhalation injury were confined in a closed environment at the time of their burns. Respectively, 93% and 52% of patients with and without inhalation injury sustained facial burns. Predicted mortality rate, based on the severity index, and observed mortality rate, respectively, were 17.9% and 9.6% in patients without inhalation injury and 48.2% and 46.6% in patients with inhalation injury. The relationship between inhalation injury and burn size for all patients is shown in Figure 2. With increasing burn size, there was a corresponding rise in the incidence of inhalation injury. With increasing burn size, the incidence of pneumonia increased in patients with injuries of less than 90% of the total body surface; beyond this, the incidence decreased, possibly because many such severely injured patients died soon after injury (Fig. 3). The incidence of pneumonia and predicted and observed mortality with or without inhalation injury, diagnosed either by bronchoscopy or by ^{133}Xenon lung scan alone, are displayed in Figure 4. There was a stepwise increase in the incidence of pneumonia from the patients without inhalation injury (8.8%) to the patients with abnormal ^{133}Xenon lung scan only (19.5%) to the patients with abnormal findings on bronchoscopy (45.8%). Figure 5 shows the incidence of pneumonia, postburn day of diagnosis of pneumonia, age, and burn size for all patients with and without inhalation injury diagnosed either by bronchoscopy or by ^{133}Xenon lung scan. The average day of di-

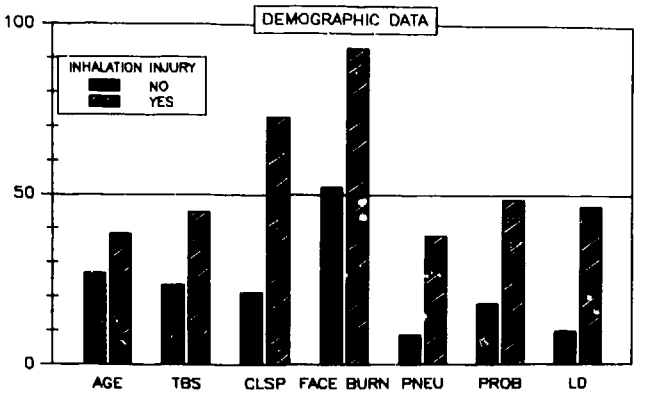

FIG. 1. Data on patients with and without inhalation injury. In patients with inhalation injury, age and total burn size (TBS) were slightly higher; more patients had injury in closed spaces (CLSP) and there was a higher incidence of facial burns and pneumonia (PNEU). Age and burn size-adjusted probability of death (PROB) and observed mortality (LD) per 100 patients were also higher in that group.

TABLE 1. *Patient Characteristics*

	No. of Patients	Age (years)*	Burn Size Percentage*	Patients with Closed Space Injury (%)	Patients with Face Burn (%)	Probability of Death (%)	Observed Mortality Rate (%)
No inhalation injury	685	27 (±20)	23 (±19)	21	52	17.9	9.6
Abnormal results on xenography	113	37 (±18)	33 (±22)	61	89	31.2	21.2
Abnormal results on bronchoscopy	260	39 (±21)	50 (±24)	78	95	55.6	57.7

* Numbers enclosed in parentheses indicate SD.

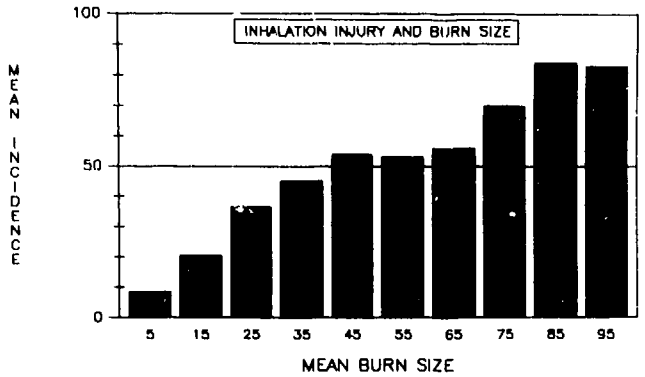

FIG. 2. Relationship between burn size and incidence of inhalation injury illustrates the rise in occurrence of inhlalation injury with increasing burn size.

