OBSERVATIONS ON THE ELECTRIC LANCE AND THE WELFARE OF WHALES: A CRITICAL APPRAISAL

D K Blackmore[1], P Madie[2†] and G R G Barnes[3]

[1] The New Zealand Foundation for the Study of the Welfare of Whales, 371 Albert St, Palmerston North, New Zealand

[2] Cetacean Investigation Centre, Faculty of Veterinary Science, Massey University, Palmerston North, New Zealand

[3] Department of Physics, Massey University, Palmerston North, New Zealand

† Contact for correspondence and requests for reprints.

Final acceptance: 17 May 1996

Abstract *Animal Welfare 1997, 6:* 43-51

*Japanese whalers use the electric lance as a secondary method of killing minke whales (*Balaenoptera acutorostrata*). The lances are dropped into the body, and currents varying between 2.2 and 14.0A, with a mean of 6.8A, are applied.*

When currents of 5A were applied to the carcasses of dead whales, varying in size from 1.8 to 15.7m in length, no current densities induced in the target organs were sufficient to cause either insensibility (10mA cm^{-2} in the brain), or to cause ventricular fibrillation (0.5mA cm^{-2} in the heart), except in a few cases where electrodes were specifically placed to span the heart. When electrodes were placed in positions normally used in whaling operations, no current densities were produced which would have been sufficient to cause brain and cardiac dysfunction.

Further investigations on changes in current density with time post mortem *after application of a controlled current of 5A showed, during a 60 hour period, a fourfold increase in the current density in the heart, and more than a twofold increase in the brain. Thus contrary to previous criticisms, if these studies had been carried out on live animals, all current densities would have been below threshold values.*

There are no records of signs of epileptiform seizure, which are associated with an effective electrical stun, in whales subjected to the electric lance.

It is concluded that the electric lance as used in whaling operations is ineffective and likely to cause extra pain and suffering to an already distressed animal.

Keywords: *animal welfare, behaviour, brain, conductivity, current density, electric lance, heart, insensibility, pain, ventricular fibrillation, whales*

Introduction

Commercial whaling is mainly confined to the slaughter of minke whales (*Balaenoptera acutorostrata*). Animals are usually captured by means of an exploding harpoon, attached by a line to the catching vessel. The majority of whales are not killed instantaneously and many are still alive when winched alongside the boat (Kestin 1995). In such circumstances a secondary method of killing is employed. In Norwegian operations live harpooned animals are shot with a rifle (Øen 1992). In Japanese operations the electric lance is used as a so-called secondary method of killing (Government of Japan 1995). Published data on the electric lance will be outlined in greater detail, later in this paper. Essentially the use of the electric lance consists of dropping two or more electrodes into the whale and applying a current at a controlled voltage of between 110 and 220V. This procedure has been claimed to cause death by causing cardiac fibrillation (Hayashi 1980). To cause instantaneous insensibility and cardiac fibrillation the current would need to be sufficient to cause depolarization of the neurones in the brain, and to affect the sino-atrial node in the heart (pacemaker) and other conducting systems affecting the function of cardiac muscle. These are the physiological effects used to evaluate the effectiveness of head-to-body electrical stunning of domestic stock in an abattoir (Blackmore & Delany 1988).

In domestic stock the effectiveness of electrical stunning on cerebral function can be objectively assessed by means of electroencephalograms (EEGs), and cardiac function by electrocardiograms (ECGs). A less objective, but still useful assessment can also be made from the behaviour of stunned animals; those which have been effectively stunned will exhibit signs of a classical epileptiform seizure, with both tonic and clonic convulsions (Blackmore & Delany 1988).

Another approach, which can be used when interpreting data from dead animals, is to determine the current density in the heart and brain measured in milliamperes per cm^2, as opposed to the current applied to the animal to achieve these effects which is measured in amperes. Such measurements should determine whether or not a predetermined applied current is sufficient to reach a threshold density in these target organs, which would have ensured both brain and cardiac dysfunction if the animal had been alive (Barnes *et al* 1996).

The authors of the present paper carried out such investigations of current density on dead, stranded whales in New Zealand. This work was originally presented to the International Whaling Commission (IWC) (Blackmore *et al* 1994; Barnes *et al* 1995) and later submitted for publication in much greater detail (Barnes *et al* 1996). The authors concluded that the electric lance was ineffective in causing death or insensibility, and furthermore, the sub-lethal currents were likely to cause extra pain and suffering to an already distressed animal.

