

Animal Biotechnology

Technologies, Markets & Companies

by
Prof. K. K. Jain
MD, FRACS, FFPM
Jain PharmaBiotech
Basel, Switzerland

December 2017

A Jain PharmaBiotech Report

A U T H O R ' S B I O G R A P H Y

Professor K. K. Jain is a neurologist/neurosurgeon by training and has been working in the biotechnology/biopharmaceuticals industry for several years. He received graduate training in both Europe and USA, has held academic positions in several countries, and is a Fellow of the Faculty of Pharmaceutical Medicine of the Royal College of Physicians of UK. Currently, he is a consultant and CEO at Jain PharmaBiotech.

Prof. Jain's 473 publications include 28 books (5 as editor + 23 as author) and 50 special reports which have covered important areas in biotechnology, gene therapy and biopharmaceuticals. He has also written a textbook of gene therapy, which is the first book on this subject to be translated into the Chinese language. A book on gene therapy companies was published in 2000 by John Wiley & Sons and the 2017 version is included in a special report on gene therapy available from Jain PharmaBiotech Publications. Other recent publications include "Handbook of Biomarkers" (Springer 2010, Chinese ed Chemical Press 2016, 2nd ed 2017), Handbook of Nanomedicine (Springer 2008; Chinese ed, Peking University Press 2011; 3rd edition Springer, 2017), and Applications of Biotechnology in Oncology (Springer 2014).

**December 2017 (originally published in September 2002)
Copyright © 2017 by**

**Jain PharmaBiotech
Bläsiring 7
CH-4057 Basel
Switzerland**

**Tel & Fax: +4161-6924461
Email: info@pharmabiotech.ch
Web site: http://pharmabiotech.ch/**

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, or otherwise without the prior written permission of the Publisher. This report may not be lent, resold or otherwise traded in any manner without the consent of the Publisher. While all reasonable steps have been taken to ensure the accuracy of the information presented, the Publisher cannot accept responsibility for inadvertent errors or omissions.

TABLE OF CONTENTS

0. Executive Summary	13
1. Introduction to Animal Biotechnology	15
Introduction	15
Historical evolution of animal biotechnology	15
Basics of biotechnology	16
DNA	16
RNA	16
Genes.....	17
Single nucleotide polymorphisms	17
Copy number variations in the genome.....	17
DNA sequences.....	18
Gene expression	18
Gene regulation	19
Proteins	19
<i>Functions of proteins</i>	<i>20</i>
<i>Recombinant proteins.....</i>	<i>20</i>
Animal genetics	21
Molecular genetics	21
Twinning in cattle.....	21
Pig genetics.....	21
Genetic studies in dogs.....	22
Animal genomics	22
Avian genomes	22
<i>Chicken genome</i>	<i>22</i>
<i>Turkey genome.....</i>	<i>23</i>
The mouse genome.....	24
The cat genome.....	24
The dog genome.....	25
<i>Sequencing of the dog genome.....</i>	<i>26</i>
<i>Comparison of genomes of healthy and diseased dogs.....</i>	<i>27</i>
<i>Analysis of DNA copy number variation.....</i>	<i>28</i>
Marsupial genomes	28
Genome of the Tibetan antelope	29
Livestock genomics	29
<i>Bovine genome.....</i>	<i>30</i>
<i>Bovine SNP map</i>	<i>31</i>
<i>1,000 Bull Genomes Project</i>	<i>32</i>
<i>Bovine stomach microbiome genes.....</i>	<i>32</i>
<i>Camel genome</i>	<i>33</i>
<i>Goat genome.....</i>	<i>33</i>
<i>Horse genome</i>	<i>34</i>
<i>Pig genome.....</i>	<i>35</i>
<i>Sheep genome</i>	<i>36</i>
Fish genomes	36
<i>The Salmon genome.....</i>	<i>36</i>
<i>Genome of the Northern snakehead</i>	<i>38</i>
Whale genome	38
Genomes of non-human primates	39
<i>Chimpanzee genome</i>	<i>39</i>
<i>Genome of the rhesus macaque.....</i>	<i>39</i>
<i>Genome of gorilla</i>	<i>40</i>
Priority genome list of the National Human Genome Research Institute	40
Animal proteomics	41
Applications of proteomics in animals	41
<i>Caseins in goat milk</i>	<i>42</i>
<i>Lactic acid bacteria.....</i>	<i>42</i>
<i>Applications of proteomics in animal healthcare</i>	<i>42</i>
Bioinformatics	42
Biomarkers and animal health	44
Personalized medicine for pet animals.....	46
Monoclonal antibodies and animal health	46
Antigenomics.....	46
Nanobiotechnology and animal health	47
Stem cells and animal biotechnology	47
Rescuing extinct animals with stem cells.....	47
Animal biotechnology in relation to other technologies	48