agnosis of pneumonia was similar in all groups: 11 days for all patients, 15 days for patients without inhalation injury, and 10 days and 11 days, respectively, for patients with inhalation injury diagnosed by bronchoscopy or ^{133}Xenon lung scan. It should be noted, however, that in patients without inhalation injury, only 39% of cases of pneumonia developed within the first week, whereas in patients with inhalation injury, 69% had pneumonia within the first week. The lengths of time for pneumonia to develop in patients with abnormal findings on bronchoscopy and in patients with abnormal ^{133}Xenon lung scans were similar and are shown in Figure 6. The average age of all patients with pneumonia was 45 years, and the average burn size was greater than 52% of the total body surface area (Fig. 5).

Using a stepwise logistic regression algorithm, a predictor of inhalation injury was developed. The variables entering the equation were injury in a closed space (CLSP), presence of facial burns (FB), age, and total burn size (TBS):

$$Y = -4.4165 + 1.61(CLSP) + 1.77(FB) + .0237(TBS) + .0268(AGE)$$

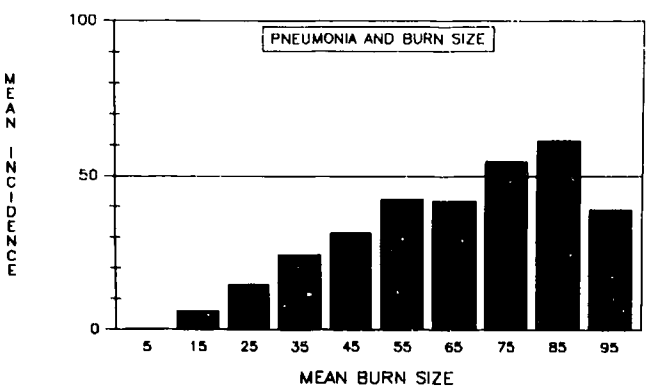

FIG. 3. There was a progressive rise in the incidence of pneumonia with increasing burn size except in patients with burns greater than 85% of the total body surface.

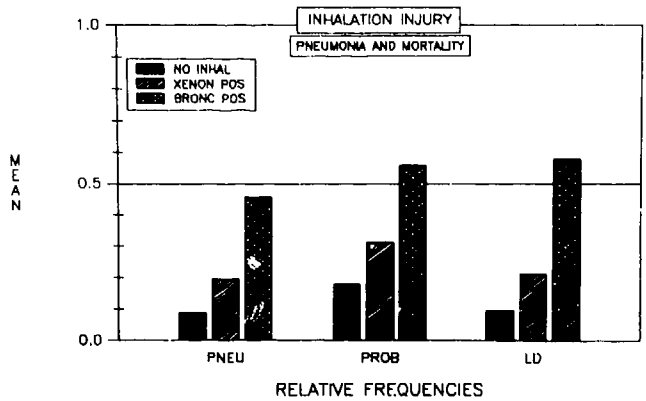

FIG. 4. There was a stepwise rise in the occurrence of pneumonia (PNEU) from patients without inhalation injury (NO INHAL) to those with inhalation injury diagnosed either by ^{133}Xenon lung scan alone (XENON POS) or by bronchoscopy (BRONC POS). Age and burn size-adjusted expected mortality (PROB) and observed mortality (LD) for patients with inhalation injury (XENON POS, BRONC POS) were also higher.

CLSP = 0, 1 (absence, presence of injury in closed space)
FB = 0, 1 (absence, presence of facial burn)
TBS = total burn as percent of total body surface area
AGE = age in years

$$P_{(II)} = \frac{e^Y}{1+e^Y}$$

$P_{(II)}$ = expected proportion of such patients with inhalation injury (limits = 0, 1)

A comparison of the observed incidence of inhalation injury and that predicted by the above equation is shown in Figure 7. At each level, prediction closely approximated observation.