At the IWC meeting in 1995, these claims were refuted by some on the basis that some of the whales investigated had been dead for more than two days. They stated that the resistivity of tissues changes after death, and as a result the current density would decrease, and that the distribution of current would change within the carcasses. Thus if similar trials had been carried out on live animals, the current densities recorded would have been sufficient to be effective in inducing immediate insensibility (Anon 1995). Hayashi (1995) also claimed to have carried out trials on dead dogs, and demonstrated a 50 per cent decrease in carcass conductivity (increased resistivity) after death. This is contrary to all other published information.

The present paper will attempt to cover four main topics. First, it will give an outline of the published information on physical aspects of the electric lance with special reference to the electrical characteristics associated with its use. Second, it will summarize the published work on current densities recorded in dead whales and threshold values required to induce brain and cardiac dysfunction. Third, it will present new data on changes in current density with time, which occur in whales *post mortem*. Finally, it will attempt to critically review all the data available, including the behaviour of whales subjected to electric currents, in an attempt to provide an objective appraisal of welfare aspects of the electric lance. Part of the material presented here was published in the 1996 Proceedings of the International Whaling Commission's Aberdeen technical meeting.

The electric lance

The electric lance consists of a long pole insulated from a sharp pointed electrode. Two or more are dropped into the body of the whale from the catching vessel. It is claimed that one lance is placed in the vicinity overlying the heart, and the other more caudally in the dorsal surface of the body (Government of Japan 1993). From the data presented by McLachlan (1995), placement of the lances appears to occur in a much more haphazard manner.

Both Kestin (1995) and McLachlan (1995) give good general descriptions of the apparatus. A 1993 report (Government of Japan 1993) provides a diagram of the lances and states that the electrodes are 900mm long, and sharp pointed. Hayashi (1980) states they are 50mm in diameter.

The current applied at the electrodes is from the ship's generators. Originally it was stated to be at a controlled voltage of 110V at 60Hz with a maximum current output of 5A (Hayashi 1980). More recently, a controlled voltage of 220V has been used by some catching vessels. In a paper presented to the IWC in 1995 (Government of Japan 1995), it was claimed that the currents applied varied between 2.2 and 14.0A, with a mean and median of 6.8 and 6.7A respectively. Interpretation of these data was difficult as the techniques employed were not described, the graphical presentation was confusing and the maximum current output from the ship's generators was not stated. By application of a controlled voltage, as opposed to a controlled current, current densities in, and associated physiological effects on, the animal will be subject to considerable variation. This is illustrated by the reported variations in current referred to above.

Hayashi (1980) claims to have carried out ECG studies on whales in the sea, subsequent to application of the electric lance, and to have demonstrated the induction of ventricular fibrillation of the heart. However, this work does not stand up to critical analysis for a variety of reasons. He does not explain how he avoided the problems related to measuring such small electrical impulses in an environment of sea water. He fails to show a recording of ventricular fibrillation. The ECG recording of what he considers to be normal cardiac activity, is far from convincing.

Previous work on current densities in the brain and heart of dead whales

The authors of the present paper have studied the current densities in the brain and heart of dead stranded whales, resulting from the application of a controlled current of 5A. Detailed description of the methods used, and the results obtained, are published elsewhere (Barnes *et al* 1996). Six carcasses were used, varying in size from a 1.8m pygmy sperm whale (*Kogia breviceps*) to a 15.7m sperm whale (*Physeter macrocephalus*), and included a 3.2m minke whale (*Balaenoptera acutorostrata*). The estimated time after death when measurements were made varied between 36 and 60 hours. Currents were applied to the carcasses by electrodes of two sizes, one being similar to that used in the electric lance. Current densities were recorded by means of specially designed sensors inserted in the brain and heart.

The minimal current densities generated in the target organs by a current applied elsewhere to the body have been determined as: 10mA cm^{-2} to cause depolarization of neurones in the brain of domestic stock (Barnes *et al* 1996); and 0.5mA cm^{-2} to cause ventricular fibrillation in pigs, dogs and other species (Reilly 1994). The validity of these estimated threshold values is discussed in greater detail elsewhere (Barnes *et al* 1996). Even when electrodes were placed in optimal positions to span the brain, the maximum current density in the brain was 5mA cm^{-2}, recorded from the relatively small pygmy sperm whale. In four cases the mean current density in the heart exceeded the threshold value of 0.5mA cm^{-2}. These included the pygmy sperm whale, a 3m strap-toothed whale (*Mesoplodon layardii*), a 5.8m Bryde's whale (*Balaenoptera edeni*) and the 3.2m minke whale.

