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Assessing the welfare of modified or treated animals

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Abstract

Animal welfare can be assessed in a precise way using measures of several kinds of abnormal behaviour, aversion, physiological responses including adrenal and opioid activity, immunosuppression, opioid activity, disease incidence, weight gain, reproductive success and life expectancy. Welfare may be affected in various ways in transgenic animals and animals treated with biotechnology products. In order to assess this, carefully controlled studies using a wide range of welfare indicators are needed. These should be carried out for at least the total farm life of a breeding animal and for at least two generations. No such comprehensive studies of either category of animals have been reported in the scientific literature to date although some measures of the effects of bovine somatrophin have been made and are described. Neither the use of recombinant DNA products nor the keeping of transgenic animals should be permitted on commercial farms until it is clear that the welfare of these animals is not adversely affected in comparison with that of animals which do not have the products administered to them or which are not produced by transgenic procedures.

Keywords : welfare assessment, transgenic animals, recombinant DNA, biotechnology, bovine somatotrophin.

Introduction

If animals are to be produced as a consequence of transgenic procedures, or if substances produced following the use of such procedures in other organisms are to be administered to animals, are there effects on the welfare of those animals and how should any such effects be evaluated? The first section of this paper explains the concept of welfare and briefly reviews some ways in which welfare might be affected by the use of genetic engineering. This is followed by a description of relevant aspects of welfare measurement. The list of measures which should be included in an answer to the question posed above is essentially the same as that in any comprehensive list of indicators of poor welfare. A difficulty in the assessment of the effects of transgenic procedures, or to a lesser extent the administration of biotechnology products, is that these may have wide ranging effects on the functioning of the individual. The procedure may be aimed at one kind of change, for example increased production, but may cause many different changes in the animal. Some of these may be of particular significance in relation to welfare whilst some may make welfare assessment more difficult so this problem is discussed further below. A third section of the paper explains how such measures can be used in experimental studies and the final section includes examples of the limited amount of information which is available on this subject.

Possible effects of genetic engineering on welfare

Animals use a variety of methods to try to cope with the difficulties which they encounter during life. These may succeed or fail but we can measure how much they are used and to what extent they fail. The welfare of an animal is its state as regards its attempts to cope with its environment (Broom 1986). The state as regards attempts to cope refers both to how much the individual is having to do in order to cope, e.g. how much coping behaviour or physiological response is shown, and the extent to which there is failure to cope with

consequent impairment of individual fitness. An individual's physical functioning and its mental functioning, including its feelings are taken into account when welfare is being assessed. Welfare is a characteristic of an animal, many aspects of which can be measured and it may vary from very poor to very good. These points are discussed further by Broom (1988, 1991a, b) and by Broom and Johnson (in press).

If any substance is administered to an animal there could be an effect on how much it has to do to cope with its environment or on how well it copes. As explained above, both of these aspects are relevant to welfare. A substance might cause pain but no reduction in growth, survival chances or reproductive success or it might reduce survival chances without causing any pain or discomfort. In either case the welfare of the individual would be poorer than that of another individual which was not affected in any of these ways.. The purpose of administering the substance may be to benefit the animal, for example to improve its ability to combat disease, or it may be to increase production or change the timing or quality of production of meat, milk, offspring etc. In either case, welfare could change for the better or for the worse. There can be short term adverse effects on welfare, for example those caused by an injection, followed by long-term effects which are different. Both should be assessed and, where there are good and bad effects, as in injection of an antibiotic, an attempt should be made to evaluate the overall effect. A substance which affects growth rate, milk production or reproduction may also have short-and-long-term adverse effects on welfare. The long-term effect on welfare could be neutral or beneficial but high rates of metabolism and growth can lead to joint problems and various production related diseases. These and other possible effects on welfare should be monitored thoroughly.

An animal which is changed phenotypically by conventional breeding procedures may have more or less problems in coping with its environment than its parents or earlier ancestors. The positive effects of reducing fear responses to man have been important in the domestication of animals. Negative effects include defects in dogs which were allowed to continue because selection was aimed at producing physical characteristics in the dog which were aesthetically pleasing to some humans. In farm animals, examples of negative effects include those which have resulted from selection for double muscling in Belgian Blue and other cattle to the point where some strains can only be perpetuated by the frequent or inevitable use of caesarian section. Selection for fast and efficient muscle growth in broiler chickens, pigs and beef cattle has resulted in a substantial increase in leg problems because the leg structure does not develop as fast as the muscles.

