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THE PORCINE, PALE, SOFT, EXUDATIVE MUSCLE CONDITION – WHAT IS THE BASIC BIOCHEMICAL LESION?

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The porcine stress syndrome occurs with increasing frequency in breeding and fattening pigs of the Piétrain, Landrace, and Poland China breeds (Briskey, 1964; Bickhardt, Giese, Chevalier & Reinhard, 1972; Patterson & Allen, 1972). The syndrome manifests itself as sudden death over a wide range of stressful conditions, such as heat, anoxia, service, parturition, transport, herding, and certain forms of anaesthesia. In slaughtered pigs the syndrome occurs in the form of a pale, soft, exudative musculature (Wismer-Pedersen & Briskey, 1961; Bendall & Lawrie, 1964; McLoughlin & Gold spink, 1964). Such pigs are said to be stress-susceptible in contrast to the stress-resistant Chester White and Large White breeds (Bendall & Lawrie, 1964; Topel, 1969). Stress-susceptibility is associated with a highly accelerated metabolism, particularly glycolysis and phosphate ester hydrolysis, and overproduction of lactic acid in the skeletal muscles. Even under mild to moderate conditions of stress, as much as 100 μmoles of lactate per gram of tissue may accumulate in the muscles of susceptible animals. The accumulation of high levels of lactate near body temperature at the time of death or slaughter results in the development of pale, soft, exudative characteristics in the skeletal musculature (PSE). Stress-resistant pigs show a low rate of glycolysis and lactate accumulation, and do not develop PSE characteristics in their musculature. Stress-susceptibility in certain breeds of pig appears to be the result of intensive genetic selection for high total muscularity, high growth rate, and maximal food conversion over many generations.

Bendall (1966) and McLoughlin (1970) postulated that the rapid rate of post-mortem glycolysis and lactate accumulation were due to intense trains of neural stimuli reaching the muscle. The hyperirritability of the muscles of stress-susceptible pigs has been interpreted by Lister (1971) to indicate an increased permeability of the sarcolemma to sodium and potassium ions. This would mean that the membrane potential of muscles of stress-susceptible animals is lower and probably more unstable than that of stress resistant animals. In view of Van der Kloot's (1967) discovery that the membrane potential has an important controlling influence on the rate of muscle metabolism, Lister's suggestion of a defect in the ionic permeability of the sarcolemma of susceptible pigs becomes more attractive, although difficult to test experimentally. Schmidt, Goldspink, Roberts, Kastenschmidt, Cassens & Briskey (1972) have postulated that acetylcholine might accumulate at the neuromuscular junction and produce hyperirritability in stress-susceptible pigs. This might occur due to a deficiency of the enzyme cholinesterase, which hydrolyses acetylcholine to acetic acid and choline, leading to an accumulation of the transmitter. Sybesma & Eikelenboom (1969) obtained evidence suggesting that the mitochondria of muscle of stress-susceptible pigs have an uncoupled oxidative phosphorylation system and an inefficient synthesis of adenosine triphosphate (ATP). Such an uncoupling of oxidative phosphorylation would result in the energy which is normally conserved in the terminal phosphate ester bond of ATP being dissipated as heat, while oxygen consumption remains normal or is even increased. Glycolytic synthesis of ATP would have to increase to compensate for the decreased mitochondrial energy supply. Under stressful conditions this would lead to the build up of lactate as the compensatory energy supplying role of glycolysis is stepped up. There is evidence that the cellular lesion responsible for halothane-induced malignant hyperthermia in certain Landrace pigs is in the sarcoplasmic reticulum (Harrison, 1973). Also, Harrison (1972) considers that the PSE condition, the porcine stress syndrome, and the malignant hyperthermia syndrome are all expressions of the same basic lesion in the musculature. If this hypothesis is correct, current ideas on the aetiology of malignant hyperthermia both in man and the pig could help in developing an understanding of the primary cause which initiates the sequence of cellular reactions leading to the PSE state and vice versa. It might then be possible to eliminate the defect of stress-susceptibility, whilst retaining the economically important traits, in a breeding programme with a new selection index for 'breeding out' stress-susceptibility.

In what follows the four main theories which have been advanced to explain the metabolic basis of PSE will be examined in some detail in the light of recent publications on PSE, the porcine stress syndrome, and the malignant hyperthermia syndrome. Because much of the literature on PSE is scattered in many journals and some of the nomenclature is confusing, the macroscopic and biochemical symtoms of PSE will be examined first.

