



Review

Getting priorities straight: Risk assessment and decision-making in the improvement of inherited disorders in pedigree dogs

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ABSTRACT

The issue of inherited disorders in pedigree dogs is not a recent phenomenon and reports of suspected genetic defects associated with breeding practices date back to Charles Darwin's time. In recent years, much information on the array of inherited defects has been assimilated and the true extent of the problem has come to light. Historically, the direction of research funding in the field of canine genetic disease has been largely influenced by the potential transferability of findings to human medicine, economic benefit and importance of dogs for working purposes. More recently, the argument for a more canine welfare-orientated approach has been made, targeting research efforts at the alleviation of the most suffering in the greatest number of animals.

A method of welfare risk assessment was initially developed as a means of objectively comparing, and thus setting priorities for, different welfare problems. The method has been applied to inherited disorders in pedigree dogs to investigate which disorders have the greatest welfare impact and which breeds are most affected. Work in this field has identified 396 inherited disorders in the top 50 most popular breeds in the UK. This article discusses how the results of welfare risk assessment for inherited disorders can be used to develop strategies for improving the health and welfare of dogs in the long term. A new risk assessment criterion, the Breed-Disorder Welfare Impact Score (BDWIS), which takes into account the proportion of life affected by a disorder, is introduced. A set of health and welfare goals is proposed and strategies for achieving these goals are highlighted, along with potential rate-determining factors at each step.

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Introduction

Selective breeding of dogs for human needs and aesthetics has a rich history that speaks of considerable commitment by breeders and has led to the domestic dog becoming the most morphologically diverse mammalian species (Boyko et al., 2010). The process of selective breeding was formalised with the founding of the UK Kennel Club (KC) in 1873, which introduced and has maintained written templates, the breed standards that define in detail the conformation, temperament, coloration and other traits that characterise a breed. Over 100 countries worldwide have since adopted the KC system for the registration of pedigree dogs. More than 200 breeds are now defined by a KC standard in the UK and 161 breeds are recognised in the USA under the auspices of the American Kennel Club.

Many excellent breeders set health and welfare traits as priorities, are passionate about their breed and work hard to eradicate

any inherited disorders that arise. Nevertheless, breeding to conform to breed standards has been harmful for some breeds of dogs, with recent research showing that each of the top 50 breeds are predisposed to at least one disorder linked to their conformation (Asher et al., 2009). This may occur for two main reasons:

- (1) Some individual breed standards stipulate morphological features which, when taken to extremes, are deleterious to health. These include brachycephaly or chondrodysplasia, which are a feature of more than a dozen breeds, including the Basset Hound, Dachshund, Corgi and Pekingese (Parker et al., 2009). Other standards specify very long ears, domed heads, long backs, screw tails, great or very small body size, wrinkled skin and other features which also can have an adverse impact on health and welfare, either directly or indirectly.
- (2) Even where standards do not explicitly stipulate conformations or features that predispose to ill-health or poor welfare, imprecise wording has permitted a level of interpretation that could lead to some dogs being bred to

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extremes. This is not a new problem; Frankling (1963) described an attitude amongst some breeders of '*the more the better*' with regard to questionable characteristics that are advocated in breed standards.

Although much recent attention has been paid to the issue of inherited defects in pedigree dogs, it is by no means a modern problem. Darwin (1868) discussed a range of physical and physiological differences that correlate with large size in dogs. In 1963, a British Small Animal Veterinary Association symposium on abnormalities and defects in pedigree dogs identified 13 conditions of concern: hip dysplasia, patella luxation, entropion, retinal atrophy, prolonged soft palate, abnormal temperament, skin fold dermatitis, uterine inertia, elbow dysplasia, ectropion, trichiasis and deafness (Hodgman, 1963). The issue was raised again in reports from the Council for Science and Society (1988) and the Companion Animal Welfare Council (CAWC, 2008). In 2008, the BBC aired a television documentary, *Pedigree Dogs Exposed*, which prompted renewed interest in the issue.