2. Application of Biotechnology in Animals	51
Introduction	51
Applications of animal genomics.....	51
Bovine ankyrin 1 gene and beef tenderness	51
Chicken breeding based on genomics	52
Genomics of disease resistance.....	52
Genomic selection to exploit gene-environment interactions.....	52
Genome wide associations and milk production in cows	53
Low cost genotyping for genetic improvement in dairy cattle.....	53
SNPs and longevity in dairy cattle	53
Share genomic data to improve cattle breeding programs.....	54
Statistical genomics to improve breeding	54
Genetic engineering and gene editing.....	54
CRISPR/Cas9 gene editing in animals	54
Disease control by genetic engineering	55
Improvement of livestock by genetic engineering.....	55
Limitations and precautions for genetic engineering	55
Transgenic animal technology	55
Cloning animals	57
<i>Nuclear transfer technology.....</i>	<i>57</i>
<i>Nuclear bisection for cloning.....</i>	<i>58</i>
<i>Zona-free cloning method.....</i>	<i>59</i>
<i>Abnormalities in cloned animals.....</i>	<i>59</i>
<i>Cloning from embryonic cells.....</i>	<i>61</i>
<i>Cloning of rabbits.....</i>	<i>61</i>
<i>Cloning the rat</i>	<i>61</i>
<i>Cloning the horse.....</i>	<i>62</i>
<i>Cloning the cow</i>	<i>62</i>
<i>Cloning the dog</i>	<i>62</i>
<i>Cloning in primates</i>	<i>63</i>
Episomal vector-mediated gene delivery	63
Lentiviral transduction of male germ-line stem cells	64
Lentiviral transgenesis.....	64
Retrovector-mediated production of transgenic animals	64
Sperm-mediated gene transfer	64
Production of recombinant proteins.....	65
Transgenic pharmaceuticals	66
Proteins from the milk of transgenic animals	67
Advantages of milk as source of transgenic proteins.....	67
<i>Therapeutic proteins from rabbit milk</i>	<i>68</i>
<i>Recombinant human antibodies from cows.....</i>	<i>69</i>
<i>Therapeutic proteins from goat milk</i>	<i>69</i>
Chicken transgenesis for the production of biopharmaceuticals	70
Concluding remarks about production of transgenic proteins in animals	70
Companies involved in production of transgenic pharmaceuticals	71
Transgenic food products	71
Milking genetically modified cows.....	71
Genetically modified fish	71
<i>Genetically engineered salmon</i>	<i>72</i>
<i>Gene transfer approaches to enhance growth of other fish species</i>	<i>73</i>
Cloned animals as sources of milk and meat.....	73
Animal feeds from transgenic plants	73
Transgenic modification of plants to increase nutritional value of animal feeds.....	73
Transgenic disease models	74
Technologies to create transgenic disease models	74
<i>Gene manipulation techniques.....</i>	<i>74</i>
<i>Embryonic stem cells for gene targeting</i>	<i>74</i>
<i>Homologous recombination</i>	<i>75</i>
<i>Transgenic animal models of human diseases.....</i>	<i>75</i>
Transgenic models for studying human drug metabolism and toxicity	76
The Human Genome Project and the role of transgenics	76
Genomic and proteomic analyses of transgenic animal models.....	77
Concern about health and welfare of transgenic animals	77
Safety of transgenic technology	78
Concluding remarks about use of transgenic animals.....	78
RNA interference technology	79
RNAi versus antisense	79
Applications of RNAi in animal biotechnology	79
Xenotransplantation	80
Pigs for xenotransplantation.....	80
<i>Genetically engineered pigs for transplants</i>	<i>80</i>