If genotype changes are accelerated by the use of transgenic procedures, the chances that some effect on the welfare of individuals might occur will be increased. The gene or genes transgenically added to an existing farm animal genotype are very likely to be those which might increase production efficiency in some way. There must be some biological limit to the production efficiency which is possible with a particular body design and as this limit is approached system failure will be more frequent. Hence a further increase in efficiency in an already efficient animal is likely to have some adverse effects on welfare. Gene changes whose aim is to produce a relatively small quantity of a novel protein are less likely to cause problems and those aimed at increased resistance to disease may well have an overall beneficial effect for the animal. Whatever the aim of the gene change, however, a careful study of the welfare of the transgenic animal is necessary.

There could be many effects of genetic manipulation or of substance administration on an animal. Sensory functioning, structure of bones or muscles, hormone production, detoxification ability, neural control mechanisms or many other aspects could be affected. Our concern here is not to ascertain whether there are effects but to assess the consequences of all of these effects for the welfare of the individual. In order to do this, carefully controlled comparisons of modified or treated and control animals must be carried out. A wide range of measures of welfare must be used in such studies since there are many possible effects and individuals vary, both in their coping responses and in the extent to which they fail to cope (Koolhaas et al 1986, Mendl et al 1992b, Broom and Johnson in press Ch.4). A single welfare indicator could show that welfare is poor but absence of an effect on an indicator, e.g. on growth rate, does not show that welfare is good. For example if the major effect was behavioural abnormality or increased disease susceptibility but appropriate measurements were not made and growth rate was not affected, spurious results could be obtained.

Measures of welfare

Most of the measures detailed here are principally indicators of poor welfare. However, since all studies would be comparisons with unmodified or untreated animals, each has the potential to demonstrate that the welfare of the experimental animal is better than that of the control. Preference studies are often of particular value in studies of animal welfare but they are difficult to use when the object of the study is to compare a modified and unmodified animal. It is important to try to find out about the animals' feelings but the modification may have affected the ability of the animal to have such feelings as well as the ability of the animal to cope or the extent to which it has to show coping behaviour. For example, a transgenic procedure could result in an individual being attracted by conditions much hotter

than those which a normal individual would find attractive and which would quickly cause tissue damage. Alternatively the pain system could be modified in a transgenic individual so that the normal, important, protective function of pain with its associated responses might alter preferences for or against situations which might be painful. Hence it is possible that, in transgenic animals, studies of positive preferences could give ambiguous results. Negative preferences, or aversion behaviour, can usefully be studied but should also be interpreted carefully taking account of other welfare measures.

The range of welfare indicators summarised here has been discussed, elsewhere in greater detail (Broom 1988, 1991a, Fraser and Broom 1990, Broom and Johnson in press). All of the measures described give information about welfare and the order of listing them is not an order of importance. The first two measures are of poor welfare associated with fitness reduction whilst the remaining measures need not indicate fitness reduction, although they could do so. They indicate how poor the welfare is by showing how much difficulty the individual has in trying to cope with its environment or how aversive it finds some aspect of its environment.

A general problem with studies of transgenic animals is that the genetic manipulation could have directly affected the particular functioning of the body which is monitored using a welfare indicator. A hypothetical example is that the insertion of a gene increasing prolificacy might reduce the amount of adrenocorticotrophic hormone which is produced in the anterior pituitary for a given level of corticotrophin releasing factor. This would result in lower levels of plasma glucocorticoids in a variey of emergency situations. As a consequence the individuals might be less well able to show appropriate action in the circumstances and might therefore show more abnormal behaviour and more tissue damage.

It will clearly be difficult to use some particular measures if there are such effects but care must be taken in any study to try to ascertain whether this has happened.

Life expectancy

If one management method results in a shorter life expectancy than another, the welfare is poorer when the first method is used than when the second is (Hurnik and Lehman 1988, Broom 1991a, in press). The majority of people would regard the animal which has a shorter life, perhaps living at a higher rate, to be under greater stress then that which lives longer, perhaps at a slower rate. The best known examples are captive wild animals like cetaceans whose life expectancy in small zoo pools is short. As most dairy farmers know, the life expectancy of dairy cows is shorter now than it was 20 years ago and Agger (1983) reported that in Denmark it had halved between 1960 and 1982 (Fig 1.). Since the animals concerned had all been sent to vendering plants, much of the increased mortality must be a consequence of increased metabolic rate and feed conversion efficiency leading to more production related disease, reproductive problems and actual mortality. Any further factor which increased metabolic pressure on the cow, as bovine somatotrophin injection could, would probably reduce life expectancy still more.