Subsequently, three independent reviews into dog breeding have been published (APGAW, 2009; Rooney and Sargan, 2009; Bateson, 2010), and an independent Advisory Council on the Welfare Issues of Dog Breeding has been formed.¹ In January 2009, the KC announced revisions to 78 of its 209 breed standards and a commitment to tackle exaggerations through better training of judges and other initiatives. This is the latest in a series of incremental standard reviews, which has, for example, seen the description of the bulldog's head revised from '*The skull should be very large – the larger the better*' (pre-1987) to the current '*Skull relatively large in circumference*' (Kennel Club, 2010).

Where breed standard changes have been made, they have not been drastic. However, there are potential genetic benefits in revising the standards in small steps. For example, too large a change could lead to a population bottleneck if the proportion of the population that fails to align with a reviewed breed standard is removed entirely from the gene pool. There has also been a suggestion that alteration of standards could lead to some breed clubs breaking away from the KC altogether. It is unclear what impact the revised changes that have been made to date will have on the health and welfare of individual breeds.

Amending breed standards is a complex issue, with cultural as well as scientific considerations. However, there is a clear need for a more quantitative and objective approach to the decision-making processes. In this paper, we examine ways of identifying, establishing priorities for and monitoring inherited disorders in pedigree dogs.

Canine health research

Although extensive research has been carried out on several inherited disorders in pedigree dogs, there are still many for which the mode of transmission, prevalence and the specific genetic abnormality are unconfirmed (Asher et al., 2009; Summers et al., 2010).² It is worth considering the factors that have historically driven research into certain disorders and how we might achieve a better balance between canine welfare and human interest-orientated approaches.

Some financial support for research into canine genetic diseases is available specifically for the health improvement of dogs; the KC records over £1.7 million³ in health-related grants donated to UK universities and research bodies by their Charitable Trust in the last

decade.⁴ However, beyond the KC and funding frameworks of other animal charities, the allocation of funding for research in this field historically has been substantially influenced by the potential transferability of findings to human medicine.

Genetically distinct canine population subgroups (breeds) with inherited disease are extremely useful as models of similar disorders in human medicine (Sutter and Ostrander, 2004; Fleischer et al., 2008). Availability of pedigree records allows likely modes of transmission of some disorders to be estimated even before more in-depth laboratory research is attempted. The recent full description of the canine genome (Lindblad-Toh et al., 2005) will allow specific genetic abnormalities associated with canine disorders to be identified, many of which, such as muscular dystrophy, are also reported in humans (Collins and Morgan, 2003; Switonski et al., 2004; Wang et al., 2009). Development of genetic tests for early diagnosis of particular conditions is beneficial to the health of both species, for example via genetic counselling of prospective human parents and dog breeders (Traas et al., 2006).

Other factors of human interest that influence the distribution of funding across various canine inherited disorders may reflect the public profile of a given breed. Popular companion (non-working) breeds can benefit from campaigning or fundraising by proactive breed enthusiasts. An example of note is the UK Cavalier King Charles Spaniel Club which has been raising funds for disease-specific research into the breed since the 1980s⁵ and has made significant efforts to promote heart screening for mitral valvular disease and other disorders. Conditions in breeds commonly used for guide, assistance, military or other service work (e.g. German shepherd dogs and Golden retrievers) may also attract more financial support through the charities or organisations which invest substantially in training them for human assistance roles (Helmink et al., 2003; Fraser et al., 2008).

The relative complexity of a disease process can also influence the likelihood of it being subjected to empirical research. Market forces within the animal care sector may favour investigations into conditions likely to yield a definitive and preferably marketable outcome, such as a genetic test for a monogenic condition in a single breed. Rod-cone dysplasia type 1 was virtually eliminated from Irish Setters in the UK using such a test to direct breeding strategies (Clements et al., 1993; Petersen-Jones et al., 1995).

Polygenic or multifactorial conditions have a complex aetiology and have proved to be more difficult to control, despite ongoing research efforts and phenotype-based breeding strategies. Unfortunately, many common disorders, such as hip dysplasia, fall into this category (Leighton, 1997; Swenson et al., 1997; Leppanen and Saloniemi, 1999; Zhu et al., 2009; Ginja et al., 2010). However, two recent studies have indicated that phenotypic selection against hip dysplasia is achieving genetic improvements in the UK (Lewis et al., 2010a) and the USA (Hou et al., 2010).