Symptoms of the pale, soft, exudative muscle condition.

The characteristics of the PSE condition are: (a) a pale, muscle colour, noticably less red than normal; (b) the presence of very large amounts of free fluid in the muscle; (c) a very soft, spongy texture. The muscles which are most affected are the *longissimus dorsi* and the *semimembranosus*, and to a lesser extent the rectus femoris. The *longissimus dorsi* is affected to different extents along its length, the most susceptible areas being between the ninth and eleventh thoracic and second and fourth lumbar vertebrae (Lawrie & Gatherum, 1961). In the muscles of pigs which eventually become PSE, the pH falls very rapidly *post-mortem*, that is, there is an unusually rapid production of lactic acid while the body temperature is still close to 37°C (vide review, McLoughlin, 1971). The high level of acid at body temperature causes denaturation of the sarcoplasmic proteins, precipitation of the latter on the myofibrillar proteins, and a masking of the colour of the muscle pigment myoglobin.

(b) **Increased permeability of the sarcolemma.**

The hyperirritability of the muscles of stress-susceptible pigs has led to the suggestion that the sarcolemma is more permeable to sodium ions than the sarcolemma of normal muscles. In a study of the resting membrane potential in muscles of stress-susceptible Poland China and stress-resistant Chester White pigs, Schmidt *et al.* (1972) found that the membrane potential, measured forty five minutes post-mortem, was 20 – 25 mV lower in the stress-susceptible animals. The decreased membrane potential may reflect an increased sodium permeability, or it may indicate a defect in the sodium-potassium activated adenosinetriphosphatase enzyme which is responsible for repolarisation. The findings of the above authors certainly suggest that the muscle fibre membrane may be an important site of abnormality in the muscles of stress-susceptible pigs. Before a definite conclusion can be made as to the nature of the defect in the cell membrane, it will be necessary to measure the *in vivo* membrane potential of affected muscles, and to follow its rate of decay *post-mortem.* In the experiments of Van der Kloot (1967), already referred to, depolarisation of the cell membrane of frog muscle caused an increased oxygen consumption apparently mediated by calcium. If this finding is applicable to pig muscle, the released calcium would activate the myofibrillar adenosinetriphosphatase and cause contraction. If the membrane potential of the muscles of stress-susceptible pigs is an unstable one, it follows that the muscles will be hyperirritable, and that more energy will be required to maintain the muscle fibres in the polarised state.

(c) **Alteration of the relaxing system in the sarcoplasmic reticulum.**

Most of the evidence indicating the role of the sarcoplasmic reticulum in the genesis of the malignant hyperthermia syndrome in stress-susceptible pigs has come from the experiments of Harrison, Saunders, Biebuyck, Hickman, Dent, Weaver, & Terblanche (1969), Berman, Harrison, Bull & Kench (1970), and Harrison (1973). The latter author has shown that halothane induces malignant hyperthermia in stress-susceptible pigs even under conditions of neuromuscular block by curare. Furthermore, Harrison found that procaine blocked the initiation of the syndrome by halothane. It has long been known that caffeine causes a persistent contraction similar to rigor in skeletal muscle fibres (Sandow, 1970), and that is persists until the caffeine is removed. The *rigor* is due to stimulation of calcium release and interference with calcium rebinding by the sarcoplasmic reticulum. The net effect is to increase the sarcoplasmic concentration of calcium, which activates the myofibrillar contractile proteins and maintains contraction. Procaine is known to block the action of caffeine by preventing the efflux of calcium from the sarcoplasmic reticulum. These experiments clearly localise the defective site in the muscle fibre to the sarcoplasmic reticulum. Since halothane initiates malignant hyperthermia in stress-susceptible pigs, but not in stress-resistant animals, there must be an intrinsic functional defect in the sarcoplasmic reticulum of the susceptible animals. Since the PSE condition is observed only in the musculature of stress-susceptible pigs and pigs slaughtered with the captive-bolt and electrical stunning methods, it is most probable that an increased sarcoplasmic calcium concentration is responsible for the very elevated rates of ATP hydrolysis and glycolysis observed in muscles *post-mortem*, and which eventually exhibit PSE characteristics (Heffron & McLoughlin, 1971; Heffron, 1971; Klingbiel & Naudé, 1972).