Multiple logistic regression was also used to analyze mortality of all patients as a function of TBS, age, inha-

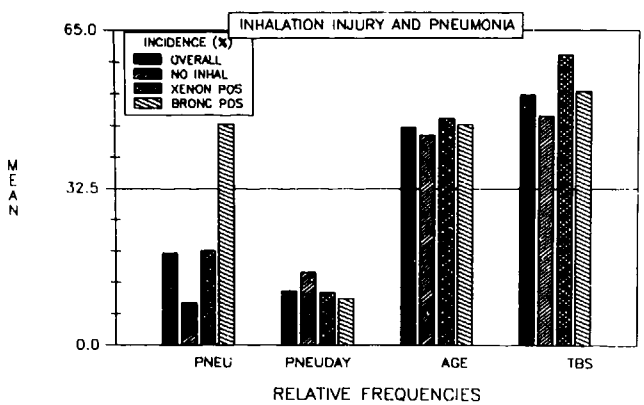

FIG. 5. Overall incidence of pneumonia (PNEU), day of diagnosis of pneumonia (PNEUDAY), age, and total burn size (TBS) for entire group (OVERALL) for patients without inhalation injury (NO INHAL) and for patients with inhalation injury diagnosed either by ^{133}Xenon lung scan only (XENON POS) or by bronchoscopy (BRONC POS) are shown. Note the highest incidence of pneumonia is in patients with inhalation injury diagnosed by bronchoscopy. The average day of diagnosis of pneumonia, age, and burn size, however, appear similar for all groups.

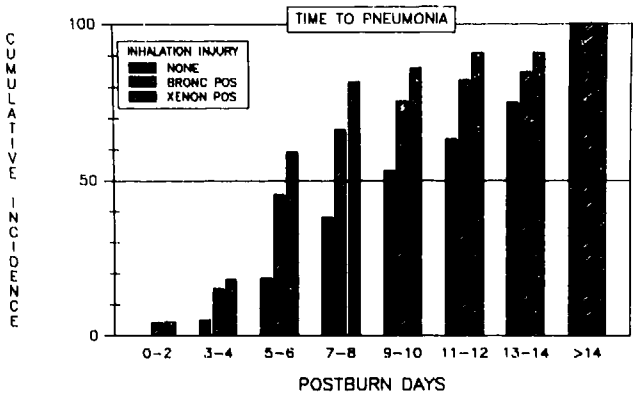

FIG. 6. Times to pneumonia for patients with inhalation injury diagnosed by ^{133}Xenon lung scan only (XENON POS) or by bronchoscopy (BRONC POS) were similar. Early pneumonia was more frequent in patients with inhalation injury.

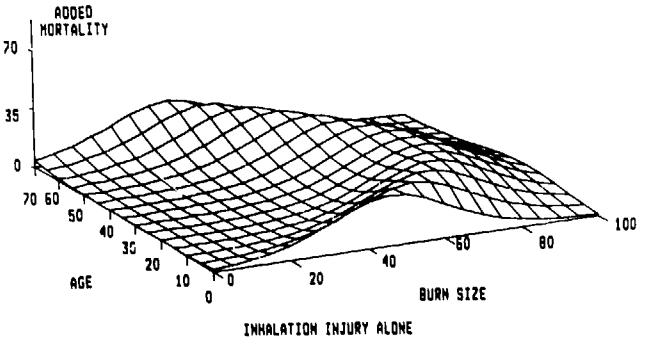

FIG. 8. Burn size as percentage of total body surface area on X axis, age on Y axis, and percent increment in mortality due to the presence of inhalation injury on Z axis are shown. Mortality, in the presence of inhalation injury alone, rose by a maximum of approximately 20% in patients in midrange of severity of injury as indexed by age and burn size.

lation injury (II), and pneumonia (PNEU), yielding the following equation:

$$Y = -3.4953 + .09589(TBS) - .19881(AGE) + .0044788(AGE^2) - .000020314(AGE^3) + .59056(II) + .92530(PNEU)$$

TBS = total burn as percent of total body surface area
AGE = age in years
II = −1, +1 (absence, presence of inhalation injury)
PNEU = −1, +1 (absence, presence of pneumonia)

$$P = \frac{e^Y}{1+e^Y}$$

P = expected mortality (limits = 0, 1)