In all these cases the electrodes were placed to span the heart. When electrodes were inserted in the positions recorded by McLachlan (1995) as occurring in Japanese whaling operations, current densities in neither the brain nor the heart reached the threshold values necessary to cause dysfunction (Barnes *et al* 1996).

It was concluded that the electric lance was ineffective, and that the sub-lethal current densities were likely to cause extra pain and suffering to an already distressed animal.

Changes in current density with time *post mortem*, measured in the brain and heart of whales

As mentioned earlier, when these results were presented to the IWC (Barnes *et al* 1995), they were criticized on the grounds that the studies had been conducted on dead whales. It was suggested that if similar studies had been carried out on live whales, recorded values would have been above threshold values, and the technique of electric lancing vindicated.

These assertions were surprising from two points of view. First, as a controlled current was applied, any changes in tissue resistivity, whether up or down, would have been counteracted by an appropriate change in voltage, and 5A would still be applied. Thus, current densities at the target organs would remain the same, providing changes in resistivity did not alter the pathways of flow through the carcass. Second, contrary to previously published material (Swatland 1980; Zheng *et al* 1984), it was suggested that the resistivity of tissues increases after death, and therefore the results presented were a significant underestimate.

In an attempt to resolve these criticisms and differences in opinion, it was decided to measure changes in current density in the carcasses of whales for up to five days *post mortem*, resulting from the application of a controlled current of 5A without movement of the carcass, the current application electrodes or the sensing electrodes in the brain and heart. Although the following results are preliminary in that they are part of a longer-term project, they are believed to be valid in terms of this review of the humane aspects of the electric lance.

The first investigation was carried out on a 3m pilot whale (*Globicephala melaena*), which died in a mass stranding 13 hours before the first measurement was made. The techniques and equipment employed were the same as previously described in detail (Barnes *et al* 1996). The current application electrodes were inserted 300mm through the blubber and into the muscle. The cranial electrode was in contact with the caudal aspect of the skull, and the other electrode was inserted one metre caudally. Both electrodes were in the dorsal surface of the carcass, 50–60mm lateral to the mid-line. The sensing electrodes were inserted into the brain and heart, and the accuracy of placement was confirmed by dissection at the completion of the trial.

Measurements of current density in the brain and heart resulting from the application of a controlled current of 5A were recorded approximately every 12 hours for up to 95 hours after the death of the animal. Recordings of the voltage were also made. Readings of current density were made in groups of ten during two intervals of less than 30 seconds spaced five minutes apart. By the tenth reading, stability had largely been reached. The mean of these last two stable readings was used for further comparisons and in Figures 1 and 2.