The source of heat in malignant hyperthermia has been the subject of much dispute, though the evidence at this stage favours anaerobic metabolism of the form of breakdown of glycogen to lactate, neutralisation of hydrogen ions, and hydrolysis of high energy phosphate esters (Berman & Kench, 1973). Gatz (1973) investigated most of the agents commonly associated with the malignant hyperthermia syndrome for their possible effects on the uncoupling of oxidative phosphorylation in dogs and rats. Because halothane, chloroform, thiopentone, and chlorpromazine were found to uncouple oxidative phosphorylation and to enhance 2,4-dinitrophenol-induced hyperpyrexia, the author concluded that most of the heat in the syndrome arises from an uncoupled oxidative phosphorylation. However these results are in conflict with those of Eikelenboom & van den Bergh (1971), already referred to, who showed that halothane inhibited the oxygen consumption of mitochondria from stress-susceptible pigs.

Furthermore it must be borne in mind that although malignant hyperthermia may be induced by many different drugs, it remains to be proven that they all affect the calcium accumulating system of the sarcoplasmic reticulum as halothane does (Steward & Thomas, 1973). The porcine stress syndrome will result in rigidity and hyperthermia without pharmacological challenge, thus indicating the very unstable nature of the relaxing system of these pigs. The evidence thus suggests a defective sarcoplasmic reticulum, with the heat having its origin in the associated, accelerated anaerobic metabolism.

(d) **Changes in the myoneural junction.**

Very little detailed attention has been given to possible changes in the myoneural junction in the stress-susceptible pigs. Schmidt et al. (1972) found that the cholinesterase activity of muscles from stress-susceptible and stress-resistant pigs was not significantly different, thus ruling out the possibility of accumulation of the transmitter at the myoneural junction being responsible for the observed hyperirritability.

Conclusions.

The capacity of the sarcoplasmic reticulum to bind calcium is similar in stress-susceptible and normal pigs. Although calcium uptake is similar before anaesthesia with halothane, it is decreased by about half in the sarcoplasmic reticulum of stress-susceptible pigs after halothane anaesthesia, thus proving that halothane alters the relaxing system in the reticulum *(vide* Denborough, Hird, King, Marginson, Mitchelson, Nayler, Rex, Zapf, & Condron, 1973). These authors showed that the flux of calcium in the sarcoplasmic

It is the denaturation of the muscle proteins that leads to the appearance of abnormally high amounts of free fluid in the tissue, that is, the water-binding capacity of the muscle is reduced by denaturation of the proteins. Unusually low ultimate pH values (24 hours post-mortem) are occasionally observed in watery pork muscles, values as low as 4,6 having been reported in England (Bendall & Lawrie, 1964). Generally the ultimate pH values of muscles of stress-susceptible pigs are in the range for normal animals, 5,1 – 5,4.

Morphological studies have thus far shown that the ultrastructure of muscles of stress-susceptible pigs is not dramatically different from that of normal animals (Venable, 1973). The muscles of stress-suceptible animals tend to have greater proportions of classical white fibres and a lower capillary density than the stress-resistant animals (Merkel, 1971). The term "dystrophy" has often been used in reference to PSE muscle, but it has little to do with such a pathological state, and there are no clear or definable symptoms associated with PSE in living muscle. Bickhardt (1971) is of the view that there are decreased levels of the high energy phosphates, phosphocreatine and ATP, in the muscles of stress-susceptible animals, most probably due to the primary dependence of the muscle fibres on the glycolytic pathway for ATP synthesis, and to a decreased capillary density. Bickhardt *et al.* (1972) point out that stress-susceptible pigs may have an exertional myopathy which remains clinically latent but that the myopathic process is activated by bodily exertion, and there occurs an increased efflux of lactate and enzymes (creatine phosphokinase and aldolase) into the extracellular space. In this regard it is interesting that Isaacs and Barlow (1970) consider that the halothane-induced malignant hyperthermia in humans may be due to a subclinical myopathy, and that its pattern of inheritance is autosomally dominant. Clinically the malignant hyperthermia syndrome in man is indistinguishable from that in the pig. The pig exhibits hyperthermia which is usually fatal, and the skeletal muscles become rigid, and as in man, the causative agents are halothane and succinylcholoine.