Dog breeders, charities, welfare scientists and animal-loving members of the public may argue that dog welfare must be truly paramount and, as such, available funding must be targeted at the alleviation of the most suffering in the greatest number of animals (Collins et al., 2010). However, in working towards such an ideal, it is important to be aware of the strong influence of other factors (such as financial gain or human health benefits) in attracting funds for research in the field of canine breed-associated disease. To capitalise on potentially available resources in this area, it will be necessary to balance both human and canine interests, with reference to the nature and impact of individual disorders. Lessons from the past suggest that dogs can easily miss out if human benefits alone are allowed to drive decision-making. Emerg-

¹ See: www.dogadvisorycouncil.org.uk.

² See: www.eurolupa.org.

³ £1=approx. €1.13, US\$1.63 at 13th June 2011.

⁴ See: www.doggenetichealth.org/actions.php.

⁵ See: www.doggenetichealth.org/cavalier_king_charles_spaniel_club.php.

ing methods of quantification and comparison of the welfare impact (WI) of different diseases are important tools with which to present clear arguments for setting priorities for tackling the inherited disorders of greatest welfare concern in pedigree dogs.

Welfare risk assessment: reliability, suitability to purpose and weaknesses

Risk is defined by the Oxford English Dictionary (OED, 2010) as '*(Exposure to) the possibility of loss, injury, or other adverse or unwelcome circumstance; a chance or situation involving such a possibility*'. By nature, risk assessment characterises the probability of a negative event occurring and quantifies the consequences of such an event. The use of risk assessment methods is becoming increasingly common in the field of animal welfare as a way of comparing different hazards and their impacts on the welfare of the affected individual and/or population on the basis of a number of key factors (EFSA, 2008, 2009, 2010a,b; Collins et al., 2010). The three basic factors are intensity of consequences, duration of effect of consequences and prevalence. However, these factors alone do not give a complete picture of a hazard and its associated consequences. Rather, to get a complete picture, it is important also to consider information about the hazard itself: duration and probability of exposure to the hazard.

Data are collected on each of these factors, either directly from research published in peer-reviewed papers (Asher et al., 2009; Summers et al., 2010) or from experts in the field (EFSA, 2008, 2009, 2010a,b). Expert opinion-based risk assessments are the most common form of welfare risk assessment produced. Most risk assessments concern a wide range of hazards where systematic reviews would be enormous. It is therefore quicker and simpler to rely on the assimilated knowledge of a group of independent experts. In addition, for many animal welfare problems, appropriate data do not exist in the peer-reviewed literature to permit a comprehensive risk assessment.

In the absence of data, opinion-based assessments can be useful, since, through a process of estimation with confidence indicators, experts can generate a useful proxy for published data. Whether one can consider experts within the same field to be truly independent is a matter for consideration and could lead to the introduction of bias into the assessment. Ideally, risk assessment would be based on a database complete with appropriate information on all factors, for all hazards. This is a longer term goal and, in the absence of this ideal, it is necessary to capitalise on the information available and to attempt to weight each piece of information according to its reliability (EFSA, 2010a,b).

Once data are collected for each of the factors, risk scores can be calculated to determine the population-level WI of each hazard. The risk score is typically a function of the intensity, duration of consequences and prevalence scored for each hazard, although additional factors (e.g. duration and probability of exposure to hazard) can be incorporated to give a more accurate score if data are available to quantify them. The result of these calculations is a list of hazards, each with a risk score that can be ranked in order of magnitude to determine which hazards should be determined to be priorities for management. The calculated risk scores are only ever relative between hazards; they are not absolute indicators of the risk each hazard poses.

Finally, risk assessments consider each hazard to be independent. In animal welfare, where multiple hazards are often found in combination, or the consequences of one hazard can be considered to be a hazard in itself, this assumption can never truly be met. However, to date, this lack of independence remains a problem without a solution. This must be considered when interpreting risk assessment results.

Risk assessment on inherited disorders in pedigree dogs

The Generic Illness Severity Index for Dogs (GISID) is a scoring system that uses information from the veterinary and scientific literature to express aspects of disease duration and severity. It could be applied at population-level to estimate the magnitude of canine welfare compromise attributable to particular inherited conditions. It was developed during a recent review of inherited disorders in pedigree dogs to allow comparisons between the impact of diseases (Asher et al., 2009; Summers et al., 2010) (Fig. 1). For any given condition, the likely prognosis, treatment, complications and behavioural implications are each scored from 0 to 4 to give a maximum total score of 16.

