Severe thermal burn produces in the dog an immediate and profound reduction in the cardiac output. This finding was reported originally by Gilmore and Handford, Dobson and Warner, and has been confirmed by other investigators. The decrease in cardiac output is unrelated to changes in right atrial pressure, and occurs too rapidly to be explained on the basis of changes in plasma volume or heart rate. The restoration of plasma volume by the infusion of intravenous solutions does not result in a return of the cardiac output to preburn levels. When a cardiac glycoside is administered with the intravenous fluids, however, an increase in cardiac output to preburn values occurs. These observations suggest that a defect in myocardial contractility may occur after severe thermal trauma.

The present study was designed to determine directly whether or not a true defect in myocardial function can be demonstrated after severe thermal injury. The left ventricular function (VF) curve was utilized as an index of myocardial contractility. VF curves were obtained on dogs before and after 30 per cent body surface area thermal burn.

Methods

Fasting inbred beagles and mongrel dogs of both sexes (mean weight, 9.1 Kg.; range, 5.0 Kg. to 16.8 Kg.) were anesthetized with morphine sulfate (2 mg./Kg.) intramuscularly, followed in 30 minutes by chloralose (60 mg./Kg.) and urethane (600 mg./Kg.) intravenously. The trunks of the animals were shaved. The right and left femoral arteries, the left femoral vein, and the left jugular vein were cannulated. A tracheostomy tube was inserted. The cannula in the right femoral artery was connected to a Sanborn Pressure Transducer (267A) and arterial pressure recorded on a Sanborn 150 Multichannel Recorder. The jugular cannula was a small-bore plastic tube of sufficient length to reach approximately to the level of the right atrium. The left side of the chest was opened by means of a longitudinal incision in the anterior axillary line, transecting four or five ribs. Artificial respiration was carried out with a Respiration Pump Model 607. The pericardium was opened widely and two small electrodes were attached to the left atrial appendage. These electrodes were connected to a Model S4 Stimulator, and the heart paced at a constant rate (160 ± 20). A rigid metal cannula with an internal diameter of 2.9 mm. was inserted into the apex of the left ventricle through the apical dimple and sutured in place. The cannula was attached directly to a Sanborn Pressure Transducer (267B) and ventricular pressure recorded. The tip of the cannula was used for the zero reference point in recording ventricular pressure.

Cardiac output was determined by the continuous sampling dye-injection technique using indocyanine green and the Cuvette Densitometer. Dye was injected into the right atrium via the jugular cannula, and blood withdrawn at a constant rate from the left femoral artery through the cuvette by means of a falling column of mercury. Densitometer output was recorded on the multichannel recorder and cardiac output calculated by the formula described by Hamilton et al.

The data for the VF curves were obtained by the method described by Sarnoff et al. Gain settings for recording left ventricular end-diastolic pressure (LVEDP) were adjusted so that a pressure change from 0 to 30 to 40 cm. H2O produced a full-scale pen deflection. The respirator was turned off while the high-speed LVEDP tracings were obtained. Changes in LVEDP were determined. The opinions or assertions contained herein are the private ones of the writer and are not to be construed as official or reflecting the views of the Navy Department or the naval service at large.

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produced by the rapid infusion of heparinized whole blood from donor dogs. This blood was not mixed with that of the experimental animals prior to the determination of the first VF curve. Blood was removed slowly via the femoral vein at the conclusion of the VF curve procedure. Withdrawal was continued until LVEDP, cardiac output, and mean arterial pressure had returned to preinfusion levels. Arterial hematocrit was determined at the beginning and end of each VF curve procedure. No anticoagulant other than that contained in the donor blood was used.

The LVEDP was read at the point on the left ventricular diastolic pressure curve immediately before the onset of systole. Readings on 10 successive contractions were taken and mean LVEDP obtained. Stroke work in gram-meters was calculated by the formula described by Sar- noff and Berglund.

Data for plotting VF curves were obtained from 38 dogs. The animals were then blackened with powdered lampblack and 25 were subjected to a 20 cal/cm² (third-degree) burn of approximately 30 per cent of the body surface area. The remaining 13 control animals received sham burns. They were manipulated in a manner exactly similar to burning, but were not actually burned. The burn source and technique of burning were described in detail in a previous report from this laboratory. In brief, multiple small-area burns of five seconds' duration were administered in rapid succession on adjacent areas of skin until the desired body surface area was covered. The time required for the burning procedure varied, depending on the size of the animal, from 35 to 65 seconds. The VF curve procedure was repeated 30 to 60 minutes after the burn (or after sham burn). The animals were sacrificed after the postburn measurements were completed.

In each procedure, the preburn and postburn (or post sham burn) VF curves were plotted, and the direction of the shift in the position of the postburn curve in relation to the preburn curve was noted: to the right (impaired contractility), to the left (improved contractility), or no change. The number of dogs showing shifts in each direction was tabulated in the burned and unburned groups, and the results compared by chi-square analysis for multinominal data, testing the hypothesis that the burned and control groups were samples taken from the same population.