Stress-suceptible pigs develop tachycardia and the respiratory rate increases during the first ten minutes of heat stress (Judge & Marple, 1971). These authors have obtained direct evidence of adrenal insufficiency in stress-susceptible pigs using a sensitive radioimmunoassay for plasma levels of ACTH and a competitive protein binding method for plasma corticosteroids. They calculated the ratio of plasma corticosteroid levels to plasma ACTH levels as an index of adrenocortical responsiveness to endogenous ACTH. Throughout the course of a six week period of imposed environmental stress the corticosteroid: ACTH ratio was two-to-three times higher in the stress-resistant than the stress-susceptible pigs. Adaptation to stress in its manifold forms is accomplished by the sequential action of the hormones adrenaline, cortisol, and 11-deoxycorticosterone. These hormones participate in the provision of energy under conditions of stress and aid in the restoration of cell potassium in the recovery phase. This typical metabolic response to stress has been referred to as the "general adaptation syndrome" by its discoverer, Selye (1950). The circulating levels of corticosteroids participate in a sensitive feedback system with the hypothalamic corticotrophin releasing factor. Stress accomodation is effected by the concerted action of the hypothalamus, the adrenal, and pituitary glands. Adaptational disease sets in when the normal homeostatic mechanisms become inadequate. In stress-susceptible pigs, relative adrenal insufficiency results in a severely impaired ability to adapt to stress, and should the intensity and duration of stress become too great death follows quickly.

Theories of the biochemical basis of PSE.

At present there are four main theories of the biochemical basis of PSE, namely: (a) uncoupling of oxidative phosphorylation of muscle mitochondria; (b) increased permeability of the sarcolemma; (c) alteration of the relaxing system of the sarcoplasmic reticulum; (d) changes in the myoneural junction. Discussion of the relevant evidence for each theory will be based on the hypothesis proposed by Harrison (1972) that the PSE state, the porcine stress syndrome, and the malignant hyperthermia syndrome share a common, primary, biochemical lesion.

(a) Uncoupling of oxidative phosphorylation.

A theory of aberrant muscle metabolism based on uncoupling of mitochondrial oxidative phosphorylation in the muscles of stress-susceptible pigs was first advanced by Sybesma & Eikelenboom (1969) to explain the rapid metabolic rate and excessive heat production in these animals. Uncoupling of oxidative phosphorylation would explain the increased rate of heat production observed in stress-susceptible pigs. Gatz (1973) proposed a similar mechanism for the promoting effect of halothane on 2,4-dinitrophenol-induced malignant hyperthermia in dogs. However further work by Eikelenboom & Van den Bergh (1971) showed that mitochondria from stress-susceptible pigs had a lower oxygen consumption than mitochondria from stress-resistant pigs. A lower rate of synthesis of ATP in mitochondria of muscle of stress-susceptible pigs would be of central importance since, ATP, utilised in muscular activity, will be synthesised at a much slower rate during activity and the subsequent recovery period. The resulting lower level of ATP and higher level of ADP will accelerate glycolysis by allosteric activation of the key enzyme of the glycolytic cycle, phosphofructokinase. Thus glycolysis would be stimulated to an extent which compensates for the decreased mitochondrial ATP synthesis. Since glycolysis produces three moles of ATP per mole of glucose (from glycogen) and mitochondrial oxidative phosphorylation produces thirty six moles of ATP, it is clear that compensatory glycolysis must be stimulated several-fold depending on the extent of decreased oxygen consumption of the mitochondria. Muscle lactate will increase accordingly, and will soon appear in the general circulation due to the inadequacy of the mitochondria in oxidising the sarcoplasmic NADH which enters the mitochondria via the glycerol-3-phosphate cycle. The theory of uncoupling of oxidative phosphorylation has been abandoned in favour of a theory of diminished mitochondrial oxygen consumption.

reticulum of stress-susceptible pigs was doubled. These results and those of Harrison (1973) suggest the following biochemical basis of the porcine stress syndrome: the sarcoplasmic reticulum of stress-susceptible pigs is highly unstable due most probably to a defect in the enzyme responsible for pumping calcium against its concentration gradient, or in the protein responsible for binding calcium within the reticulum; thus an unstable relaxing system produces increased muscle tone and an accelerated ATP hydrolysis in *vivo*. The hypothesis is consistent with the hereditary nature of the syndrome (Patterson & Allen, 1972) since it only occurs in pigs which have been genetically selected for high growth rate and total muscle mass. It appears to be transmitted as a genetically altered protein defect of the sarcoplasmic reticulum of the so-called stress-susceptible animals.

