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Toward a veterinary informatics research agenda: An analysis of the PubMed-indexed literature

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ABSTRACT

Purpose: Veterinary medicine and human health are inextricably intertwined. Effective tracking of veterinary information – veterinary informatics – impacts not only veterinary medicine, but also public health, informatics research, and clinical care. However, veterinary informatics has received little attention from the general biomedical informatics community.

Methods: To identify both active and under-researched areas in veterinary informatics, we retrieved Medical Subject Heading (MeSH) descriptors for veterinary informatics-related citations and analyzed them by topic category, animal type, and journal.

Results: We found that the categories of veterinary informatics with the most growth were information/bibliographical retrieval, hardware/programming, and radiology/imaging. Less than two articles per year were published in the areas of computerized veterinary medical records, clinical decision support, standards, and controlled vocabularies. Veterinary informatics articles primarily address production animals such as cattle and sheep, and companion animals such as cats and dogs. Six journals account for 31% of the veterinary informatics literature, 35 journals account for 66%.

Conclusions: Veterinary informatics remains an embryonic field with relatively few publications. With the exception of radiology/imaging, published articles are primarily focused on non-clinical areas such as hardware/programming and information retrieval. There are very few publications on controlled vocabularies, standards, methodologies for integrating disparate systems, computerized medical records, clinical decision support systems, and system usability. The lack of publications in these areas may hamper efforts to collect and track animal health data at a time when such data are potentially critical to human health.

1. Introduction

Over 61% of the 1415 known infectious human pathogens are zoonotic in origin, and 75% of emerging diseases are zoonoses [1]. Further, most agents identified as significant bioterrorism or public health threats affect animals as well as humans. Bioterrorism using the zoonotic disease anthrax, and recent outbreaks of other zoonoses including bovine

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spongiform encephalopathy (BSE or “mad cow disease”), monkeypox, SARS, and avian influenza, have highlighted the important role of veterinarians in protecting human health [2–6]. In addition, many non-infectious diseases such as diabetes, cancer, and renal failure are similar in both animals and humans. For these reasons, effective tracking of veterinary information – veterinary informatics – is relevant not only to veterinary medicine, but also to public health, clinical research, and medical informatics.

However, veterinary informatics is an embryonic field. There appear to be no journals or even journal sections devoted to veterinary informatics. Therefore, the veterinary informatics literature is scattered in a variety of journals. The purpose of this paper is to provide an objective bibliographic analysis to determine which areas of veterinary informatics are growing, which are in need of further research, and to determine the species of animals upon which veterinary informatics work has been concentrated.

1.1. *Veterinary versus medical informatics*

Beyond the obvious patient-related differences, there are also fundamental differences between human and veterinary medicine with respect to practitioners, data, and practices that significantly influence veterinary informatics research and applications. Physicians are able to concentrate on a single species, but veterinarians work with a variety of animals. Each species, and sometimes even breed, has its own unique anatomy, physiology, normal ranges, susceptibility to disease, and sensitivity to drugs. Therefore, systems for health records, decision support, drug interactions, and laboratory reporting must account for this complexity.

Veterinary medicine also has a dichotomy that generally does not exist in human medicine, in that a certain amount of routine health care is provided by non-veterinarians. For example, a rancher may provide primary care, including vaccinations, antibiotics, and even routine obstetrical care, relying on the veterinarian for more complex issues as well as consultation and advice. The rancher may then document this care in privately held individual- and herd-level records, which can encompass a variety of data, such as breeding and parturition dates, medications, illnesses, and gender and number of offspring per breeding. Merging individual records into herd-level records presents interesting research questions; some of which are similar to questions addressed by public health informatics. In addition, the technological and financial barriers to merging privately held data with the veterinarian’s medical record to produce a complete health record are a major challenge to veterinary informatics.

There are also financial differences between human and animal medicine that impact veterinary informatics. For example, payment is due when veterinary services are rendered and there are generally no third-party payers. While this simplifies reimbursement issues and eliminates the need for CPT and ICD9/10 coding, the absence of standardized coding also means that, with the exception of corporate-owned practices, no data are sent outside the practice and therefore there are limited opportunities to aggregate data across practices.