Reduced reproductive success

Inability to reproduce may be evident from studies of physiology or behaviour or it may only be demonstrated by large scale comparative studies. When the effects on welfare of housing and management of animals are studied, the welfare of individuals which are unable to reproduce, or whose reproductive success is seriously impaired because of those conditions, is poorer than that of individuals not so affected. For example some animals are seldom or never able to reproduce after pairing in zoo conditions and inappropriately reared farm

animals may fail to breed (Houpt 1984, Beilharz 1985, Price 1985). This measure of welfare could also be used in most studies of the effects of biotechnology procedures, the only difficult area being that in which a transgenic procedure results in direct modification of the reproductive system. Some modifications of the reproductive system would have an inevitable effect on reproductive success so this measure would not be valid. For example a procedure which resulted in immunocastration would obviously reduce reproductive success and such effects should be differentiated from effects on reproduction of stress which was an accidental consequence of a biotechnology procedure.

Weight changes

Another indicator of poor welfare is depressed weight gain in young animals, for example piglets, or abnormal weight loss in adults. The measure must be used carefully, however, because a temporary loss of weight in a rutting stag or a lactating mother which has gained much weight before parturition would not be construed as indicating poor welfare. Neither would the welfare of an obese young pig be regarded as better than that of a normal pig. Some biologically relevant standard must be used in such assessments.

Disease incidence and anatomical defect measures

Direct measurement of disease occurrence and studies involving experimental disease challenge also give information about the welfare of animals. One example of a study of farm animal management procedures in relation to disease incidence is that of Ekesbo (1981) whilst the series of studies by Gross and Siegel (e.g. 1981) on the susceptibility of chickens to disease challenge demonstrated that social mixing results in increased adrenal activity with consequent immunosuppression and increased susceptibility to many diseases. Any increase in disease incidence necessarily means poorer welfare but careful comparisons must be made in order to be sure of the exact cause of a higher level of disease in animals of a particular genotype or animals treated in a particular way.

Recent work on hens has shown that those reared in battery cages with insufficient opportunity for exercise have weak bones (Knowles and Broom 1990, Norgaard Nielsen 1990) and that the bones are much more likely to be broken during handling prior to slaughter than are the bones of hens which do get enough exercise. The possibility of anatomical effects of this kind should be investigated in genetically modified or treated animals. Changes in anatomy should be described and any effect which reduces the animal's ability to cope with its environment should be considered to be an indicator of poor welfare. Just as immuno-suppression is an indicator of poor welfare even in the absence of disease challenge, weak bones or some other anatomical change which renders the animal more vulnerable to damage or to frustration because of some inability, are also indicators of poor welfare. The welfare of the animal with weak bones is poorer than that of the animal with normal bones but the welfare is much poorer if there is bone breakage and suffering (Broom 1991b, in press). Those who would not consider that welfare is poor until the bone is broken

would generally advocate measurement of bone strength, or other measures of this kind, as being desirable in relation to welfare assessment.

Heart rate and blood measures

Heart rate measurement is of particular value when assessing welfare in the short-term so a genetic modification or treatment which changed anatomy in such a way that it caused localised pain or movement difficulty might be detectable in experiments by measuring brief increases in heart rate. General sampling of heart rate gives little information about long-term welfare problems.

Several other measurements of blood itself have been used when welfare assessment is intended but most have shown no consistent relationship with other measures. Counts of eosinophils indicated the severity of the effects of repeated immobilisation of mink Mustela vison (Jeppesen and Heller 1986) but these responses were to short-term problems and it is not clear that the measure would be of much use in assessing long-term effects on welfare.

Adrenal function measures

If adrenaline is produced from the adrenal medulla it disappears from the blood within a few minutes and glucocorticoids secreted from the adrenal cortex are usually gone from the blood in less than an hour. As a consequence, random sampling of blood for these products is unlikely to be of use when assessing welfare in the long-term. However, as with heart rate, responses to localised discomfort or intermittent movement difficulties can be readily assessed by measuring levels of adrenal cortex products. Most of such work has involved the measurement of glucocorticoids in plasma but care must be taken to ensure that the sampling itself does not cause the changes measured. Saliva sampling is sometimes easier and levels

of free glucocorticoids in saliva can be assayed (Cooper et al 1989). Regular sampling of catheterised cattle has revealed that the number of cortisol peaks was different for different housing conditions (Ladewig and Smidt 1989). Although a single peak does not necessarily mean that the animal has a problem, the presence of many peaks in the level of plasma cortisol indicates that the individual has often had to show an emergency reaction.