References

BENDALL, J.R., 1966. The effect of pre-treatment with curare on the post-mortem rate of pH fall and the onset of rigor mortis in the musculature. *J. Sci. Fd. Agr. 17,* 333.

BENDALL, J.R. & LAWRIE, R.A., 1964. Watery pork. *Anim. Breed. Abstr. 32,* 1.

BERMAN, M.C., HARRISON, G,G., Bull, A.B., & Kench, J.E., 1970. Changes underlying halothane induced malignant hyperpyrexia in Landrace pigs. *Nature, Lond. 225,* 653.

BERMAN, M.C. & KENCH, J.E., 1973. *Biochemical features of malignant hyperthermia in Landrace pigs.* In, International Symposium on Malignant Hyperthermia, Eds. Gordon, R.A., Britt, B.A. & Kalow, W., 287. Springfield, Illinois: C.C. Thomas.

BICKHARDT, K., 1971. Personal communication.

BICKHARDT, K., Giese, W., Chevalier, H.J. & Reinhard, H.J., 1972. Akute rückenmuskelnekrose und belastungsmyopathie beim schwein. Untersuchungen zur pathogenese. *Zbl. Veterinärmed, Reihe A,* Sup. 18.

BRISKEY, E.J., 1964. Etiological status and associated studies of pale, soft, exudative porcine musculature. *Adv. Food Res. 13,* 89.

DENBOROUGH, M.A., HIRD, F.J.R., KING, J.O., MARGINSON, M.A., MITCHELSON, K.R., NAYLER, W.G., REX, M.A., ZAPF, P. & CONDRON, R.J., 1973. *Mitochondrial and other studies in Australian Landrace pigs affected with malignant hyperthermia.* In, International Symposium on Malignant Hyperthermia, Eds. Gordon, R.A., Britt, B.A. & Kalow, W., 229. Springfield, Illinois: C.C. Thomas.

EIKELENBOOM, G. & VAN DEN BERGH, S.G., 1971. *Aberrant mitochondrial energy metabolism in stress-susceptible pigs.* In, Proc. 2nd. int. Symp. Condition Meat Quality Pigs, Zeist, Eds. Hessel-de-Heer, J.C.M., Schmidt, G.R., Sybesma, W. & van der Wal, P.G., 66. Wageningen: Pudoc Press.

GATZ, E.E., 1973. *The mechanism of induction of malignant hyperpyrexia based on in vitro to in vivo correlative studeis.* In, International Symposium on Malignant Hyperthermia, Eds. Gordon, R.A., Britt, B.A. & Kalow, W., 399. Springfield, Illinois: C.C. Thomas.

HARRISON, G.G., 1972. Pale, soft, exudative pork, porcine stress syndrome and malignant hyperpyrexia – an identity? *J1 S. Afr. vet. Ass. 43,* 57.

HARRISON, G.G., 1973. *The effect of procaine and curare on the initiation of anaesthetic-induced malignant hyperpyrexia.* In, International Symposium on Malignant Hyperthermia, Eds. Gordon, R.A., Britt, B.A. & Kalow, W., 271. Springfield, Illinois: C.C. Thomas.

HARRISON, G.G., SAUNDERS, S.J., BIEBUYCK, J.F., HICKMAN, R., DENT, D.M., WEAVER, V. & TERBLANCHE, J., 1969. Anaesthetic-induced malignant hyperpyrexia and a method for its prediction. *Br. J. Anaesth. 41,* 844.

HEFFRON, J.J.A., 1971. Enzymatic basis of rapid post-mortem glycolysis in porcine skeletal muscle. *Ir. J. agric. Res. 10,* Supplement x.

HEFFRON, J.J.A. & McLOUGHLIN, J.V., 1971. *The relationship between the rate of adenosine triphosphate hydrolysis and glycolysis post-mortem in skeletal muscle.* In, Proc. 2nd. int. Symp. Condition Meat Quality Pigs, Zeist, Eds. Hessel-de-Heer, J.C.M., Schmidt, G.R., Sybesma, W. & van der Wal, P.G., 109. Wageningen: Pudoc Press.

ISAACS, H. & BARLOW, M.B., 1970. Malignant hyperpyrexia during anaesthesia: Possible association with subclinical myopathy. *Br. med. J. 1,* 275.