Yet veterinary practices are similar to medical practices in other respects. While almost all veterinary practices in the U.S.A. use practice management systems for office tasks such as invoicing and inventory, few have adopted electronic medical records. Like physicians, veterinarians are also dealing with an explosion of new information, increased expectations of quality medical care, and increased costs. Additionally, veterinary practices are increasingly being acquired by corporations, which may impose corporate standards for information systems and compliance with data entry. Therefore, human and animal medicine share some of the same drivers for computerization.

Finally, some veterinary medicine is more analogous to human public health, in that production-animal veterinarians routinely work with populations such as flocks and herds, both for preventative care and for treatment of illnesses. Veterinarians must constantly watch for animal diseases that could impact the food supply or the national economy, such as BSE, foot-and-mouth disease or classical swine fever. Veterinarians are also the first line of defense against zoonotic diseases that could be used in a bioterrorism attack, such as anthrax and plague [4].

1.2. *Previous work*

In 1991, Talbot described the general areas of medical informatics and how they relate to veterinary medicine [7]. In 2000, Smith and Williams analyzed the veterinary informatics literature for the 30 years spanning 1966–1995 [8]. They defined a list of 87 Medical Subject Heading (MeSH) descriptors that were relevant to veterinary informatics, grouped these descriptors into 11 categories, and reported the number of citations that were labeled with each descriptor. Smith and Williams found that hardware and programming, information and bibliographic retrieval, decision support, and radiology/imaging were the most common categories of citations in decreasing order of frequency. There have been no subsequent reports describing the areas where work in veterinary informatics is concentrated. Motivated by a desire to characterize the field of veterinary informatics and to move toward a research agenda, we performed a bibliometric analysis to determine the areas of veterinary informatics that are actively being pursued by researchers, areas that are under-studied, journals where work is being published, and what animal types are being investigated.

2. Methods

2.1. *Descriptor list*

We reviewed the list of descriptors identified by Smith and Williams and used the MeSH database (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?db=mesh) to locate each descriptor in the MeSH hierarchy. Some descriptors (Computer User Training, Computer-Assisted Instruction, Monitoring, Physiologic, Office Automation, and Programmed Instruction) were not under the Medical Informatics hierarchy. We also located a number of new informatics-related descriptors that had subsequently been added to the Information Science hierarchy, which is the parent of the Medical Informatics hierarchy. Therefore, to obtain maximal coverage of informatics terms, we broadened our search to all Information Science descriptors instead of only the Medical Informatics descriptors extracted by Smith and Williams. By manual literature review, we identified one additional descriptor, Animal Identification Systems, which was outside the Information Science hierarchy.

We then defined veterinary medicine descriptors to be included by using the MeSH browser (http://www.nlm.nih.gov/mesh/MBrowser.html). We included all descriptors except "Carbaryl" as a review of citations did not indicate that this term was relevant; and we added the term "Brucellosis" as this term had been included by Smith and Williams.

2.2. *Data extraction*

Two Python programs were developed to retrieve PubMed citations concerning veterinary informatics. The first program posted a query to PubMed and retrieved the PubMed identification numbers (PMIDs) for the matching citations. A second program used these PMIDs to retrieve the full citations. The query was aimed at the conjunction (via Boolean AND) of information science and veterinary medicine. Veterinary medicine was defined by the union (via Boolean OR) of citations bearing either the veterinary qualifier or one of the veterinary descriptors. The relevant portion of the resulting query is shown in Fig. 1.

We executed the programs once for each publication year from 1995 to 2004 inclusive, as this period covers significant technological advancements affecting informatics. We then ran a third program that counted the number of occurrences of each MeSH descriptor that fell hierarchically under the broad descriptor Information Science. We then imported these data into a spreadsheet (Excel 2003, Microsoft, Redmond, WA) to calculate the total occurrences for each descriptor and each category for the 10-year period and the total of all descriptors for each year.

We manually retrieved the descriptors that were outside the Information Science hierarchy by executing the query from Fig. 1 in PubMed, substituting the specific descriptor for the Information Science entry, and limiting the date range with the [EDAT] parameter. These counts were then added to the spreadsheet. The category for each informatics-related term was also added.

We compared veterinary informatics to medical informatics and the overall literature. All articles indexed into PubMed ([EDAT]) in 1995–2004, inclusive, were counted. Similarly, all articles labeled with Medical Informatics [mh] were also counted.