In Asher et al. (2009) and Summers et al. (2010), each disorder identified was scored on the GISID scale from its most-to-least severe manifestations, under the assumption that appropriate veterinary care was provided. Scoring was based on information available from the scientific literature, which was collected alongside breed-specific prevalence information, where available.

From an animal welfare perspective, the disorders that should be of most concern are those with the highest severity (in this case as scored by the GISID) and the highest prevalence. Of the 396 disorders identified by Asher et al. (2009) and Summers et al. (2010), we identified nine disorders assigned (in the most severe cases) the maximum possible score on the GISID of 16 (Table 1). Whilst this is a useful starting point, in the future efforts must be made to examine the distribution of severity between individuals. For example, it could be that most dogs suffering from a disorder would be scored at the lower end of the range of severity and very few cases fall within the upper range. In this case, using the upper range of the severity score would be misleading and a more central measure may be more appropriate. Furthermore, we can identify disorders with the highest breed-specific prevalence (in the top 5th percentile) according to the peer-reviewed literature (Table 2).

Using published data from the international scientific literature, it was possible to plot the maximum severity score (GISID) for 244 breed-disease combinations against the maximum available prevalence estimates across different countries (Fig. 2). However, the existing data do not easily permit comparisons between disorders in different countries. Indeed, given the general lack of reliable prevalence data, there are problems associated with identifying priority areas even within a country. This was attempted in a study by Collins et al. (2010), which examined inherited disorders in pedigree dogs in the UK. Where UK prevalence data were available, a comparative risk assessment combining severity and prevalence for each breed-disorder combination was conducted, yielding WI scores. WI was calculated as the product of prevalence (given as a percentage) and severity (GISID score divided by 16, the maximum possible GISID score), to give a WI score for each breed-disorder combination that ranged from 0 (no WI) to 100 (maximum WI).

A possible next step could be the calculation of Breed-Disorder Welfare Impact Scores (BDWIS), to take into account the duration of the disorder as a proportion of the dog's life, which would be calculated as follows:

$$\text{BDWIS} = \text{Prevalence} \times \text{Severity} \times \text{Proportion of life afflicted}$$

$$\text{where Prevalence} = \left(\frac{\text{Number of affected individuals in a population at a given time}}{\text{Total population size}} \right) \times 100$$

$$\text{Severity} = \frac{\text{GISID score}}{\text{Maximum possible GISID score}}$$

$$\text{Proportion of life afflicted} = \frac{(\text{Mean breed lifespan} - \text{Mean age of onset})}{\text{Mean breed lifespan}}$$