JUDGE, M.D. & MARPLE, D.N., 1971. *Adrenal insufficiency in stress-susceptible pigs.* In, Proc. 2nd. int. Symp. Condition Meat Quality Pigs, Zeist, Eds. Hessel-de-Heer, J.C.M., Schmidt, G.R., Sybesma, W. & van der Wal, P.G., 47. Wageningen: Pudoc Press.

KLINGBIEL, J.F.G. & NAUDE, R.T., 1972. The effect of two stunning techniques on the pH_1 values of muscles in carcasses of bacon pigs. *S. Afr. J. Anim. Sci. 2,* 105.

LAWRIE, R.A. & GATHERUM, D.P., 1961. Observations on so-called "white muscle disease" in relation to analytical differences between pig muscles. *7th. Meeting European Meat Research Workers,* Paper No. 7.

LISTER, D., 1971. *Some observations on problems of pork quality, their identification and alleviation.* In, Proc. 2nd. int. Symp. Condition Meat Quality Pigs, Zeist, Eds. Hessel-de-Heer, J.C.M., Schmidt, G.R., Sybesma, W. & van der Wal, P.G., 235 Wageningen: Pudoc Press.

McLOUGHLIN, J.V., 1970. Muscle contraction and post-mortem pH changes in pig skeletal muscle. *J. Fd. Sci. 35,* 717.

McLOUGHLIN, J.V., 1971. *The death reaction and metabolism post-mortem of porcine skeletal muscle.* In, Proc. 2nd. int. Symp. Condition Meat Quality Pigs, Zeist, Eds. Hessel-de-Heer, J.C.M., Schmidt, G.R., Sybesma, W. & van der Wal, P.G., 123. Wageningen: Pudoc Press.

McLOUGHLIN, J.V. & GOLDSPINK, G., 1964. Post-mortem changes in the colour of pig longissimus dorsi muscle. *Nature, Lond. 198,* 584.

MERKEL, R.A., 1971. *The relationship of some cardiovascular and haematological parameters to porcine muscle quality.* In, Proc. 2nd. int. Symp. Condition Meat Quality Pigs, Zeist, Eds. Hessel-de-Heer, J.C.M., Schmidt, G.R., Sybesma, W. & van der Wal, P.G., 97. Wageningen: Pudoc Press.

PATTERSON, D.S.P. & ALLEN, W.M., 1972. Biochemical aspects of some pig muscle disorders, *Br. vet. J. 128,* 101.

SANDOW, A., 1970. Skeletal muscle. *Ann. Rev. Physiol. 32,* 87.

SCHMIDT, G.R., GOLDSPINK, G., ROBERTS, T., KASTENSCHMIDT, L.L., CASSENS, R.G. & BRISKEY, E.J., 1972. Electromyography and resting membrane potential in longissimus muscle of stress-susceptible and stress-resistant pigs. *J. Anim. Sci. 34,* 379.

SELYE, H., 1950. *The physiology and pathology of exposure to stress.* Montreal: Acta Inc.

STEWARD, D.J. & THOMAS, T.A., 1973. *Intracellular calcium metabolism and malignant hyperpyrexia.* In, International Symposium on Malignant Hyperthermia, Eds. Gordon, R.A., Britt, B.A. & Kalow, W., 409. Springfield, Illinois: C.C. Thomas.

SYBESMA, W. & EIKELENBOOM, G., 1969. Malignant hyperthermia syndrome in pigs. *Neth. J. vet. Sci. 2,* 155.

TOPEL, D.G., 1969. *Relationship of plasma glucocorticoid levels to some physical and chemical properties of porcine muscle and the porcine stress syncrome.* In, Recent points of view on the condition and meat quality of pigs for slaughter, Eds. Sybesma, W., van der Wal, P.G. & Walstra, P., 91. Zeist: IVO.

VAN DER KLOOT, W.G., 1967. Membrane depolarisation and the metabolism of muscle. *Am. Zool. 7,* 661.

VENABLE, J.H., 1973. *Skeletal muscle structure in Poland China pigs suffering from malignant hyperthermia.* In, International Symposium on Malignant Hyperthermia, Eds. Gordon, R.A., Britt, B.A. & Kalow, W., 208. Springfield, Illinois: C.C. Thomas.

WISMER-PEDERSEN, J. & BRISKEY, E.J., 1961. Rate of anaerobic glycolysis versus structure in pork muscle. *Nature, Lond. 189,* 318.