The fact that frequent unpleasant stimulation, with consequent adrenal cortex activity, can result in greater synthetic enzyme activity or other facilitation in the hypothalamic-pituitary-adrenal cortex axis (Restrepo and Armario 1987) can be used in an adrenal cortex function test. Challenge with adrenocorticotrophic hormone (ACTH) has been shown to give greater cortisol responses in farm animals after close confinement (Friend et al 1977, Dantzer et al1983), high stocking density (Meunier Salaun et al 1987) and frequent loss in social encounters (Mendl et al 1991, 1992b). The dexamethasone suppression test can also give useful information about the welfare of the individual in the period before testing (Mendl et al 1992a, b). However, as emphasised by Broom and Johnson (in press) more information is needed about how to interpret these tests.

Measures of immune system function

Difficulties in coping with the environment can often be associated with some degree of immunosuppression (Kelley 1985, Broom and Johnson in press). It is argued elsewhere (Broom 1988, 1991b, in press) that, in a comparison of two treatments, the welfare of animals whose immune system is suppressed is worse than that of individuals not thus affected. The welfare is worse if there is disease and suffering as well as immunosuppression

Immunosuppression can be measured by actual white cell counts, especially by counts of categories of T-lymphocytes. It can also be indicated by measuring antibody response to an antigen challenge. Metz and Oosterlee (1981) challenged sows with sheep red blood cells and found the antibody response to be less in recently tethered sows. Zanella et al (1991a) found that there was a relationship between high response to ACTH challenge in sows and lower levels of antibody production to challenge with tetanus toxoid or atrophic rhinitis vaccine (Fig.2). Measures of T-lymphocyte function which provide information about immunosuppression and hence welfare are many and varied. Some techniques involve the use of a non-specific lymphocyte stimulator, such as phytohaemagglutinin (PHA) or dinitro-fluorobenzene, hence care must be taken in experiments to take account of the subjects' previous experience of antigens. Environmental conditions such as high or low ambient temperature have been shown to reduce the immunological response in such tests (Kelley et al 1982) so they might also be useful to assess the effects of biotechnology procedures. More precise measures which can be carried out *in vitro* involve assessing the rate of lymphocyte proliferation in the presence of mitogens such as PHA, concanavalin A or pokeweed mitogen (e.g. Coe et al 1989). Assays of the efficacy of natural killer cells and of macrophages are also possible. Few of these procedures have been used in studies of farm animal welfare but it is of considerable importance to use measures of immunosuppression when assessing animal welfare.

Opioids

Following the discovery that analgesia can be mediated by endogenous opioids (Hughes et al 1975) and that such opioids are produced by animals in a variety of difficult conditions, it became clear that self narcotisation was another potentially measurable way of trying to cope with the environment (Cronin et al 1985, Broom 1986, 1987). Studies of a variety of species

including sheep (Shutt et al 1987) and horses (Taylor 1987) have shown that plasma levels of the opioid ß-endorphin increase after surgery and other treatments. However, these increases may have no relevance to any analgesic effect. Long term changes in animals showing disturbed behaviour are different in respect of this measure, indeed the plasma ß endorphin level in tethered sows measured by Wiepkema and Schouten (1992) was lower than the normal level for sows. Experiments using opioid inhibitors have also given some results which are interesting, if difficult to interpret. Recent work in which the density of opioid receptors in parts of the brain has been measured are also particularly promising (Zanella et al 1991b). As mentioned earlier, any study like that in which opioid action in the brain is assessed would have to be interpreted carefully if the subjects are transgenic animals in which a direct effect on such mechanisms might occur.

Behaviour measures

The best indicators of long-term problems for an animal are frequently measurements of behaviour (Broom and Johnson in press). Behaviour changes can be quantified just as precisely as physiological changes and the measurements can usually be made with less disturbance to the animal. For some measures video-recording is desirable and it is always necessary to record the behaviour for a long enough period and to compare with an adequate number of controls. Abnormalities of locomotion are the simplest behaviour changes to record and they can indicate localised pain. Modified feeding, sexual, or social behaviour can also be recognised if observations are carried out in appropriate test conditions.