<i>Risks of xenotransplantation</i>	81
World Health Organization and xenotransplantation	81
Ethical aspects of animal biotechnology	82

3. A Biotechnology Perspective of Animals Diseases 83

Introduction	83
Infections in animals	83
Viral infections.....	84
<i>Avian viral infections</i>	84
<i>Avian influenza</i>	84
<i>Animal biotechnology implications of H1N1 influenza</i>	87
<i>Animal corona viruses and human SARS</i>	88
<i>Avian coronavirus</i>	88
<i>Acute lymphoproliferative disease of cattle</i>	89
<i>Bluetongue virus</i>	90
<i>Canine virus infections</i>	90
<i>Classical swine fever</i>	91
<i>Developing new treatments against FMD</i>	91
<i>Equine viruses</i>	92
<i>Feline virus infections</i>	93
<i>Foot-and-mouth disease</i>	93
<i>Porcine reproductive and respiratory syndrome virus</i>	95
<i>Rabies</i>	95
<i>Rinderpest</i>	96
<i>Schmallenberg virus</i>	96
<i>Virus infections in fishes</i>	97
Bacterial infections.....	97
<i>Bovine tuberculosis</i>	97
<i>Brucellosis</i>	98
<i>Mycoplasmal pneumonia</i>	98
Fungal infections.....	98
Protozoal infections	99
<i>Coccidiosis</i>	99
<i>Neosporosis</i>	99
<i>Toxoplasmosis</i>	100
<i>Trypanosomiasis</i>	100
Nematodes.....	100
Infections that cross the species barrier.....	101
Complications of bacterial infections and antibiotic use in animals	101
Transmissible spongiform encephalopathies (TSEs)	102
Inter-species transfer of prions.....	102
Scrapie.....	102
Bovine spongiform encephalopathy	103
<i>Epidemiology of BSE</i>	103
<i>Biomarkers in the urine of BSE infected cattle</i>	104
<i>Human health implications of BSE</i>	104
<i>Breeding animals protected against BSE</i>	105
TSE research	105
<i>Prion gene haplotyping</i>	105
<i>Pharmacological approaches to TSE research</i>	105
<i>Molecular diagnostic approach to TSE research</i>	106
<i>RNAi for knockdown of the bovine prion gene</i>	106
Chronic wasting disease	107
<i>Chronic wasting disease in wildlife</i>	107
<i>Chronic wasting disease of the cattle</i>	108
Genetic disorders in farm animals	109
Genetic predisposition to acquired diseases in animals	109
Diseases of pet animals	109
Canine anemia	109
Canine autoimmune diseases	110
Canine neuropsychiatric disorders.....	110
<i>Canine obsessive-compulsive disorder</i>	110
<i>Canine dementia</i>	111
<i>Canine epilepsy</i>	111
Canine glaucoma	111
Canine cardiovascular disease	112
<i>Heart failure</i>	112
<i>Cardiac complications of canine babesiosis</i>	112
Diabetes	113
<i>Role of biotechnology in management of diabetes</i>	113
Arthritis	114