**Results**

In the control group, the sham burn produced a shift in the VF curve to the right in six dogs, to the left in five dogs, and no change in two dogs. This distribution is listed in table 1 under observed shifts in the control group.

Among the 25 burned dogs, 18 showed a shift of the VF curve to the right following burn, 6 remained unchanged, and in only 1 was there a shift of the postburn curve to the left. This distribution is listed in table 1 under observed shifts in the burned group.

Chi-square analysis of these data indicates that the two groups are heterogeneous ($\chi^2 = 7.90, P < 0.03$). Thus there was a significant difference between the response of the dogs which received thermal burn and the response of the animals which received sham burn.

In 11 of the 18 burned dogs in which a shift to the right was noted, the shift was to a marked degree, as indicated by a change in the slope of the curve as well as a change in the position. In only one of the six controls in which a shift to the right was noted did such a marked change occur.

Figures 1 to 4 are examples of VF curves obtained on individual dogs before and after burn. They illustrate the range in configur-
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Experiment 31. Dog weight, 8.6 Kg.; heart rate, 180. S.W. = stroke work in gram-meters; L.V.E.D. = left ventricular end-diastolic pressure in cm. H2O. Ventricular function curves before and after burn in which the position of the postburn curve was to the left of the preburn curve. Data for the postburn curve were obtained 29 minutes following the burn.

Mean arterial pressures below 70 mm. Hg were encountered immediately postburn in 9 of the 25 burned dogs, and following manipulation in 3 of the 13 controls. In all cases, the hypotension was associated with a shift of the VF curve to the right. This hypotension was not associated with significant changes in calculated peripheral vascular resistance11 or LVEDP. Hematocrit did not vary by more than 10 per cent during any procedure.

Discussion

The data presented indicate that in the animals studied, a reduction of myocardial contractility occurred following thermal burn. The control dogs subjected to a similar manipulation without burn showed significantly less evidence of such a change.

Reduced myocardial contractility, as indicated by a shift of the VF curve to the right, can occur by any one of several mechanisms. Elevated blood pressure produces a shift in the curve to the right by causing carotid sinus stimulation and a reflex decrease in cardiac sympathetic nerve activity.12 An increase in arterial pressure was not encountered after burn in this study but has been noted by other observers13 immediately following burn, presumably related to peripheral vasoconstriction. However, Gilmore found that pretreatment with dibenamine did not prevent the decrease in cardiac output which followed thermal burn, although it prevented this vasoconstriction.13 It therefore appears unlikely that the contractility change is related to increased carotid sinus pressure. Severe anemia results in a shift of the VF curve to the right,8 but could not have produced the
changes noted in this study since hematocrit did not change by more than 10 per cent between the preburn and postburn VF curves. Other investigators have noted that in the same type of burn used in this study, red cell mass decreases minimally or may actually increase during the early postburn period.\textsuperscript{14} Increased vagal activity does not alter the relationship between LVEDP and stroke work when heart rate is kept constant,\textsuperscript{9} and could not explain the observed changes. Direct impairment of the myocardium therefore appears to be the most plausible explanation for the contractility change which occurred postburn in the present study.

A shift of the VF curve to the left occurred in a greater per cent of control dogs than burned dogs. Stellate stimulation, infusion of sympathomimetic drugs, and decreased carotid sinus pressure produce a shift of the VF curve to the left.\textsuperscript{6,12} In this study, when hypotension was present, it was associated with a shift of the curve to the right. Increased sympathetic activity is therefore the most likely cause of a curve shift to the left. In spite of a probable increase in sympathetic activity following burn, however, only 1 of 25 burned dogs showed a shift to the left.

The mechanism by which the burn produced the observed findings is not clear. The elaboration of a toxic substance with properties which are inhibitory to the myocardium has been suggested as a possible cause for the decrease in cardiac output which occurs after thermal burn\textsuperscript{1,2} and could well account for the changes noted in this experiment. Another possibility is an inadequate sympathetic-adrenal medullary response to the burn. This phenomenon has been described after thermal burn, although not in the immediate postburn
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period. Myocardial ischemia secondary to hypovolemia and/or splanchnic pooling is a third alternative. Postburn electrolyte imbalance must also be considered, although electrolyte changes which have been reported in dogs postburn are not of great magnitude until several hours after burn. The results of the study do not indicate which of these factors, if any, is primarily responsible for the observed defect in contractility.

The possibility that the observed changes were the result of alteration in myocardial distensibility rather than contractility cannot be ruled out. If toxic factors are involved in the VF curve shifts, they could modify distensibility as well as contractility.

Summary
Several investigators have suggested that a defect in myocardial function occurs in the dog following severe thermal burn. A study was therefore undertaken in which myocardial contractility was measured before and after burn. The left ventricular function curve was used as an index of contractility. Ventricular function was measured immediately before and 30 minutes following 30 percent body surface area burn in 25 dogs, and before and after a sham burn in 13 control dogs. It was found that the burn produced a significantly greater impairment of myocardial contractility than did the sham burn. The mechanism by which the burn produced this alteration in contractility was not apparent from the results of this study.

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