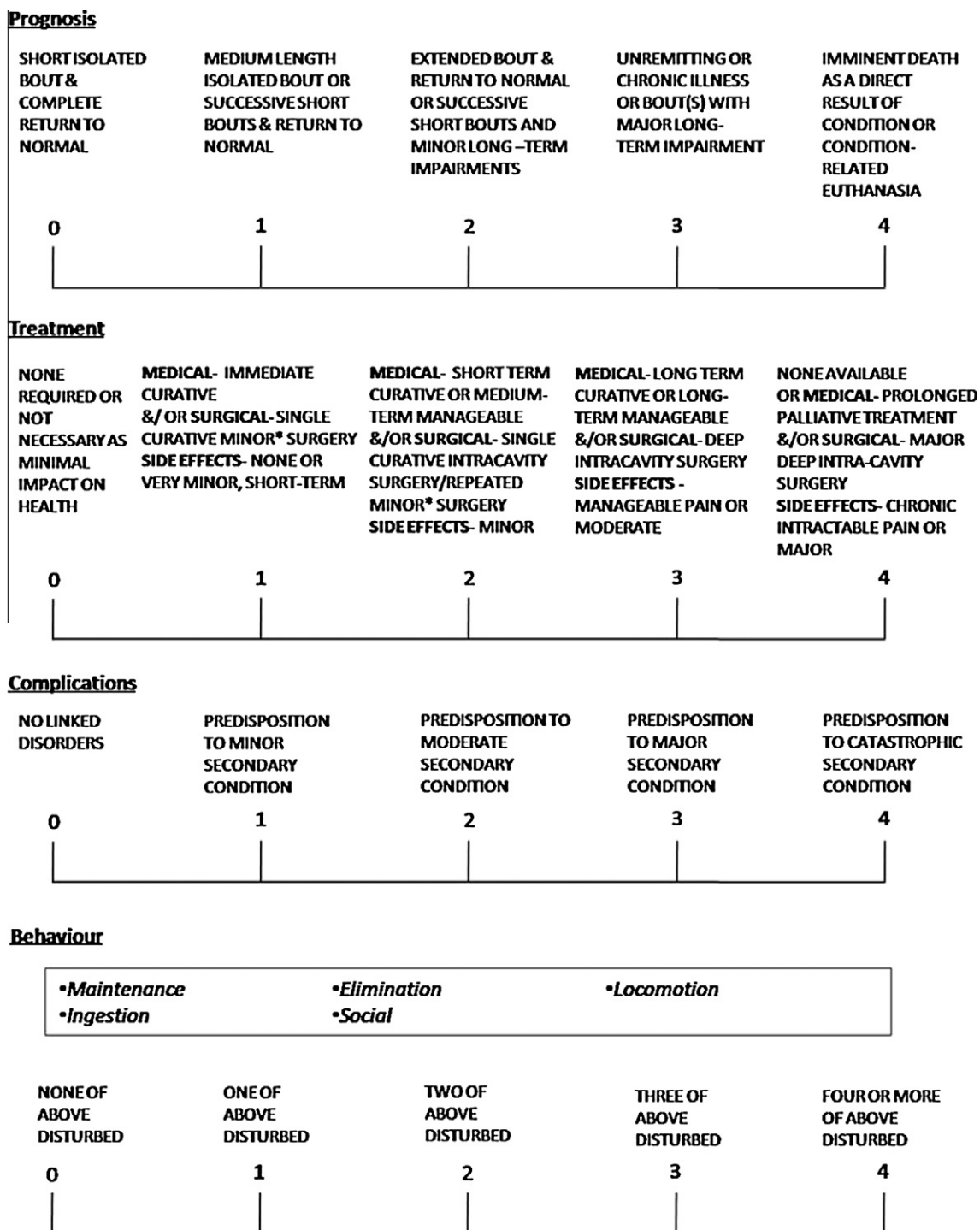


Fig. 1. The Generic Illness Severity Index for Dogs (GISID). Each disorder is scored overall, from the most and least severe manifestations, by summing scores of the four components. * Minor surgery is defined as not intra-cavity.

BDWISs have been calculated for a number of disorders identified as being high in severity and prevalence and where the information was available (Table 3). As there is generally more information available about disorders that have been the focus of more research, risk assessments for these are more accurate than lesser known or less well studied disorders. Therefore, there is an inherent bias in the risk assessment results based on availability of information.

The major challenge when performing risk assessments for inherited disorders is the absence of accurate prevalence data. In

the case where prevalence data are available for each of 396 disorders identified in the top 50 dog breeds, this would result in a total of 19,800 breed-disorder prevalence estimates. According to our findings, currently just 244/19,800 (1%) of this information is available. Even within this 1%, many of the prevalence estimates are based on populations in a number of countries (and so are not always easily comparable), are not current, are based on biased populations (e.g. those subjected to screening by breeders before assessment for disease) or small sample sizes. The great importance of collecting prevalence data for all breeds, for all identified

Table 1

Disorders with the maximum possible severity score on the Generic Illness Severity Index for Dogs (GISID) at the most severe manifestations.

Disorder	GISID score
Cyclic neutropenia	16
Gastric torsion	14–16
Renal hypoplasia, bilateral	12–16
Renal agenesis, bilateral	12–16
Globoid cell leucodystrophy	11–16
Dysautonomia	8–16
Brain tumour, non-specific	7–16
Hypoplasia of dens	7–16
Bullous pemphigoid	6–16

Disorders ranked in decreasing order of the upper GISID score.

Table 2

Generic Illness Severity Index for Dogs (GISID) scores for disorder-breed combinations with the highest prevalence estimates (top 5th percentile).