Cancer in dogs.....	114
<i>Biotechnology-based anticancer therapeutics.....</i>	114
<i>Cancer clinical trials in dogs</i>	115
<i>Canine Comparative Oncology & Genomics Consortium.....</i>	116
Preventive veterinary medicine	116
Prevention of introduction of foreign animal diseases.....	116
Producing transgenic cattle resistant to BSE	116
Zoonotic diseases	117
Global impact of zoonotic diseases	117
Viruses that emerge in animals and spread to humans	117
Collaborative management of animal and human health	118
Vaccines for zoonotic viral diseases	118
4. Molecular Diagnostics in Animals	120
Introduction	120
Nucleic acid technologies.....	120
The polymerase chain reaction	120
<i>Basic Principles of PCR.....</i>	120
<i>Target selection</i>	121
<i>Detection of amplified DNA.....</i>	121
<i>Real-time PCR systems.....</i>	121
<i>LightCycler PCR system</i>	122
<i>Molecular beacons.....</i>	122
<i>Applications of PCR in veterinary medicine</i>	122
Fluorescent in situ hybridization.....	123
Immunodiagnosics	125
Enzyme-linked immunoassays	125
Bovine Gamma Interferon Test	125
Antigen diagnosis of trichinosis.....	126
Parachek™ for the diagnosis of Johne's disease	126
Antibodies for differentiation between vaccinated and infected animals.....	127
Biochip/microarray technology	127
Applications of microarrays in animal biotechnology	128
<i>Cattlearray3800 for functional genomics</i>	128
<i>eSensor™ electrochemical biochip.....</i>	129
<i>FR 48 microfluidic biochip</i>	129
<i>SNPchiMp v.3 for standardizing livestock SNP data.....</i>	129
Biosensors	130
Immunosensors.....	130
<i>Biosensor for ovulation prediction in dairy cows.....</i>	131
Flow cytometry for animal diagnostics	132
Molecular imaging in animals	132
Veterinary cytogenetics	133
Applications of sequencing for veterinary diagnostics	133
Role of sequencing in detection of cancer biomarkers	133
DNA sequencing for study of bacterial epidemics	134
Role of sequencing in epidemic of Shiga toxin-producing E. coli	134
Role of sequencing in the study of genetic disorders in animals	134
Applications of molecular diagnostics in animals.....	135
Canine DNA testing	136
Cat pedigree determined by gene tests.....	136
Diagnostic aids to selective breeding	136
<i>Selection of desirable traits</i>	136
<i>Gene variations and fat content of beef</i>	137
<i>Using genetic markers for improved milk production in dairy cattle</i>	137
<i>Application of bovine genomics for improving milk yield.....</i>	138
<i>Recognition of hereditary syndromes.....</i>	138
Genetic markers in animals	139
<i>SNP genotyping in animals.....</i>	139
<i>SNP genotyping for selective breeding of chicken.....</i>	139
Animal identity and parentage analysis.....	139
Animal species identification in food	140
Diagnosis of infections.....	140
<i>Bacterial infections.....</i>	140
<i>Diagnosis of fungal infections in animals</i>	141
<i>Diagnosis of viral infections.....</i>	141
<i>Molecular diagnosis of avian influenza</i>	143
<i>Molecular diagnosis of swine influenza</i>	144
<i>Diagnosis of parasitic infections</i>	145
<i>Detection of natural or bioterror threats to livestock.....</i>	145
<i>Detection of Tritrichomonas foetus DNA in cattle.....</i>	146