If animals are unable to perform a behaviour which they wish to perform, or are otherwise frustrated, or are in a situation in which they have insufficient control over their interactions with their environment, a variety of behavioural responses may occur. The animal may show

stereotypies, or self-mutilation, or excessive aggression, or inactivity and unresponsiveness. Any of these abnormalities might occur more or less in genetically modified animals or in those to which substances are administered. For details of such behaviours see Fraser and Broom (1990) or Broom and Johnson (in press). There could also be abnormal behaviour which is caused by specific, localised, painful or irritating stimulation.

Many of the behaviour measures indicate that some general or specific aspect of the environment with which the animal interacts is aversive. Experimental assessment of aversiveness is also possible. Rushen (1986) found that sheep which had been driven down a race and had experienced something aversive at the end of it were considerably harder to drive down the race on subsequent days. Certain aspects of the environment might be more aversive to genetically modified or treated animals than to controls, for example if the effect of the procedure was to make eyes very sensitive to light or to cause difficulties in movement.

Which measures should be used?

Ideally, a number of independent measures, sufficient to cover all coping methods and all consequences of failure to cope, should be used in an investigation of the welfare of genetically modified or treated animals. However, some measurements take much longer to make than others, for example mortality rates take a long time to discover. Certain of the measures, such as heart-rate changes, immediate adrenal cortex responses and some behaviour changes, are used only where there are short-term effects on welfare, for example when an individual with localised pain has to exercise beyond the point where the pain can

be avoided. In most studies, it will be the long-term welfare measures which are the most important. A proper study would include: several measures of behaviour; some investigation of adrenal function and of any immunosuppression; direct assessment of disease incidence and injury levels; measures of growth and measures of reproductive success. Only in such a wide ranging study will it be possible to take account of variations in individual response. The study should last for a long period since some effects may not be apparent for some time. The animals should be studied for at least the maximum farm life and, since the effects of transgenic procedures could be different in the second generation, welfare assessment should continue for at least two generations.

Demonstrated effects on welfare of genetic manipulation or substance administration. No comprehensive study, using an adequate variety of measures, of the welfare of transgenic animals or animals treated with substances produced by recombinant DNA technology has yet been reported in the scientific literature although certain aspects of welfare assessment have been covered by Phipps (1989) and by papers in van der Wal et al (1989). Certain transgenic animals have been so obviously affected in an adverse way that no detailed study of welfare was necessary. In many instances the animals did not survive long. The most widely publicised welfare problem was that of the Beltsville pigs carrying human or bovine growth hormone genes, which showed various pathological conditions including joint pathology and whose locomotion, standing up and lying down appeared to be abnormal (Pursel et al 1989). Given the large number of transgenic animals which have been produced and the substantial amount of work on farm animal welfare carried out in recent years, it is surprising that programmes aimed at producing commercially valuable transgenic animals have not incorporated welfare assessment, at least in the latter stages of development.

Work on the effects of recombinant bovine and porcine somatotrophin injection has also been directed almost entirely towards finding out how to improve productivity in dairy cows and pigs. Any results which indicate what the effects on the welfare of the animals might be have been derived largely as an incidental by-product of the main study. This rather short-sighted approach to the testing of BST and PST and lack of concern for the animals has been one of the causes of public disquiet about the use of these products.

Since BST occurs naturally, low levels of it are unlikely to have any adverse effects on welfare but even at low levels the effects need to be checked because each of the different forms of recombinant BST available has some differences in amino acid sequence from the natural form. BST injection results in increases in the amount of insulin-like growth factor-1 (IGF-1) in the blood and in milk (Prosser et al 1989, 1991, Prosser and Mepham 1989). These increases can be substantial and it has been shown that high levels of IGF-1 can affect rat bone growth (Juskevich and Guyer 1990). Low levels of IGF-1 are likely to have no adverse effect but it is a potent mitogen and it is not known what effects high levels of it have on the cow, or on the calf which consumes the milk, or indeed on people who do so (Mepham 1991).