2.3. *Data analysis*

We imported the retrieved citations into a bibliographical database program (EndNote 7, Thomson ResearchSoft, Stamford, CT). Because we expanded our query to include the full Information Science hierarchy, we created an EndNote query to display only the citations with at least one informatics-related MeSH descriptor. This included the descriptors identified by Smith and Williams as well as the additional descriptors that we identified (described above). To determine the distribution of veterinary informatics citations by journal, we exported the journal titles for the informatics citations from EndNote into Excel, sorted alphabetically, and subtotaled. We used a similar procedure to determine the distribution of veterinary informatics work by animal type for the articles that specified an animal type. Finally, we aggregated similar species into groups as shown in Fig. 2.

```
(veterinary[sh] OR
 Animal Technicians[mh] OR
 Hospitals, Animal[mh] OR
 Veterinary Medicine[mh] OR
 Pathology, Veterinary[mh] OR
 Surgery, Veterinary[mh] OR
 Veterinary Service, Military[mh] OR
 Abortion, Veterinary[mh] OR
 Brucellosis, Bovine[mh] OR
 Anatomy, Veterinary[mh] OR
 Education, Veterinary[mh] OR
 Hospitals, Animal[mh] OR
 Legislation, Veterinary[mh] OR
 Schools, Veterinary[mh] OR
 Veterinary Drugs[mh] OR
 Venereal Tumors, Veterinary[mh]) AND
 Information Science[mh]
```

Fig. 1 – Query for veterinary and information science descriptors.

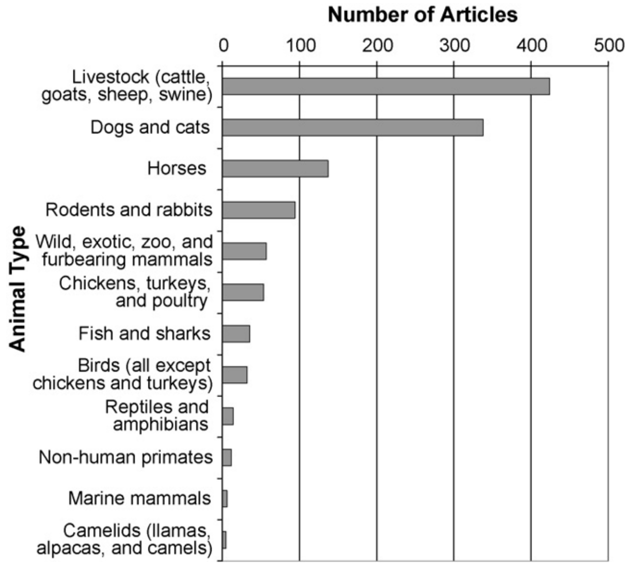

Fig. 2 – Number of articles by type of animal (of 1208 articles that specified an animal type).

3. Results

In addition to the 87 descriptors identified by Smith and Williams, we identified 28 informatics terms that were either added to the Information Science hierarchy since 1995 or were not considered by Smith and Williams (Table 1). We added two categories, Telemedicine and GIS and Animal Identification Systems, which contained the MeSH descriptors Animal Identification Systems and Geographic Information Systems to Smith and Williams original 11. We then assigned each of the 28 new descriptors to one of these 13 categories.

We retrieved citations with at least 1 of 364 MeSH descriptors from the Information Science hierarchy as well as the additional terms we identified. We analyzed citations that contained at least 1 of the 115 informatics-related descriptors and identified a total of 1385 veterinary informatics citations for articles published over the past 10 years. Thirty-five journals accounted for 914 (66%) of these citations; the remaining 471 (34%) were distributed across 214 other journals. Six journals, *The Journal of the American Veterinary Medical Association*, *The Veterinary Record*, *Preventive Veterinary Medicine*, *Veterinary Radiology and Ultrasound*, *Revue Scientifique et Technique*, and *The American Journal of Veterinary Research*, accounted for 31% of the veterinary informatics citations.

The growth rate of the veterinary informatics literature increased from 72 articles in 1995 to 146 articles in 2004, for a growth rate of 103% (Fig. 3). For comparison, the growth rate of the medical informatics literature increased from 4367 articles in 1995 to 12,153 in 2004, an increase of 178%. In contrast, the overall growth of PubMed increased from 404,021 articles in 1995 to 623,934 articles in 2004, an increase of 54%. Therefore, the growth rate of the veterinary informatics literature is approximately double that of PubMed. The medical informatics literature accounts for 69,350 of the 5,186,908 articles added to PubMed (1.34%) over the past 10 years. In contrast, the veterinary informatics literature accounts for only 1385 articles (much less than 1%).