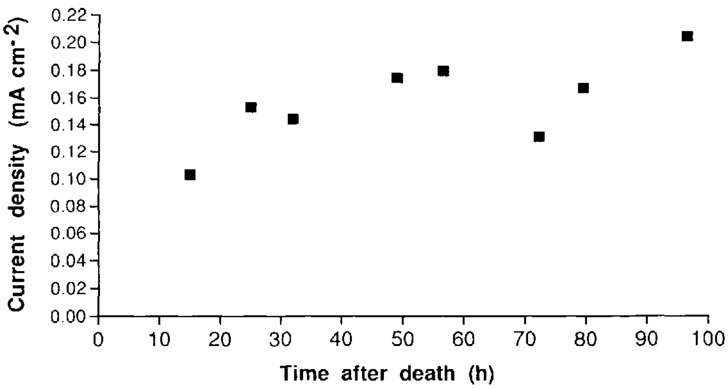

Figure 1 **Brain current density vs time after death.**

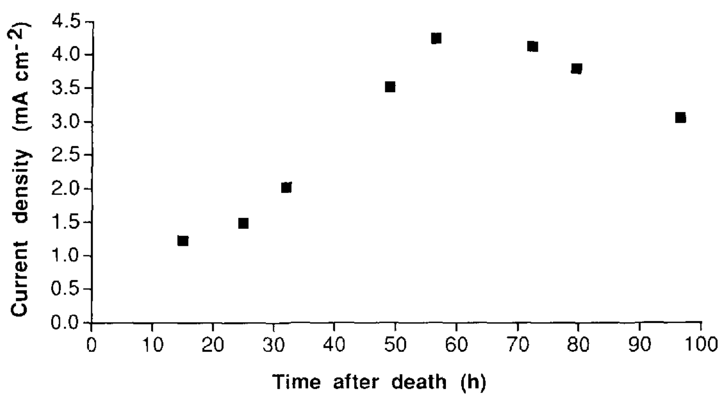

Figure 2 **Heart current density vs time after death.**

Figures 1 and 2 illustrate the results obtained. Current densities in the brain rose approximately twofold in the first 2½ days, and current densities in the heart fourfold in the same period. The subsequent apparent decline in the current density in the heart after 60 hours could possibly be associated with the formation of bubbles of gas in the blood in the heart. This could result in poor contact between the sensing electrodes and the tissues and fluids in the heart.

It is also interesting to note that the measurements made are very similar to those previously recorded from similar sized whales at the same times after death (Barnes *et al* 1995). Even the highest measurements did not reach the minimum threshold values required to induce dysfunction.

Another point of interest is that although the current was controlled at 5A, and the current densities increased in relation to time, the voltage remained relatively constant. This probably indicates that, as might be expected, there were different changes in the resistivity of different tissues with time after death. Thus as the body of an animal can be considered in simple terms as a number of resistors in parallel, the pathway of current from the electrodes to the brain and heart may have changed.

Although it is still necessary to study possible changes in current density from immediately after death for at least 13 hours, the data presented clearly demonstrates that measurements of current density in dead whales are a valid method for evaluating the likely effects of the electric lance in live animals. The work also indicates that recorded measurements in whales, which have been dead for more than 13 hours, will give an overestimate of the current densities which would be induced in live whales.

The behaviour of whales subjected to electric currents

As mentioned previously, an effective electrical stun induces an epileptiform seizure characterized by tonic convulsions with marked contraction of muscles, followed by clonic convulsions with associated incoordinate violent movements, affecting the whole body. In sheep the tonic phase persists for at least 15s, and is characterized by rigid extension of the forelegs. The following clonic phase persists for around 25s and is characterized by violent kicking movements. Similar signs occur in pigs and cattle (Blackmore & Delany 1988).

In the 1930s when trials were being carried out on electrical harpoons as a primary method of killing whales, as opposed to the electric lance, currents of up to 56A and over 200V were employed. From the review of this early literature (Mitchell 1986), it would appear that with these more realistic applications of currents, whales exhibited the signs of an epileptiform seizure. These signs included flexion of the body and extension of the flippers. As whales derive their forward propulsive force by an upward stroke of their tail (Bryden 1989), it would be logical to assume the extensor muscles are more powerful than the flexor muscles in the tail. Thus tonic spasms are likely to result in upward extension of the tail as recorded in the early German trials (Mitchell 1986).

No written records of the signs of an epileptiform fit associated with the currently used electric lance have been found. Neither has scrutiny of films shown on public television revealed such signs. Violent convulsions apparently occur as soon as the current is applied. These clonic movements, without preceding tonic convulsions, are more likely to be indicative of local muscle stimulation and probably pain, rather than insensibility.

General discussion

Based on a knowledge of the amount of electrical energy required to stun domestic stock, the power delivered to whales by the electric lance would appear to be totally inadequate. It is recommended in New Zealand (Anon 1994) that with electrodes spanning the brain, at least 1A must be applied to the head of sheep in order to achieve sufficient current density in the brain, and in such cases the voltage may rise to over 400V. Thus for a 50kg animal, 400 watts are required for an effective stun. The electric lance is applied to 6 tonne minke whales without accurate placement of electrodes, and according to the most recent data (Government of Japan 1995), delivers only a mean of 6.8A at either 110 or 220V. This equates to 748 or 1496 watts being applied to an animal with a mass of over 100 times that of a sheep. Without details of how these figures of mean applied current were obtained, one must consider the possibility that electric current in the whales is considerably less than that implied, due to current occurring in sea water between the electrodes (short circuiting).