Disorder (breed)	GISID score	Range of prevalence estimates (%)
Cutaneous mucinosis (Shar-Pei)	3–7	100
Mitral valve disease (Cavalier King Charles spaniel)	7–12	9–100
Spondylosis deformans (Boxer)	1–8	84
Collie eye anomaly (Rough collie)	6–12	54–72
Collie eye anomaly (Border collie)	6–12	64
Dystocia (Smooth and long-haired dachshunds)	2–6	63
Entropion (Bulldog)	2–9	14–60
Entropion (Shar-Pei)	2–9	58
Elbow dysplasia (Rottweiler)	4–6	2–55
Elbow dysplasia (Bull mastiff)	4–6	14–54
Cervical vertebral instability (Dobermann)	6–12	49

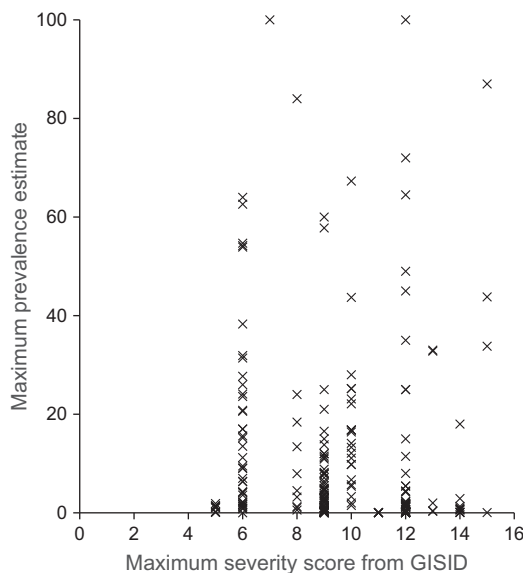


Fig. 2. Distribution of breed-disorder combinations according to the maximum severity score and maximum prevalence estimate. GISID, Generic Illness Severity Index for Dogs.

disorders, across countries has been stated previously (APGAW, 2009; Rooney and Sargan, 2009; Bateson, 2010; Collins et al., 2010) and must be a priority if we are to accurately determine the impact of each of the inherited disorders identified in dogs.

Risk scores such as WI (Asher et al., 2009; Summers et al., 2010) and BDWIS are sensitive to the manner in which the severity, dura-

tion and probability of occurrence (prevalence) are scored and combined. Rather than producing only a definitive score, it may also be helpful for risk assessments to present these inputs separately in order to assist stakeholders in making informed decisions. Decision makers may also decide to weight factors according to ethical assessment, e.g. is quantity or quality of life more important (Sandøe and Christiansen, 2007). However, weighting based on scientific evidence is currently not possible due to a lack of sufficient data.

Transforming risk assessment into policy: the decision-making process

Any successful strategic reworking of dog breeding practices will be dependent on international support from stakeholder organisations, including breeding and veterinary associations. For modern dog-breeding practices to be sustainable, puppy purchasers may have to pay more than they generally do at present for dogs bred in alignment with strategic health goals (McGreevy and Bennett, 2010). This is in line with Webster's (1994) view that consumers should bear the costs of animal welfare advances. For example, the best breeders may already charge extra to cover costs of disease monitoring schemes.

A greater appreciation of the demand for healthy, long-lived companionable dogs should allow tradition to give way to the contemporary breeding practices that apply, for example, in production animal industries (McGreevy, 2007). For such an appreciation to develop fully, a comprehensive public education programme in puppy buying and the welfare requirements of dogs throughout their lives will be required. This sort of programme to raise awareness and inform consumer choices is currently being implemented for higher welfare meat, dairy and eggs in the UK by non-governmental organisations such as Compassion in World Farming.

The most commonly suggested solutions for concerns regarding inherited disorders have revolved around the necessity for changing breed standards and relaxing the rules regarding crossing different breeds (Asher et al., 2009; Bateson, 2010; Rooney and Sargan, 2010; Summers et al., 2010). Any strategy for long-term improved health requires agreement between stakeholders on which data are needed to inform the strategy's selection goals, how these data are to be sourced and how selection criteria are to be ranked. The strategy for each breed is likely to differ, but the reasoning that underpins it should, in theory, be the same if dog welfare is the key driver.