Most citations (1208 of 1385, 87%) were labeled with at least one MeSH descriptor indicating a specific type of animal. Of

Table 1 – Terms added to the Information Science hierarchy since 1995 or not considered by Smith and Williams

Category or descriptor	Total 1995–2004
GIS and Animal Identification Systems	
Animal Identification Systems*	141
Geographic Information Systems	20
Decision support	
Decision support systems, clinical	4
Education	
Multimedia	5
Hardware and programming	
Computer security*	3
Computers, handheld	0
Computing methodologies	0
Data compression	0
Hypermedia	1
Medical informatics applications*	0
Medical informatics computing	1
Speech recognition software	0
Information/bibliographical retrieval	
Databases	8
Electronic mail	2
Information management	2
Information services*	28
Internet	80
Logical observation identifiers names and codes	0
PubMed	2
Systematized nomenclature of medicine	0
Terminology	118
Vocabulary, controlled	4
Radiology/imaging	
Imaging, three-dimensional	10
Pattern recognition, automated	2
Radiotherapy planning, computer-assisted*	4
Teleradiology	1
Telemedicine	
Telemedicine*	13
Telepathology	0

* Indicates descriptor present prior to 1995.

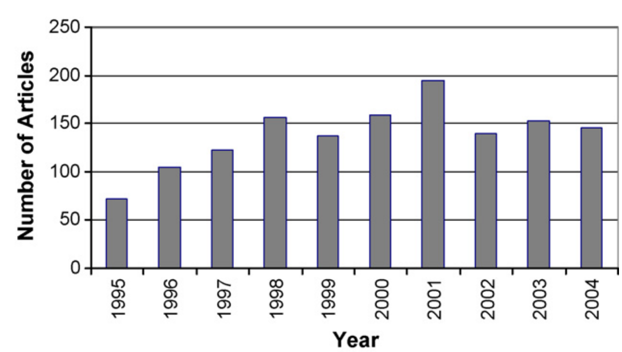

Fig. 3 – Growth of the veterinary informatics literature 1995–2004.

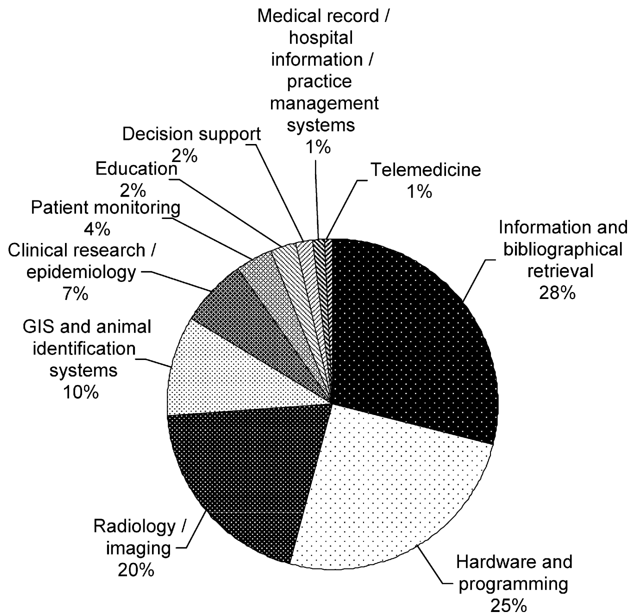

Fig. 4 – Veterinary informatics MeSH terms by category. In this graph, the number of MeSH terms was used instead of the number of articles, to account for the fact that some articles contained more than one relevant MeSH term.

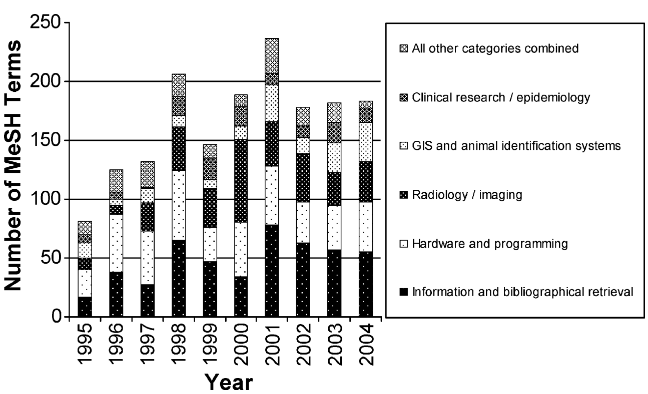

Fig. 5 – Veterinary informatics MeSH terms per year (by category). In this graph, the number of MeSH terms is used instead of the number of articles, to account for the fact that some articles contained more than one relevant MeSH term.

these, 35% were focused on food or production animals such as cattle and sheep (Fig. 2). The next largest category was for dogs and cats.