The hypothesis, that the electrical output of the electric lance is totally inadequate, is strongly supported by the work on current densities in the brain and heart of dead whales after application of controlled currents of 5A. First, these were controlled currents, not controlled voltages as used in the lance. Thus variations in overall impedance of the carcass would have less effect on the measurements recorded than if controlled, steady voltages had been used. Second, the threshold figures of 10mA cm^{-2} and 0.5mA cm^{-2}, considered to be necessary to cause brain and cardiac dysfunction respectively, were extremely conservative. The calculated figure for brain dysfunction in pigs was above 20mA cm^{-2} (Barnes *et al* 1995). The current density required to induce ventricular fibrillation also has been determined as 0.5mA cm^{-2} by a totally independent worker in the USA for a wide variety of species (Reilly 1994). As discussed earlier, if measurements had been carried out on live whales, the current densities would have been even lower.

Apart from the inadequate current densities induced by the electric lance in the brain and heart, there is no evidence that any whale subjected to the effects of the electric lance shows any behavioural signs of an effective electrical stun.

The previous criticisms of our work, based on hypotheses formulated on changes in tissue conductivity with time after death, would seem to be negated by both the references to previous literature on the subject, and our preliminary work on a dead whale from 13 to 96 hours *post mortem*. Work by others (Swatland 1980; Zheng *et al* 1984) have demonstrated decreases in tissue resistivity with time after death commencing within a few hours after death. Further work is being carried out by the present authors, on both sheep and cetaceans, from the point of death for up to five days. When this work is completed, the findings will be discussed in detail and the resulting manuscript will also be submitted for publication in a refereed journal. It is regretted that so many of the references to the electric lance, quoted in this paper, were unrefereed papers submitted to the IWC and apparently not also published in recognized scientific journals and subject to peer review and criticism.

Animal welfare implications

Based on the information contained in this paper, the authors can find no reason to alter their opinion that the electric lance as currently used in whaling operations, is ineffective and likely to cause extra pain and suffering to an already distressed animal. In order to stop this inhumane treatment of whales a prohibition of the use of electricity to kill these animals must

be enforced. It is hoped that the IWC will finally ban the use of the electric lance at its meeting in 1997. This would be a great step forward for the welfare of whales.

Acknowledgements

The authors wish to acknowledge the Royal Society for the Prevention of Cruelty to Animals (RSPCA) for a specific grant to investigate changes in the conductivity of cetacean tissue *post mortem*. We are also most grateful to the RSPCA, the Whale and Dolphin Conservation Society and the World Society for the Protection of Animals for general financial support. This work could not have been achieved without the cooperation and assistance of members of the Department of Conservation in New Zealand.

References

Anon 1994 *Code of Recommendations and Minimum Standards for the Welfare of Animals at the Time of Slaughter at Licensed and Approved Premises.* Animal Welfare Advisory Committee. Ministry of Agriculture: Wellington, New Zealand

Anon 1995 Report of the workshop on whale killing methods. *Proceedings of the International Whaling Commission.* IWC/47/18

Barnes G R G, Madie P and Blackmore D K 1995 Further investigations relevant to the use of the electric lance in whaling. *Proceedings of the International Whaling Commission.* IWC/47/HK2

Barnes G R G, Madie P and Blackmore D K 1996 An assessment of the humane aspects of electric lancing of whales by measurement of current densities in the brain and heart of dead animals. *Medical & Biological Engineering & Computing 34:* 1-11

Blackmore D K and Delany M W 1988 *Slaughter of Stock: A Practical Review and Guide.* Publication No 118, Veterinary Continuing Education, Massey University: Palmerston North, New Zealand

Blackmore D K, Nutman A, Barnes G R G, Madie P, Davies A S, Bowling M C, Donoghue M and Kirk E J 1994 Preliminary investigations of techniques for killing whales. *Proceedings of the International Whaling Commission.* IWC/46/HK4

Bryden M M 1989 Adaptation to the aquatic environment. In: Harrison R H and Bryden M M (eds) *Whales, Dolphins and Porpoises* pp 112. Weldon Owen Pty Ltd: Sydney, Australia

Government of Japan 1993 Study of the humane killing of whales conducted in the Antarctic in the 1992/93 season in conjunction with the national research program. *Proceedings of the International Whaling Commission.* IWC/45/HK8

Government of Japan 1995 Report on killing method for the 1994/1995 Antarctic minke whale research operations. *Proceedings of the International Whaling Commission.* IWC/47/WK11

Hayashi Y 1980 Report on method of catching minke whales. *Proceedings of the International Whaling Commission.* IWC/SC/32/024

Hayashi Y 1995 Quoted in discussion of IWC/47/WK2. In: Report of the workshop on whale killing methods p 7. *Proceedings of the International Whaling Commission.* IWC/47/18