Molecular diagnosis of prion diseases	146
<i>Bovine spongiform encephalopathy</i>	146
<i>Testing for BSE in living animals</i>	148
<i>Prions in urine</i>	148
<i>Diagnosis of chronic wasting disease in wildlife</i>	149
Developing new tests for prion diseases.....	149
<i>Differentiation among various types of TSEs</i>	149
<i>Protein cyclic amplification</i>	149
<i>Antibody tests for prion diseases</i>	150
<i>Scrapie genotyping</i>	150
<i>A real-time ultrasonic method for prion protein detection</i>	151
Companies involved in developing molecular diagnostics for TSEs	151
Diagnosis of genetic disorders	152
<i>Genetic screening of companion animals</i>	152
<i>Genes associated with exercise-induced collapse</i>	152
<i>Preimplantation genetic diagnosis</i>	152
Diagnosis of cancer in animals.....	153
<i>Diagnosis of skin cancer</i>	153
<i>Diagnosis of canine mammary carcinoma</i>	153
Diagnosis of food-borne pathogens	154
Introduction	154
Molecular diagnostic methods used in food-borne infections	154
Detection of Listeria-contaminated foods	155
<i>Optical biosensor for detection of Listeria</i>	155
<i>Real-time PCR for detection of Listeria</i>	156
Detection of Salmonella	156
<i>MicroSEQ® Salmonella Detection Kit</i>	156
Detection of toxoplasmosis.....	156
E. Coli detection	157
<i>DuPont Bax system</i>	157
<i>MLG method for detection of multiple STEC strains</i>	157
<i>MicroSEQ® E. Coli Detection Kit</i>	157
<i>RapidFinder™ STEC</i>	158
A genomic approach to study of animal food-borne illness in humans	158
Limitations of use of molecular probes in food analysis	158
Companies with technologies for food pathogen detection	159
Biotechnology-based novel diagnostics for aquatic animals.....	160
Detection of chemicals in foods of animal origin.....	160
Companies developing molecular diagnostics for animals	161
5. Biotechnology-based Veterinary Medicine	162
Introduction	162
Biotechnology versus pharmaceutical products	162
Role of biotechnology in drug discovery and development	163
Biological therapies in veterinary medicine	163
Cost of veterinary vs. human drug discovery and development.....	163
Advantages and disadvantages of testing biotech products in animal models.....	164
Biotechnolgy-based antiparasitic drugs	164
Non-antibiotic strategies for control of infections in animals.....	164
Probiotics.....	165
<i>Potential role for probiotics in the human gut</i>	165
<i>Potential role for probiotics in animals</i>	165
<i>Probiotic bacteria for control of pathogens in cattle</i>	166
Nonantibiotic drugs for infections in animals.....	167
<i>Immunomodulation as an alternative to antibiotics in infections</i>	167
<i>Cathelicidins: effector molecules of mammalian innate immunity</i>	167
<i>Bacteriophage therapy for antibiotic resistance</i>	168
Biotechnology for treating tendon injuries	168
Use of growth factors to facilitate tendon injuries.....	168
Productivity enhancers	169
Bovine somatotropin for increasing milk production in dairy cows	169
Increasing milk production in cows by feeding propionibacteria.....	170
Use of growth factors	170
Transgenic plant products for use in animals.....	171
Biotechnology-based vaccines	171
Modern vaccines without viral non-structural proteins.....	172
Plant-derived vaccines for use in animals	172
Nano-bead vaccine adjuvant	173
Genetically engineered vaccines.....	173
<i>Application of nucleic acid vaccines in veterinary medicine</i>	173
<i>DNA vaccines</i>	173