Once we identify the types of disorders that can be made less prevalent simply by changing breed standards, we should be able to develop a parallel process for those that are not amenable to simple change and, as such, are more difficult to manage. A two-track process for disorders not related to breed standards might approach monogenic and polygenic conditions differently. Any process of change that sets priorities for breeding for quality of life should monitor the extent to which new practices may be responsible for changes in the prevalence of certain disorders. As epidemiological mapping of disorders and their heritability progresses, further disorders may be identified relating to breed standards, either directly or indirectly. Consequently, breed standards must be subjected to regular review.

However, one cautionary note is that, particularly in rarer breeds with smaller population sizes, choosing not to breed from a subset of the population that has a particular set of physical characteristics known to be associated with a predisposition to an heritable disorder could easily lead to reduced breeding populations and, paradoxically, the appearance of more recessive or rare disorders. It will therefore be critical to manage breeding-out programmes carefully, especially in rarer breeds.

Table 3
Breed Disorder Welfare Impact Scores (BDWIS) and contributing elements.

Disorder (breed)	Prevalence (%)	Severity score (GISID) range/maximum possible GISID score	Proportion of life afflicted	BDWIS range
Mitral valve disease (Cavalier King Charles spaniel)	9–100	0.44–0.75	0.53–0.91	2–68
Cutaneous mucinosis (Shar-Pei)	100	0.19–0.44	1	19–44
Entropion (Shar-Pei)	14–60	0.13–0.56	0.9	2–30
Entropion (Bulldog)	58	0.13–0.56	0.85	6–28
Myopia (Rottweiler)	64	0.19–0.38	1	12–24
Elbow dysplasia (Bull mastiff)	14–54	0.25–0.38	0.83	3–17
Elbow dysplasia (Rottweiler)	2–55	0.25–0.38	0.85	0–17
Spondylosis deformans (Boxer)	84	0.06–0.50	0.33	2–14

GISID, Generic Illness Severity Index for Dogs.

Severity is presented as a proportion of the maximum possible severity score.

Proportion of life afflicted is calculated as (Mean breed lifespan – Mean age at onset)/Mean breed lifespan.

Disorders are ranked in decreasing order of upper BDWIS score.

We predict the following processes will improve the future quality of life of pedigree dogs (Table 4).

(1) *Development of breeding objective(s)*

The overall goal is to breed healthy, long-lived, companionable pedigree dogs that retain the features of traditional merit (TM) currently valued in the show ring. This overarching goal incorporates several sub-goals relating to the health and behavioural attributes of a successful companion dog, but its primary contributing economic components are litter size, progeny success rate as companions and lifespan (Table 5).

Any disorders that compromise retention in the companion-animal niche must be factored into a selection programme. For this reason, a national disease surveillance system for dogs using anonymised veterinary diagnoses is required (APGAW, 2009; Rooney and Sargan, 2009; Bateson, 2010). This should monitor numerically significant disorders related to breed standards and also those that are not related to breed standards (Summers et al., 2010). With respect to the modification of breed standards, it must be clearly demonstrable that a breed standard related to a disorder has been satisfactorily modified to advance the welfare of

the breed and to safeguard its future quality of life. Any disease surveillance system must also monitor disorders that have yet to rank as numerically significant, since they may emerge as an inadvertent side-effect of breeding to eliminate certain high-profile disorders within a breed.

(2) *Use of welfare and economic rationales to set priorities for selection criteria and objective methods that might improve the efficiency of evaluation*

Setting priorities for dealing with disorders within a breed is of critical importance, since more than 50 disorders have been reported in some breeds (McGreevy and Nicholas, 1999; Asher et al., 2009). The calculation of breed- and disorder-specific WI scores potentially could be used, along with breed-appropriate life spans (longevity scores) and high retention rates (a reflection of companionable temperament, CT), as indicators of breed health and as a marker of breeding progress in future years. However, more immediately, BDWIS could be used to decide which disorders in which breeds should be set as priorities for the immediate development of health screens or DNA tests.

(3) *Development of operational tools, health screens and DNA tests*

These include creating a database that embraces the BDWIS, TM, CT and longevity scores for individual dogs. Additional

Table 4
Five steps to decreasing inherited defects in pedigree dogs.

