National Leadership Grants for Museums

Sample Application MG-249218-OMS-21

Chicago Zoological Society, Brookfield Zoo

Amount awarded by IMLS:	$689,419
Amount of cost share:	$691,090

The project description can be viewed in the IMLS Awarded Grants Search:
https://www.imls.gov/grants/awarded/mg-249218-oms-21

Attached are the following components excerpted from the original application.

- Narrative
- Schedule of Completion

When preparing an application for the next deadline be sure to follow the instructions in the most recent Notice of Funding Opportunity for the grant program and project category (if applicable) to which you are applying.

Project Narrative

1. PROJECT JUSTIFICATION

1a. Field-Wide Need, problem, or challenge our project will address and how identified

The zoological community is dedicated to ensuring the animal collections under their stewardship receive the highest professional standards for veterinary care and welfare. Clinical veterinarians engaged in zoo, wildlife, and aquatic animal medicine face continuous challenges in the evaluation of diagnostic images and identification of abnormal lesions in a plethora of species because adequate reference images from healthy animals are not available. When abnormal radiographic lesions are noted, clinical veterinarians often seek consult from a handful of veterinary radiologists with special interest in non-domestic species. Despite their advanced training, however, veterinary radiologists face similar challenges in providing consultation on zoo species due to a lack of available imaging studies for reference.

The introduction of digital imaging technologies over the past two decades has dramatically advanced veterinary diagnostic medicine. Digital radiography (DR; "x-rays") and advanced cross-sectional imaging (CT and MRI) have become the standards for advanced care. The digital nature of these diagnostic images has enabled more collaboration and reference data sharing than at any point in the history of zoological medicine. For domestic animals, robust reference databases provide contain comparative studies (diagnostic image sets from a single patient at a single point in time) to aid in the evaluation of health and disease states. Domestic animal veterinarians are further supported by numerous veterinary radiologists (board-certified specialists with advanced training in diagnostic imaging), who are highly skilled at image interpretation and widely available for near instantaneous consultation.

There is no corollary of support for most non-domestic species found in zoos and aquariums despite their rarity, conservation status, and biological value. The recognition of abnormal lesions on diagnostic images heavily depends on established reference images from normal, healthy animals. Correlations across species provide a general foundation, but subtle nuances between species can dramatically alter interpretations of radiographic findings and their relationship to pathological conditions. While detailed studies on normal anatomy and correlated diagnostic images exist for a small number of non-domestic animals, such published references are lacking for most species.

The Chicago Zoological Society (CZS) proposes creation of this **Zoo and Aquarium Radiology Database (ZARD)** to establish an innovative, collaborative, and centralized database solution to address these needs. Radiographs, CT, and MRI reference images from zoological species will be anonymized, catalogued, and archived in an online database that will allow queries through a web-based user portal. Veterinarians and radiologists from zoos around the globe will be able to filter searches based on a variety of parameters to identify and view comparison diagnostic imaging studies that will aid their medical care.

Our proposed project will bring together six large zoological organizations – CZS, San Diego Zoo Global (SDZG), the Wildlife Conservation Society (WCS), the Saint Louis Zoo, Disney's Animal Kingdom, and the Columbus Zoo and Aquarium – that collectively manage twelve zoological parks and aquariums, as well as numerous *in situ* conservation and field veterinary programs. Together these organizations are home to over 45,000 animals representing thousands of species. They are recognized leaders in the zoological community and share a common commitment to providing the highest caliber of care for their animals. Additionally, radiologist support will be coordinated with the American College of Veterinary Radiology's Zoo, Exotic, Wildlife Diagnostic Imaging Society (ACVR ZEWDIS). Multiple veterinary radiologists who are dedicated to advancing the field of radiology for zoological species will be included in the execution of this project. All organizational and individual partners are firmly committed to the success of this project (***Supporting Docs 4-6*** *– Letters of commitment from partner organizations, ACVR, and veterinary radiologists*).

The Chicago Zoological Society possesses the in-depth knowledge in veterinary radiology necessary to lead this project and has been at the forefront of incorporating advanced diagnostic imaging into zoological medicine for the past decade. We are one of the first zoos to invest in an in-house CT scanner and continue to maintain

the most comprehensive in-house imaging capabilities of any North American zoo. The collaborating organizations on this project are all committed leaders in advancing veterinary care in zoos and aquariums through innovative approaches. They represent four of the first ten zoological institutions globally that have invested in providing on-site CT capabilities. Furthermore, CZS was the first zoo to hire a full-time veterinary radiologist and operates the only radiology consulting service aimed specifically at zoo and aquarium species. **** A table of contents is provided as **Supporting Doc 1**, references are provided as **Supporting Doc 2**, and a glossary of terms and abbreviations is provided as **Supporting Doc 3** ****

1b. How Will the Museum Field Benefit from Project

Many zoos and aquariums have limited reference material available due to smaller collection sizes, limited resources for routine image acquisition, a lack of digital and advanced imaging equipment, and the use of contracted companion animal veterinarians for routine care. However, even large zoos face frequent challenges with adequate reference images for less common species, advanced imaging techniques, and specific pathological conditions. The absence of a cataloged, centralized database further precludes easy access to comparison studies filtered by age, sex, imaged body region, and health state of the patient.