<i>DNA vaccine for tuberculosis</i>	175
<i>DNA vaccines for West Nile encephalitis</i>	176
<i>DNA vaccines for cancer</i>	177
<i>Gene-based vaccine for Marek's disease</i>	177
<i>Genetic engineering of live rabies vaccines</i>	177
<i>Genetically engineered vaccines for equine encephalitis</i>	178
<i>Genetically engineered vaccines for Johne's disease</i>	178
<i>Rational engineering of virus capsids to produce FMD vaccine</i>	178
<i>Vaccines against avian influenza</i>	179
<i>Vaccines against parasitic infections</i>	180
Recombinant marker vaccines	180
<i>Marker vaccines for foot-and-mouth disease</i>	180
<i>Marker vaccine for Newcastle disease</i>	181
<i>Vaccines for classical swine fever</i>	181
Vaccines for tick control.....	182
Vaccination to protection swine from H1N1 influenza virus infection	182
Vaccination of cattle to prevent E. coli transmission to consumers in meat	182
Vaccines for bacterial equine respiratory infections.....	183
Use of RNAi to develop vaccines for viral infections in prawns.....	183
Companies developing biotechnology-based vaccines	184
Biotechnology in treatment of parasitic infections	184
Biotechnology in the treatment of CNS disorders in pet animals	185
Paraplegia due to acute spinal cord injury in dogs	185
Personalized approach to Niemann-Pick type C1 in cats	185
Role of biotechnology in veterinary oncology	186
Personalized management of dogs with high-grade B-cell lymphoma	186
VDC-1101 for treatment of lymphoma in dogs.....	186
Cell Therapy	187
Umbilical cord blood stem cells	187
Application of stem cells in veterinary medicine	187
<i>Use of stem cells to repair tendon injuries in horses</i>	188
<i>Stem cells for spinal cord injury in dogs</i>	188
Gene therapy	189
Gene therapy vectors	189
Gene therapy by mitochondrial transfer	190
In utero gene therapy	190
Gene editing.....	190
Genome engineering by using TALENs	190
Genome editing by using CRISPR system	191
<i>CRISPER system for creating animal models of human diseases</i>	191
<i>CRISPR-Cas9 system for producing tuberculosis-resistant cows</i>	192
<i>CRISPR-Cas9 for inactivation of pig retrovirus for xenotransplantation</i>	192
Applications of gene therapy in veterinary medicine	192
<i>Gene therapy for arthritis</i>	192
<i>Gene therapy for blindness in dogs due to Leber congenital amaurosis</i>	193
<i>Gene therapy for cardiomyopathy in dogs</i>	193
<i>Gene therapy for diabetes in dogs</i>	194
<i>Gene therapy for endocrine disorders</i>	194
<i>Gene therapy for hematological disorders</i>	194
<i>Gene therapy for inherited disorders of metabolism in dogs</i>	195
<i>Gene therapy to increase disease resistance</i>	196
<i>Gene therapy for infections</i>	196
<i>Gene therapy for renal failure</i>	196
Cancer gene therapy	197
<i>Antiangiogenic cancer gene therapy in dogs</i>	197
<i>Brain tumors in cats and dogs</i>	197
<i>Breast cancer in dogs</i>	198
<i>Canine hemangiosarcoma</i>	199
<i>Canine malignant melanoma</i>	199
<i>Canine soft tissue sarcoma</i>	200
<i>Melanoma in horses</i>	201
<i>Oncolytic virotherapy for cancer in dogs</i>	201
6. Research in Animal Biotechnology	202
Introduction	202
Research institutes	202
Ethical issues of research in animal biotechnology	210
Future prospects	211
Genome wide association studies for investigation of declining fertility in cattle	211
Strategies for control of twinning in cattle.....	212
Future developments of molecular diagnostics	212

Future of vaccine application in veterinary medicine	212
<i>Promotion of innate immunity in animals</i>	212
<i>Identification of key parasite antigens for eliciting immune response</i>	213
<i>Virus-like particle vaccines for lasting immune response</i>	213
Control of respiratory virus infections	213
Control and prevention of bioterrorism diseases in animals	214
Genetic control of disease resistance	214
<i>Production of cattle lacking prion protein</i>	215
Application of genetics and biotechnology to wildlife management	215
Future of animal genomics	216
Future prospects of in vitro meat production	216
7. Animal Biotechnology Markets.....	218
Introduction	218
Markets for biotechnology-based products for animal healthcare.....	219
Markets for biopharmaceuticals for animals	220
<i>Markets for recombinant proteins for animal healthcare</i>	221
<i>Markets for vaccines for animals</i>	221
Markets for animal diagnostics.....	221
<i>Test for bovine spongiform encephalopathy</i>	221
Animal biotechnology markets according to therapeutic areas	222
Markets for biotechnology-based animal products for humans	222
Transgenic proteins	223
Market for xenotransplantation	223
Strategies for promoting use of animal biotechnology.....	224
Financial losses from death and disease in animals	224
<i>Losses in farm animals</i>	224
<i>Losses in poultry</i>	224
<i>Losses in equine industry</i>	224
The emerging role of pet owners.....	224
Improvement in cattle through application of biotechnology	225
<i>Economic aspects of genomic evaluation of dairy cattle</i>	225
<i>Pig market</i>	225
<i>Cattle Market</i>	226
<i>Poultry market</i>	226
<i>Milk from genetically modified cows</i>	226
Impact of biotechnology on fish markets	226
Role of biotechnology in livestock performance enhancer market	227
Gene transfer technologies.....	227
In vitro meat production and animal biotechnology markets	227
Cost-benefit aspects of transgenic proteins	227
<i>Lower costs of transgenic production</i>	227
<i>Lower costs of treatment</i>	228
Unmet needs in animal biotechnology	228
Future prospects of animal biotechnology	229
Farm animals	230
<i>Global trends in epidemiology of livestock diseases</i>	230
<i>Genetic engineering of animals</i>	230
Companion animals.....	230
Animal molecular diagnostic markets.....	231
8. Regulatory issues	232
Introduction	232
Regulatory agencies for veterinary biotechnology in the US.....	232
FDA regulatory issues in agricultural biotechnology	233
FDA guidelines on use of antibiotics in food-producing animals	234
FDA and veterinary stem cell therapy	235
Food safety evaluation of transgenic animals	236
Food from cloned animals	237
FDA investigation of drug transfer into eggs	238
Animal feed safety	239
Medicated feeds.....	240
Regulatory issues for production of transgenic proteins.....	240
Risks of animal biotechnology	240
FDA regulation of bovine products.....	241
Worldwide biotechnology regulatory and trade issues	241
9. Companies Involved in Animal Biotechnology	244
Introduction	244
Biotechnology at top veterinary pharmaceutical companies	244
Profiles of selected companies.....	244