This equation was used to estimate expected mortality in the absence of both inhalation injury and pneumonia, in the presence of either alone, and in the presence of both. Subtraction of the expected mortality without inhalation injury or pneumonia from that expected in the presence of those complications permitted the construction of three-dimensional graphs depicting specific contributions to mortality of inhalation injury alone (Fig. 8), pneumonia alone (Fig. 9), and inhalation injury and pneumonia combined (Fig. 10). Expected mortality increased by a maximum of 20% in the presence of inhalation injury alone, 40% in the presence of pneumonia alone, and 60% when both inhalation injury and pneumonia were present. The contributions of inhalation injury and pneumonia were found to be independent and additive. Expected mortality in patients with very small or very large burns appeared to be relatively uninfluenced by these pulmonary complications except at the extremes of age.

Discussion

In the current study, we determined how inhalation injury and pneumonia influence the outcome after burn injury. In this consecutive series, we confirmed previous findings in a smaller sample of patients in whom inhalation injury increased mortality.[10] Additionally, the cur-

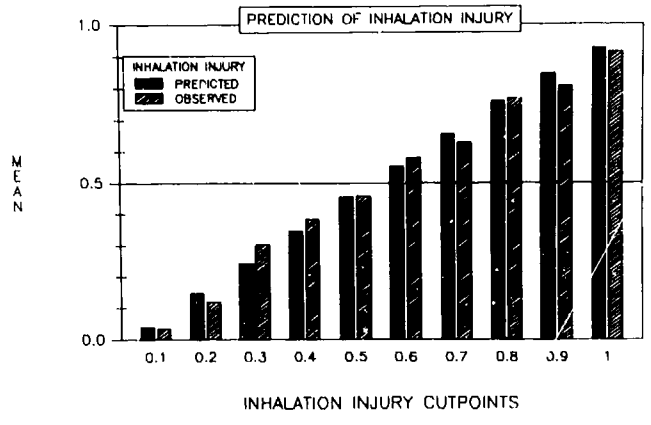

FIG. 7. Observed and predicted incidences of inhalation injury were remarkably similar (see text for details).

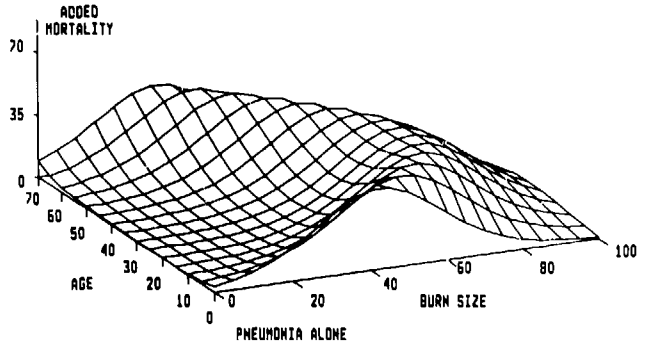

FIG. 9. Burn size as percentage of total body surface area on X axis, age on Y axis, and percent increment in mortality due to the presence of pneumonia on Z axis are shown. Mortality, in the presence of pneumonia alone, rose by a maximum of approximately 40% in patients in midrange of age and burn size.

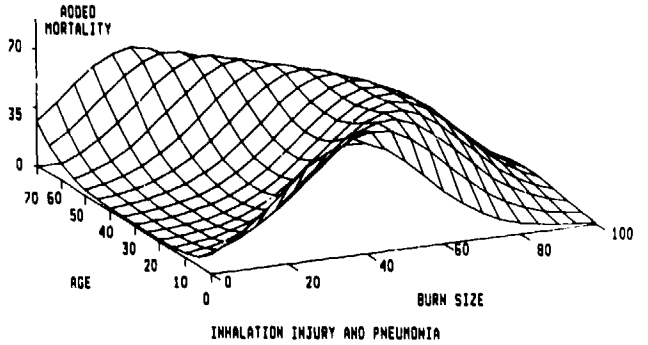

FIG. 10. Burn size as percentage of total body surface area on X axis, age on Y axis, and percent increment in mortality on Z axis are shown. Mortality rose by a maximum of approximately 60% in patients in midrange of age and burn size when both inhalation injury and pneumonia were present.