Veterinary informatics publications were concentrated in three categories: information/bibliographic retrieval, hardware/programming, and radiology/imaging (Figs. 4 and 5). Only eight citations published in the last 10 years referred to articles discussing computerized medical records in veterinary practice.

4. Discussion

Although the growth rate of the veterinary informatics literature has more than doubled during the past 10 years, we found that veterinary informatics remains a small field, averaging fewer than 140 articles per year over the past 10 years. The majority of work is concentrated on food or production animals and companion animals such as cats and dogs; far less work is focused on other species. We also found that six journals accounted for almost one-third of all published articles. Most citations focused on information/bibliographic retrieval, hardware/programming, and radiology/imaging.

Our findings were similar to those of Smith and Williams, who found hardware/programming and information/bibliographic retrieval to be the most prevalent [8]. However, we found fewer citations on decision support, which was the third most prevalent category in the Smith and Williams analysis compared to eighth in ours. Further, because of the economic significance of food animals, the majority of citations on decision support concentrate on food animal management, such as breeding decisions and culling for disease control. There were very few articles on clinical decision support; exceptions included reports on systems developed for detection of lameness in horses [9] and bovine tropical diseases [10]. Our results suggest that research on clinical decision support systems in veterinary medicine has fallen out of favor over the past 10 years. Additionally, few articles addressed computerized medical records, controlled vocabularies and standards, system evaluation or usability.

A key driver for veterinary informatics is concern about the safety of the food supply, and as a result, the human population. Further, certain diseases cause significant economic damage due to import bans on livestock and livestock products from affected nations [11]. Animal tracking may prevent and contain naturally occurring and deliberately introduced animal diseases, and can help prevent animals possibly affected by BSE from entering the food chain. Therefore, it is not surprising that there has been increased work in Animal Identification Systems and Geographic Information Systems. We speculate that the spike in veterinary informatics citations in 2001 may have been triggered by the outbreak of foot-and-mouth disease in the UK that year (Fig. 3).

4.1. *Implications for veterinary informatics*

A survey of the existing literature cannot define a research agenda for veterinary informatics. However, it is a necessary and useful step toward a research agenda. We identified three general areas of veterinary informatics that are underrepresented in the published literature: computerized medical records and clinical decision support, standards, and user interface design.

4.1.1. *Computerized medical records and clinical decision support*

Despite the importance of veterinary information tracking to both animal and human health, the recent emphasis on human electronic medical records, and articles indicating the benefits of such systems in veterinary medicine [12,13], we found only eight publications on computerized veterinary medical record systems. We reviewed these articles and found that only two [14,15] discussed the development or implementation of a system. Only a single article [16] described drawbacks of existing computerized medical record systems.

Another article discussed issues encountered during integration of data from disparate systems [17]. No article provided empirical data on system functionality, usability, or cost–benefit analysis; addressed factors influencing technology adoption by veterinarians; or compared veterinary medical record systems to analogous human systems, suggesting that these areas may benefit from additional research.

Veterinarians deal with multiple species, each having its own normal laboratory and physiological values, susceptibility to disease, and sensitivity to pharmaceuticals. Therefore, user interfaces to minimize the cognitive load on the veterinarian should also be investigated. In addition, only 2% of the retrieved articles were related to clinical decision support. Given the increasing complexity of veterinary medicine, increased client expectations of quality medical care, and efforts to reduce medical errors, research into clinical decision support systems may be justified.

4.1.2. *Standards*

In order to track animal health data on a regional, national or international scale, we must have consistent coding using controlled vocabularies and transmission of data to central repositories. Further, standards are necessary for efficient inter-system data transmission, data mining, and information retrieval. However, we found few publications on controlled vocabularies such as SNOMED and LOINC, or data transmission standards such as HL7 and DICOM. Given the American Veterinary Medical Association's (AVMA) Informatics Committee recommendation in 1993 that SNOMED be adopted as a standard for veterinary informatics [18], and the AVMA's subsequent adoption of SNOMED, LOINC, and HL7 as veterinary informatics standards [19], additional investigation of topics such as vocabulary adequacy and coverage is needed. In addition, due to the complexity of SNOMED-CT and the fact that private practices generally lack coding personnel, research into automated or semi-automated encoding of veterinary data may be timely and useful. Investigation of the current status of vendor support for these standards is also warranted.