Kestin S C 1995 Welfare aspects of the commercial slaughter of whales. *Animal Welfare 4:* 11-27

McLachlan H 1995 The use of electricity to kill whales: humane considerations. *Animal Welfare 4:* 125-129

Mitchell E 1986 Aspects of pre-world war II German electrical whaling. In: Mitchell E D, Reeves R R and Evely A (eds) *Bibliography of Whale Killing Techniques* pp 115-129. International Whaling Commission: Cambridge, UK

Øen E O 1992 The Norwegian hunt of minke whales: hunting trials using 20mm high-velocity projectiles in 1982. *Proceedings of the International Whaling Commission.* IWC/44/HKW3

General discussion

Based on a knowledge of the amount of electrical energy required to stun domestic stock, the power delivered to whales by the electric lance would appear to be totally inadequate. It is recommended in New Zealand (Anon 1994) that with electrodes spanning the brain, at least 1A must be applied to the head of sheep in order to achieve sufficient current density in the brain, and in such cases the voltage may rise to over 400V. Thus for a 50kg animal, 400 watts are required for an effective stun. The electric lance is applied to 6 tonne minke whales without accurate placement of electrodes, and according to the most recent data (Government of Japan 1995), delivers only a mean of 6.8A at either 110 or 220V. This equates to 748 or 1496 watts being applied to an animal with a mass of over 100 times that of a sheep. Without details of how these figures of mean applied current were obtained, one must consider the possibility that electric current in the whales is considerably less than that implied, due to current occurring in sea water between the electrodes (short circuiting).

The hypothesis, that the electrical output of the electric lance is totally inadequate, is strongly supported by the work on current densities in the brain and heart of dead whales after application of controlled currents of 5A. First, these were controlled currents, not controlled voltages as used in the lance. Thus variations in overall impedance of the carcass would have less effect on the measurements recorded than if controlled, steady voltages had been used. Second, the threshold figures of 10mA cm^{-2} and 0.5mA cm^{-2}, considered to be necessary to cause brain and cardiac dysfunction respectively, were extremely conservative. The calculated figure for brain dysfunction in pigs was above 20mA cm^{-2} (Barnes *et al* 1995). The current density required to induce ventricular fibrillation also has been determined as 0.5mA cm^{-2} by a totally independent worker in the USA for a wide variety of species (Reilly 1994). As discussed earlier, if measurements had been carried out on live whales, the current densities would have been even lower.

Apart from the inadequate current densities induced by the electric lance in the brain and heart, there is no evidence that any whale subjected to the effects of the electric lance shows any behavioural signs of an effective electrical stun.

The previous criticisms of our work, based on hypotheses formulated on changes in tissue conductivity with time after death, would seem to be negated by both the references to previous literature on the subject, and our preliminary work on a dead whale from 13 to 96 hours *post mortem*. Work by others (Swatland 1980; Zheng *et al* 1984) have demonstrated decreases in tissue resistivity with time after death commencing within a few hours after death. Further work is being carried out by the present authors, on both sheep and cetaceans, from the point of death for up to five days. When this work is completed, the findings will be discussed in detail and the resulting manuscript will also be submitted for publication in a refereed journal. It is regretted that so many of the references to the electric lance, quoted in this paper, were unrefereed papers submitted to the IWC and apparently not also published in recognized scientific journals and subject to peer review and criticism.

Animal welfare implications

Based on the information contained in this paper, the authors can find no reason to alter their opinion that the electric lance as currently used in whaling operations, is ineffective and likely to cause extra pain and suffering to an already distressed animal. In order to stop this inhumane treatment of whales a prohibition of the use of electricity to kill these animals must

Figures 1 and 2 illustrate the results obtained. Current densities in the brain rose approximately twofold in the first 2½ days, and current densities in the heart fourfold in the same period. The subsequent apparent decline in the current density in the heart after 60 hours could possibly be associated with the formation of bubbles of gas in the blood in the heart. This could result in poor contact between the sensing electrodes and the tissues and fluids in the heart.

It is also interesting to note that the measurements made are very similar to those previously recorded from similar sized whales at the same times after death (Barnes *et al* 1995). Even the highest measurements did not reach the minimum threshold values required to induce dysfunction.