Veterinary diagnostic images are obtained from multiple modalities including digital radiographs (DR, "x-rays"), computed tomography (CT, "CAT scans"), and magnetic resonance (MR, "MRI"). These images are stored in Digital Imaging and Communications in Medicine (DICOM) format, a universally recognized industry standard that enables transfer of images using a standard picture archiving and communication system (PACS) technology. PACS servers enable economical storage, organization, easy transfer, efficient access, and multi-location retrieval of images. The storage format is consistent across human and veterinary medicine, allowing for integration and operability across nearly all medical devices and imaging modalities. Information on the study acquisition parameters and basic patient information (e.g. patient number, name, sex, age) are captured directly within the metadata of the DICOM image and is retrievable through PACS.

The human medical field has long recognized the value PACS technology offers for centralized databases that enable large-scale sharing of images, teaching, research, meta-analysis of data, and many other opportunities (Johnson et al., 2019a, 2019b; Bustos et al., 2020). Patient data embedded in the DICOM files can be accessed from a PACS server and connected into a centralized database with other medical data to create a powerful resource. For example, the MIMIC Chest X-ray Database (https://mimic-cxr.mit.edu) developed by MIT's Lab for Computational Physiology is a freely available database containing over 370,000 anonymized chest x-ray images from over 60,000 patients. Linkages to other health data adds even further value ((Johnson et al., 2016).

Restrictions of scale prevent any single zoological organization being able to develop such a comparable database for non-domestic animals, but through a collaborative approach a centralized database is possible and would provide an immense benefit to all zoos and aquariums. By combining the veterinary diagnostic images and resources from the six zoological organizations in this collaborative endeavor, we will create a centralized database comprised of over 65,000 DR and CT/MRI studies (Table 1, provided as ***Supporting Doc 7***).

Data collation and cataloging for this project will result in an immense and immediate benefit for zoos and aquariums through the creation of a web-based resource that is globally accessible to veterinary professionals. The project will eliminate current challenges veterinarians face in finding appropriate reference studies and will provide veterinary radiologists with a powerful tool to aid their consultations with zoos around the world. Imaging studies will be anonymized, but the retention of key fields such as species, age, sex, and health status in the database will allow refined searches that adds value to all users. Data entry standards for PACS metadata is human patient focused in such a way that there is no uniform entry standard within the veterinary field, leading to a loss of some advanced search capabilities. During the anonymization process in this project, information will be standardized and added into the database in way that improves search capabilities similar to well established human radiology databases.

Approximately 7,000 additional DR and CT studies are projected to be completed annually by the collaborating institutions on this project; as such, the database will grow by approximately 21,000 studies during this three-year project. By the third year of the project the database will be able to receive studies from other zoos and aquariums through a web-based portal. This growth opportunity will allow for the creation of additional partnerships. Multiple zoos and aquariums have already expressed their desire to use and contribute to this database project and by the third year of the project they can become active partners through the web interface (***Supporting Doc 17*** *– Letters of support from 30 zoos and aquariums*). Species in which reference studies are sparse will be flagged and actively recruited, creating a "crowd-sourced" approach within the zoological community to increase available reference data. Given the global reach of this project, zoos and aquariums in the United States will also benefit from contributions made by international institutions. Many species that are uncommon and reference deficient (e.g. pangolins, giant pandas) due to limited populations in the United States are more widely represented in international zoological institutions.

Zoos and aquariums depend on healthy, reproductively sustainable populations of animals in order to deliver on their missions. Stewardship of living animal collections requires optimal health and welfare. The American Association of Zoo Veterinarians (AAZV), European Association of Zoo and Wildlife Veterinarians (EAZWV), American College of Zoological Medicine (ACZM), International Association for Aquatic Animal Medicine (IAAAM), European Association of Zoos and Aquariums (EAZA), and Association of Zoos and Aquariums (AZA) have all endorsed this project and provided letters of support (***Supporting Doc 8***).

The project will enhance the ability of veterinarians to make accurate diagnoses, determine appropriate therapies, and monitor health changes by providing reference image datasets that aid in the identification of lesions and monitoring of treatment success. Research has demonstrated the importance of diagnostic imaging for improving animal health in many species. Published studies on the diagnosis of air sacculitis in orangutans (Steinmetz et al., 2011) evaluation of sinusitis in koalas (Bercier et al., 2014) assessment of body condition in Blanding's turtles (Newman et al., 2019), and characterization of kidney stone formation in river otters (Niemuth et al., 2014) provide simple glimpses into the importance of diagnostic imaging in zoological medicine. However, even in species where the value of diagnostic imaging for a specific disease is established, the availability of reference images that aid clinicians in comparing normal to abnormal findings is often lacking. This project will lessen the burden on individual zoos for maintaining their own reference image datasets, a particularly strong benefit for smaller organizations and those with limited resources.