Further, in order to facilitate data transmission, data mining and knowledge discovery, consistency of species and breed descriptors is necessary. There has been only one article on this topic [20]; however, the needs of the various contributors and consumers of data that rely on consistent animal taxonomies should also be investigated and documented.

4.1.3. *User interface design*

Given the wide variety of animals cared for by veterinarians, flexible user interfaces must be developed that minimize the cognitive load on the user while accommodating the varying data entry and display requirements dictated by different animal types. Further, role-based systems must be developed. Human medical informatics has a subfield of nursing informatics that supports the unique needs of the nurse. In contrast, we found no articles that compared the veterinary technician's information needs to those of the veterinarian.

4.2. *Limitations*

There are some important limitations of our work. First, one may question whether MeSH and PubMed adequately capture the veterinary informatics literature. Smith and Williams discussed this point at length. We agree with their assessment that the "controlled MeSH vocabulary is superior to keyword-based, free-text searching of other veterinary-related bibliographic databases for informatics articles" [8], but acknowledge that searching PubMed using MeSH terms is not infallible. MeSH terms are assigned by indexers who are neither veterinary nor informatics experts, and that there are known inconsistencies between indexers [21]. Therefore, some relevant citations may have been missed. For example, Shamoun and Livesay's article, "Organizing the animal hierarchy into a Linnean Taxonomy in SNOMED CT" [20] was not retrieved because it contained the MeSH term "animals" but none of the veterinary-related terms we used. However, MeSH-based queries retrieve more relevant articles compared to keyword searching and are generally recommended by librarians [22].

In addition to the advantages discussed above, there are disadvantages related to using MeSH. Articles concerning a particular topic that are published before a MeSH descriptor was implemented for that topic must be retrieved either by using other descriptors or by using free text searches. Additionally, our analysis was restricted to PubMed because of the availability of the MeSH hierarchy. Murphy has pointed out that strategies for searching PubMed for veterinary literature are not directly translatable to CAB Abstracts, because of the keyword approach used by CAB Abstracts [23]. We acknowledge that further work in assessing the state of veterinary informatics should also include the development of appropriate strategies for searching other significant veterinary databases including CAB Abstracts.

Third, in order to identify under-researched areas, we chose a high recall, low precision approach by retrieving all articles with at least one of the selected MeSH terms, regardless of whether the MeSH term was flagged as a major subject heading. We recognize that this approach may have resulted in the inclusion of irrelevant articles. However, our goal was to identify under-researched areas, therefore a "wide net" was desirable. In addition, the wide variety of informatics applications in veterinary medicine not present in human health care requires a broad search. For example, a primary goal of food animal veterinarians is increasing efficiency through production; therefore, some articles addressed production improvements, such as increasing litter sizes or maximizing weight gain for slaughter. However, these areas of production medicine have no parallels in human medicine. This reveals a weakness in PubMed/Medline indexing; an area for future veterinary informatics research. A more accurate, but much more laborious and subjective strategy is to manually determine whether each article is relevant to veterinary informatics.

Finally, we recognize that there is veterinary informatics work that is either not being published or is available only through reports to funding agencies. However, a comprehensive survey of such unpublished work is beyond the scope of this paper.

5. Conclusion

Veterinary informatics is still an embryonic field. The link between human and animal health and the small number of veterinary informatics articles implies that veterinary informatics is a promising field for further investigation. However, it is also possible that research is being published in journals not indexed in PubMed, is being published elsewhere (e.g., funding agency reports), or done, but not published all. The limited number of articles that were retrieved serves to underscore the importance of disseminating the hard-won knowledge that has been acquired in veterinary informatics, so that we can build on previous efforts. We found that most veterinary informatics work published over the past 10 years and indexed by PubMed focused on hardware/programming, radiology/imaging, and information retrieval. In contrast, computerized veterinary medical records, clinical decision support, controlled vocabularies, standards, methodologies for integrating disparate systems, and usability of veterinary systems were relatively under-studied. The lack of publications in these areas may hamper efforts to collect and track animal health data at a time when such data are potentially critical to human health.

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