Another point of interest is that although the current was controlled at 5A, and the current densities increased in relation to time, the voltage remained relatively constant. This probably indicates that, as might be expected, there were different changes in the resistivity of different tissues with time after death. Thus as the body of an animal can be considered in simple terms as a number of resistors in parallel, the pathway of current from the electrodes to the brain and heart may have changed.

Although it is still necessary to study possible changes in current density from immediately after death for at least 13 hours, the data presented clearly demonstrates that measurements of current density in dead whales are a valid method for evaluating the likely effects of the electric lance in live animals. The work also indicates that recorded measurements in whales, which have been dead for more than 13 hours, will give an overestimate of the current densities which would be induced in live whales.

The behaviour of whales subjected to electric currents

As mentioned previously, an effective electrical stun induces an epileptiform seizure characterized by tonic convulsions with marked contraction of muscles, followed by clonic convulsions with associated incoordinate violent movements, affecting the whole body. In sheep the tonic phase persists for at least 15s, and is characterized by rigid extension of the forelegs. The following clonic phase persists for around 25s and is characterized by violent kicking movements. Similar signs occur in pigs and cattle (Blackmore & Delany 1988).

In the 1930s when trials were being carried out on electrical harpoons as a primary method of killing whales, as opposed to the electric lance, currents of up to 56A and over 200V were employed. From the review of this early literature (Mitchell 1986), it would appear that with these more realistic applications of currents, whales exhibited the signs of an epileptiform seizure. These signs included flexion of the body and extension of the flippers. As whales derive their forward propulsive force by an upward stroke of their tail (Bryden 1989), it would be logical to assume the extensor muscles are more powerful than the flexor muscles in the tail. Thus tonic spasms are likely to result in upward extension of the tail as recorded in the early German trials (Mitchell 1986).

No written records of the signs of an epileptiform fit associated with the currently used electric lance have been found. Neither has scrutiny of films shown on public television revealed such signs. Violent convulsions apparently occur as soon as the current is applied. These clonic movements, without preceding tonic convulsions, are more likely to be indicative of local muscle stimulation and probably pain, rather than insensibility.

General discussion

Based on a knowledge of the amount of electrical energy required to stun domestic stock, the power delivered to whales by the electric lance would appear to be totally inadequate. It is recommended in New Zealand (Anon 1994) that with electrodes spanning the brain, at least 1A must be applied to the head of sheep in order to achieve sufficient current density in the brain, and in such cases the voltage may rise to over 400V. Thus for a 50kg animal, 400 watts are required for an effective stun. The electric lance is applied to 6 tonne minke whales without accurate placement of electrodes, and according to the most recent data (Government of Japan 1995), delivers only a mean of 6.8A at either 110 or 220V. This equates to 748 or 1496 watts being applied to an animal with a mass of over 100 times that of a sheep. Without details of how these figures of mean applied current were obtained, one must consider the possibility that electric current in the whales is considerably less than that implied, due to current occurring in sea water between the electrodes (short circuiting).

The hypothesis, that the electrical output of the electric lance is totally inadequate, is strongly supported by the work on current densities in the brain and heart of dead whales after application of controlled currents of 5A. First, these were controlled currents, not controlled voltages as used in the lance. Thus variations in overall impedance of the carcass would have less effect on the measurements recorded than if controlled, steady voltages had been used. Second, the threshold figures of 10mA cm^{-2} and 0.5mA cm^{-2}, considered to be necessary to cause brain and cardiac dysfunction respectively, were extremely conservative. The calculated figure for brain dysfunction in pigs was above 20mA cm^{-2} (Barnes *et al* 1995). The current density required to induce ventricular fibrillation also has been determined as 0.5mA cm^{-2} by a totally independent worker in the USA for a wide variety of species (Reilly 1994). As discussed earlier, if measurements had been carried out on live whales, the current densities would have been even lower.

Apart from the inadequate current densities induced by the electric lance in the brain and heart, there is no evidence that any whale subjected to the effects of the electric lance shows any behavioural signs of an effective electrical stun.

The previous criticisms of our work, based on hypotheses formulated on changes in tissue conductivity with time after death, would seem to be negated by both the references to previous literature on the subject, and our preliminary work on a dead whale from 13 to 96 hours *post mortem*. Work by others (Swatland 1980; Zheng *et al* 1984) have demonstrated decreases in tissue resistivity with time after death commencing within a few hours after death. Further work is being carried out by the present authors, on both sheep and cetaceans, from the point of death for up to five days. When this work is completed, the findings will be discussed in detail and the resulting manuscript will also be submitted for publication in a refereed journal. It is regretted that so many of the references to the electric lance, quoted in this paper, were unrefereed papers submitted to the IWC and apparently not also published in recognized scientific journals and subject to peer review and criticism.