Collaborations.....	379
----------------------------	------------

10. References.....	384
----------------------------	------------

Tables

Table 1-1: Landmarks in the evolution of animal biotechnology in the 20th century	15
Table 1-2: Applications of proteomics in livestock industry and veterinary medicine	41
Table 1-3: Selected animal genomics and proteomics databases (DB)	43
Table 1-4: Examples of use of biomarkers in animal health	44
Table 2-1: Applications of genomics in livestock industry and veterinary medicine	51
Table 2-2: Expression systems for production of recombinant proteins	66
Table 2-3: Recombinant proteins obtained from milk of transgenic animals.....	68
Table 2-4: Companies involved in the production of transgenic pharmaceuticals	71
Table 2-5: A comparison of gene knockout and transgenic techniques	75
Table 2-6: Examples of transgenic mouse models of non-neoplastic human diseases	75
Table 3-1: Diseases of dairy cattle	83
Table 3-2: Causes of chronic wasting disease in animals.....	107
Table 4-1: Applications of microarrays in animal biotechnology	128
Table 4-2: Biosensor technologies with potential applications in molecular diagnostics	130
Table 4-3: Applications of molecular diagnostics in animals.....	135
Table 4-4: Viruses that can be detected by molecular diagnostics	142
Table 4-5: Testing for harmful prions in brain tissue from dead cattle.....	147
Table 4-6: Companies involved in developing molecular diagnostics for TSEs	151
Table 4-7: Pathogenic bacteria in food and targets for molecular diagnostic probes.....	155
Table 4-8: Companies involved in molecular diagnostics for food-borne infections	159
Table 4-9: Companies developing molecular diagnostics for veterinary medicine	161
Table 5-1: Veterinary biotechnology products.....	162
Table 5-2: Pharmaceutical versus biotechnology products.....	163
Table 5-3: Nonantibiotic strategies for control of infections	164
Table 5-4: Experimental DNA vaccines tested in animals	175
Table 5-5: Companies developing biotechnology-based vaccines for animals.....	184
Table 6-1: Areas for future research applications of animal biotechnologies	211
Table 7-1: Worldwide markets for biotechnology-based products for farm animals: 2016-2026	219
Table 7-2: Worldwide markets for biotechnology-based products for pet animals: 2016-2026	219
Table 7-3: Biotechnology-based markets for animal healthcare according to regions: 2016-2026.	220
Table 7-4: Biotechnology markets for farm animals according to therapeutic areas: 2016-2026	222
Table 7-5: Biotechnology markets for pet animals in therapeutic areas: 2016-2026	222
Table 7-6: Worldwide markets for biotechnology-based animal products for humans: 2016-2026	223
Table 9-1: Ranking of top veterinary companies with biotechnology products.....	244
Table 9-2: Selected collaborations of companies in animal biotechnology.....	379

Figures

Figure 1-1: Relation of animal biotechnology to other technologies and human health.....	49
Figure 2-1: Nuclear transfer technology.....	58
Figure 2-2: Generation of transgenic animals by sperm-mediated gene transfer	65
Figure 2-3: Production of therapeutic proteins in the milk of transgenic animals.	67
Figure 7-1: Unmet needs in animal biotechnology.....	229