The most clearly documented effects of BST are on disease incidence and on reproduction. The effects of BST injection are similar to changes which occur during the rising phase of lactation and high-yielding cows which are not treated with BST are particularly susceptible to disease at this time. Kronfeld (1988) states that high levels of BST, result in subclinical hypermetabolic ketosis which can lead to reduced reproductive efficiency and a higher incidence of mastitis and other production related diseases. However studies reviewed by Phipps (1989) provide no evidence for increased incidence of ketosis following BST

treatment. Several of the studies of cows treated with BST so that milk yields are particularly high, report that the incidence of mastitis can increase. There are also some reports of increased incidence of lameness (Phipps loc. cit., Craven 1991). A general survey of mastitis incidence following BST use (Phipps loc. cit) makes it clear that there have been several studies in which BST use did not result in a greater likelihood of mastitis. However high production levels are associated with greater incidence of both mastitis and lameness, and BST use can result in high production levels, so the discrepancies in research results in the effects of BST on mastitis may depend upon how great were the maximal production levels using BST. Increases in disease following BST use may be directly related to the metabolism associated with high production levels but welfare is obviously poorer if mastitis and lameness occur, whatever the exact reason for it.

Surveys of the results of several studies of BST-treated animals by Epstein (1990) and Epstein and Hardin (1990) showed that the conception rates of treated and control cows were 89%:59% and 95%:50% respectively. Assuming that the attempts to get the cows to conceive were equivalent, these results also indicate poorer welfare in BST treated cows. Phipps (1989), in reviewing the evidence for effects of BST on reproduction, distinguishes, firstly between the use of BST early in lactation and late in lactation, and secondly between higher and lower doses of BST. If the BST is administered early in lactation and at higher dose levels, the reductions in pregnancy rate reported by Epstein can be produced. However it seems that administration of lower dose levels of BST later in lactation are less likely to have any adverse effects on welfare.

A further point, which may be very important to the cows, is that each injection has some effect on a cow and repeated injections may cause swollen and tender injection sites

(Comstock 1988). More general effects of BST use are, firstly, that higher mastitis incidence may result in more antibiotic treatment and greater risk of the development of pathogen resistance and, secondly, that the possible change from smaller to larger dairy farms which could result from widespread BST usage could lead to poorer average stockmanship and less individual care of cows.

Conclusions

It is clear from all of these fragments of evidence that systematic, comprehensive studies of welfare are necessary in all developments involving the production of transgenic animals or the use of new treatments like those made possible by recombinant DNA technology. There may be adverse effects on the welfare of the animals which would not have occurred if the new technology had not been used, for example the consequences of painful deformities. There may also be an increased chance that adverse effects of management as practised at present will continue instead of being reduced, for example disease associated with high production rates in cows. On the other hand, it may be that the welfare of animals will be improved as a consequence of the new procedure, for example if disease resistance is increased. There is much public concern over these matters and it is vital for the agriculture industry that it is seen to have concern for the animals which are used. Most people consider that it is morally wrong for new technology to be applied to animals for commercial benefit if the welfare of the animal is poorer as a consequence.

The studies of the welfare of animals which are needed in order to appreciate all of the possible effects are described in this paper. Thorough studies are needed because limited measurement may fail to detect all of the diferent attempts to cope with difficulties or all of the consequences of failure to cope. Prolonged studies are necessary because effects of substance administration may appear later in life and effects of genetic manipulation may

appear at any stage in the life of an individual or may not be apparent until the next generation. Hence there should be laws governing the commercial use of these procedures. In many countries, the scientific experimentation is adequately covered so new laws need refer only to the application of the results of the experimentation. Existing laws on cruelty to animals or the welfare of farm animals do not adequately cover the problems. New laws are required which ensure that neither the use of recombinant DNA products nor the keeping of transgenic animals should be permitted on commercial farms until it is clear that the welfare of these animals is not adversely affected in comparison with that of animals which do not have the products administered to them or which are not produced by transgenic procedures.

The new developments could have good or bad effects on animal welfare but should not be licensed for public use until the facts about such effects have been ascertained.

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Figure legends

Fig.1 The rate of mortality of dairy cows in Denmark, as assessed by entries to rendering plants, doubled over a period of 20-25 years so the life-expectancy of a cow halved (after Agger 1983).

Fig.2 The relationship between the titre of tetanus antibody in sow colostrum and the level of salivary cortisol one hour after 4 μg.kg-1 ACTH injection. Each point refers to one sow and the antibody titre is expressed as the maximum dilution (10^4 - 10^7) (data from Zanella et al 1991a).