Animal welfare implications

Based on the information contained in this paper, the authors can find no reason to alter their opinion that the electric lance as currently used in whaling operations, is ineffective and likely to cause extra pain and suffering to an already distressed animal. In order to stop this inhumane treatment of whales a prohibition of the use of electricity to kill these animals must

be enforced. It is hoped that the IWC will finally ban the use of the electric lance at its meeting in 1997. This would be a great step forward for the welfare of whales.

Acknowledgements

The authors wish to acknowledge the Royal Society for the Prevention of Cruelty to Animals (RSPCA) for a specific grant to investigate changes in the conductivity of cetacean tissue *post mortem*. We are also most grateful to the RSPCA, the Whale and Dolphin Conservation Society and the World Society for the Protection of Animals for general financial support. This work could not have been achieved without the cooperation and assistance of members of the Department of Conservation in New Zealand.

References

Anon 1994 *Code of Recommendations and Minimum Standards for the Welfare of Animals at the Time of Slaughter at Licensed and Approved Premises.* Animal Welfare Advisory Committee. Ministry of Agriculture: Wellington, New Zealand

Anon 1995 Report of the workshop on whale killing methods. *Proceedings of the International Whaling Commission.* IWC/47/18

Barnes G R G, Madie P and Blackmore D K 1995 Further investigations relevant to the use of the electric lance in whaling. *Proceedings of the International Whaling Commission.* IWC/47/HK2

Barnes G R G, Madie P and Blackmore D K 1996 An assessment of the humane aspects of electric lancing of whales by measurement of current densities in the brain and heart of dead animals. *Medical & Biological Engineering & Computing 34:* 1-11

Blackmore D K and Delany M W 1988 *Slaughter of Stock: A Practical Review and Guide.* Publication No 118, Veterinary Continuing Education, Massey University: Palmerston North, New Zealand

Blackmore D K, Nutman A, Barnes G R G, Madie P, Davies A S, Bowling M C, Donoghue M and Kirk E J 1994 Preliminary investigations of techniques for killing whales. *Proceedings of the International Whaling Commission.* IWC/46/HK4

Bryden M M 1989 Adaptation to the aquatic environment. In: Harrison R H and Bryden M M (eds) *Whales, Dolphins and Porpoises* pp 112. Weldon Owen Pty Ltd: Sydney, Australia

Government of Japan 1993 Study of the humane killing of whales conducted in the Antarctic in the 1992/93 season in conjunction with the national research program. *Proceedings of the International Whaling Commission.* IWC/45/HK8

Government of Japan 1995 Report on killing method for the 1994/1995 Antarctic minke whale research operations. *Proceedings of the International Whaling Commission.* IWC/47/WK11

Hayashi Y 1980 Report on method of catching minke whales. *Proceedings of the International Whaling Commission.* IWC/SC/32/024

Hayashi Y 1995 Quoted in discussion of IWC/47/WK2. In: Report of the workshop on whale killing methods p 7. *Proceedings of the International Whaling Commission.* IWC/47/18

Kestin S C 1995 Welfare aspects of the commercial slaughter of whales. *Animal Welfare 4:* 11-27

McLachlan H 1995 The use of electricity to kill whales: humane considerations. *Animal Welfare 4:* 125-129

Mitchell E 1986 Aspects of pre-world war II German electrical whaling. In: Mitchell E D, Reeves R R and Evely A (eds) *Bibliography of Whale Killing Techniques* pp 115-129. International Whaling Commission: Cambridge, UK

Øen E O 1992 The Norwegian hunt of minke whales: hunting trials using 20mm high-velocity projectiles in 1982. *Proceedings of the International Whaling Commission.* IWC/44/HKW3

Reilly J P 1994 Scales of reaction to electric shock: thresholds and biophysical mechanisms. *Annals of the New York Academy of Sciences 720:* 21-37

Swatland H J 1980 Postmortem changes in electrical capacitance and resistivity of pork. *Journal of Animal Science 51:* 1108-1112

Zheng E, Shao S and Webster J G 1984 Impedance of skeletal muscle from 1Hz to 1MHz. *Transactions on Biomedical Engineering 31:* 477-481