rent study estimates, in a quantitative manner, the increase in patient mortality in inhalation injury. Burn patient survival was also reduced in pulmonary infection.[11]

The current study estimates the precise roles of each of these pulmonary complications in the outcome of patients with burns. Our data indicate that both inhalation injury and pneumonia are detrimental to patient survival and that a maximal deleterious effect occurs in the midrange of burn severity. We have attempted to depict the explicit, additive changes in mortality attributable to these pulmonary complications as they relate to age and total burn size. The age and burn size-specific mortality increased by a maximum of 20% with inhalation injury alone, by 40% with pneumonia alone, and by 60% with both.

Inhalation injury and pneumonia contributed minimally to mortality in patients with small burns who did well despite these ills. Similarly, in patients with extensive burns, in whom the traumatic insult exceeded the physiologic reserve, neither the presence nor the absence of pulmonary complications altered the dismal outcome.

Interestingly enough, despite similar age and burn size, the incidence of pneumonia in patients with abnormal findings on bronchoscopic examination was higher than that in patients with either an abnormal ^{133}Xenon lung scan alone or no inhalation injury. It appears that respiratory tract damage that is diagnosed by lung scan alone, in the absence of abnormal bronchoscopic findings, represents a less severe form of injury than that detectable by bronchoscopy. The increased incidence of pneumonia in patients with visually demonstrable tracheobronchial inflammation appears to be ascribable to more extensive tracheobronchial injury. With massive tissue necrosis and disruption of the alveolar capillary membrane,[11,12] protein-rich plasma exudes into the tracheobronchial tree and may serve as a medium for bacterial growth. Inhalation injury, in addition to inflicting structural damage on the respiratory tract epithelium, impairs surfactant production[13] and mucocilliary transport and produces atelectasis.[14] Inhalation injury also impairs pulmonary macrophage function.[12] The net result of these pulmonary changes, combined with the global immunosuppression of burns,[15] is the development of respiratory tract infection. In patients with inhalation injury, early pneumonia was more common than in those patients without inhalation injury; in patients with inhalation injury, 69% of pneumonias occurred within the first postburn week, whereas 38% occurred in patients without inhalation injury.

In the individuals with abnormal findings on bronchoscopy, the ^{133}Xenon lung scan added little to either diagnosis or prognosis. Routine use of ^{133}Xenon lung scan in patients with abnormal bronchoscopic examinations seems, therefore, unwarranted. An abnormal ^{133}Xenon lung scan in a patient without abnormal findings on bronchoscopy, on the other hand, is significant for prognosis, since the incidence of pneumonia is higher in these patients than in those with no inhalation injury.

Thus far, a precise grading of clinical pulmonary damage consequent to inhalation injury has been impossible. In this regard, the current data allow partitioning of patients with inhalation injury into two broad categories: those with abnormal findings on bronchoscopy irrespective of the status of the ^{133}Xenon lung scan and those with abnormal ^{133}Xenon lung scan only. Such classification is pragmatic and permits sorting of burn patients into groups of those without inhalation injury, those with modest inhalation injury (abnormal ^{133}Xenon lung only), and those with severe inhalation injury (abnormal findings on bronchoscopy). Such stratification of pulmonary damage may permit further refinement of estimates of risk.

A predictor of the proportional frequency of occurrence of inhalation injury was developed that takes into account immediately available information, such as injury in a closed space, facial burns, age, and total burn size. Such information should be useful in triage.

In summary, our data indicate that both inhalation injury and pneumonia exert discrete, measurable effects on patient mortality and can, therefore, be used along with age and total burn size to predict the likelihood of death in burn patients with such complications. Inhalation injury diagnosed on the basis of bronchoscopic findings has a worse prognosis than pulmonary damage detectable only by a ^{133}Xenon lung scan. Both complications add to the total physiologic insult in a predictable manner, with little effect on mortality in patients with small injuries where the total burn can be borne or in patients with very large injuries whose physiologic capacity is exceeded by the injury alone. In the patients in the midrange of severity of injury, however, these complications may make a sub-

lethal injury lethal, and it is in these patients that better management of pulmonary complications may improve survival.

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