Step	Requirements	Potential impediments
1. Definition of the breeding objective(s)	Agreement on drivers of change and the drivers for retention of current system of selection based on breed standards	Lack of communication between breeders and scientists who bear unwelcome messages
2. Use welfare and economic rationale to set priorities for the measurements that will drive selection	- Development of Breed Welfare Impact Score (BDWIS) for each disorder in each breed - Development of a score for each dog's traditional merit (TM) as an example of the breed, regardless of health - Development of a companionable temperament score (CTS) or a retention rate within a single home - Access to longevity data on each breed	- BDWIS and CT scores have yet to be developed. System for collecting and collating data has yet to emerge - TM scores, retention rates and longevity data/sources yet to be agreed
3. Development of operational tools and strategies	- Agreement on data that embrace the BWI, TM, CTS and longevity estimated breeding value (EBV) for individual dogs and the source of these data - Validation of new health screens and DNA tests	Registered breeders may be reluctant to embrace broad brushstroke data that include data on dogs from unregistered parents
4. Development of a plan for dog selection based on the results of the analysis	- Agreement on a blend of the BDWIS, CTS, longevity and (weighted) TM - Selection from a variety of dogs with above-average EBV for the blended scores	- Some breeders may argue that purity is more important than welfare - Popular sire effect may operate
5. Measurement of progress and success in a national breeding programme	- Ongoing analysis of the prevalence data to monitor effect of change and to guard against the emergence of new disorders - Development of new tests	- Resistance to changing breed standards to increase a BDWIS - Breeders who succeed in producing best dogs under one year's framework will resist revision of selection criteria

Table 5

Goals and sub-goals for breeding for quality of life in pedigree dogs that have a contemporary role as companions.

Progeny success rate		
Health	Longevity	Companionable temperament
Eliminate inherited disorders (Asher et al., 2009; Collins et al., 2010; Summers et al., 2010)	- Identify the value of longevity to the companion dog market - Breed from dogs that come from long-lived lines - Breed from lines that are resistant to age-related physical and cognitive deterioration (Salvin et al., 2010, 2011a,b)	- Identify the value of a companionable temperament to the companion dog market - Select dogs that show behavioural traits that are compatible with the companion animal niche rather than the working niche or show-ring (McGreevy, 2007; McGreevy and Bennett, 2010; King et al., 2009)

operational tools include new health screens and DNA tests for disorders with particularly high WI, as well as the auditing of current screens and tests.

(4) Development of a plan for breeding dog selection

Selection occurs chiefly at the following two points: (a) Selection of the dog into the companion-animal niche. Rates of selection into the niche and rates of retention of offspring should inform the breeding values of the parents; and (b) Selection of the dog or bitch into the breeding programme. While different selection pressures and measurements may be applied to dogs and bitches, both should align with the defined breeding objectives.

Within these selection processes, there is a need to determine the appropriate weighting for each selection criterion to maximise the chances of meeting the overarching goal of breeding healthy, long-lived, companionable pedigree dogs. There is a concurrent need to manage disease risk and population diversity and to use simulated data to develop strategies derived from customised computational algorithms.

(5) Measurement of progress and success in a national breeding programme

Data within the emergent genetic evaluation database will be used to calculate up-to-date breeding values. Strategies for calculating estimated breeding values (EBV) have been extensively developed and analysed for other animal industries (e.g. the dairy industry) and are being applied in dog breeding (van Hagen et al., 2004). Where genetic parameters are available, for example for hip dysplasia (Lewis et al., 2010a) and syringomyelia (Lewis et al., 2010b), incorporating them into EBV-based breeding strategies for the current purpose will be reasonably straightforward. Other disorders can be included in EBV-based selection as parameters become available.

Conclusions

Any system of dog breeding that sets priorities for health and welfare must, almost by definition, be flexible. It must review its selection criteria, including breed standards, in light of the latest disease prevalence data. The selection priorities, the resultant breeding plan and the measurements of success should not be set in stone. To do so would be to repeat the mistakes inherent in traditional pedigree dog breeding, with an adherence to historic breed standards and the maintenance of closed studbooks. It should be noted that there are a number of excellent breeders who already set priorities for health and welfare traits, who are passionate about their breed and who work hard to eradicate any inherited disorders that arise. However, not all breeders are as open to change as this and many prefer to adhere to traditional

breeding principles and closed stud books. It only after these impediments are relaxed that can we fill the companion animal niche with pedigree dogs that are as healthy, long-lived and companionable as possible.

Conflict of interest statement

None of the authors of this paper has a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.

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