The establishment of this database also creates a foundation for future research projects related to animal health and collection stewardship. The database structure will be valuable for clinical research and meta-analysis using diagnostic imaging findings to evaluate disease etiology, risk factors, lesion appearance, prognosis, and treatment efficacy. The success of over 500 Species Survival Plan (SSP) programs and 115 programs for reintroduction of wildlife into native habitats that are maintained by the Association of Zoos and Aquariums (AZA) depend on accurate assessment of animal health. This project will advance not only the evaluation of individual animals, but will provide significant data to aid in evaluation of health at the population level. Furthermore the web-based accessibility provides opportunities for research investigations that focus on allied core scientific fields of study, such as anatomy and physiology, without the need for necropsy and prosection of post-mortem specimens.

The database design allows for future expansion and enables incorporation of abnormal images representing radiographic abnormalities and disease states. Inclusion of abnormal studies will improve recognition of radiographic lesions and pathologic states by veterinarians. The previously mentioned MIMIC-CXR database comprised of human images links to other information on demographics, vital signs, laboratory tests, and medications (***Supporting Doc 9*** *– Example study*). While this is beyond the scope of our proposed project, it illustrates the powerful metaanalysis that is possible with large scale databases that support a diverse range of analytic studies spanning epidemiology, clinical decision-rule improvement, and electronic tool development. The ZARD database will be designed with forethought to application programming interfaces (API) to allow

future expansion and communication with other software that would allow for epidemiological evaluation of disease prevalence and risk factors within populations, investigations on treatment success, and studies aimed at improving animal health. Additionally, the images provide an enormous teaching and training tool for veterinarians specializing in zoological medicine and veterinary radiology.

1c. How the project will address the goals of National Leadership Grants and Project Category

This project aligns with several IMLS project categories, as well as IMLS agency-level goals for advancing innovation and increasing public access.

Collections Stewardship and Access: The zoological institutions that comprise the Association of Zoos and Aquariums (AZA) are home to approximately 800,000 animals from 6,000 species. Over 1,000 of these species are classified as threatened or endangered by the International Union for the Conservation of Nature. Maintaining the long-term sustainability of these animal populations through careful stewardship is a primary goal for all zoos and aquariums that requires dedication to animal health and the continued advancement of veterinary care. This project will create an innovative tool to aid veterinary professionals in achieving this goal. The established database will allow for research investigations into animal health and well-being to promote enhancements in animal care and population management. The collaborative methodology and digital access to data will create opportunities across institutions regardless of size, location, and financial resources. Furthermore, the shared resource created from this project establishes a framework for future inquiries and new synergies.

Digital Platforms and Applications: The database platform design in this project will provide an immediate shared access, web-based application. Beyond access and use, however, the platform will encourage active contribution of diagnostic imaging studies by other zoological institutions. By fostering engagement at the user level, we will encourage contribution of additional studies to continue building a thoroughly comprehensive resource over time. As populations of many species decrease in the wild, zoos increasingly also become a permanent archive of specimen information. Capturing reference material from individual animals in an accessible database ensures preservation of their data for future research purposes.

Professional Development: The online nature of the database makes it easily accessible and a powerful learning resource for veterinarians and zoo professionals. Beyond applications within formal higher education training programs (e.g. veterinary students, interns, residents, post-graduates), the resource will leverage digital resources to strengthen the clinical skillsets and diagnostic abilities of practicing veterinarians. The AAZV, EAZWV, and ACZM have all offered support for the proposal, noting the significant educational value of this resource. Furthermore, the database creates potential educational opportunities for other zoo professionals such as animal care specialists, interpretative staff, public relations teams, and executives.

Data and Evaluation: The collation of data through this project will create a shared resource that employs data standards for medical images, consistency in PACS storage structure, and best practices for DICOM metadata entry. The partnership of major zoological institutions in this endeavor will create a framework for other zoos to follow for future standardization within the profession. Analysis of species and modalities represented within the database will identify species where adequate reference data is lacking. This gap analysis will allow for targeted imaging study acquisition to advance the field forward and ensure comprehensive reference material.

As previously outlined, the project will create a database framework and API tools that allow for retrospective and prospective research projects investigating health and disease within animal collections, as well as longitudinal analysis to measure changes over time. The database structure will be designed to allow future interface with Species360 Zoological Information Management System (ZIMS), the largest zoological medical records database used by 1,100 zoological institutions in 96 countries, to support future quantitative epidemiological studies (***Supporting Doc 10*** *– Species360 letter of support*). These studies will have the ability to incorporate complete medical data for each animal patient retrieved from an individual animal's medical record. This "big data" approach using linked data will provide an extremely powerful meta-analytical tool.

2. PROJECT WORK PLAN

2a. Project Activities and Evaluation

We propose to bring this project to fruition through eight activity phases (correlated to the Schedule of Completion). The Chicago Zoological Society (CZS) will oversee the work plan and execution for this project, in collaboration with a "Steering Committee". A "Leadership Team" within the steering committee will be comprised of Dr. Mike Adkesson (CZS, VP Clinical Medicine), Dr. Matt Kinney (SDZG, Senior Veterinarian), Dr. Eric Hostnik (The Ohio State University College of Veterinary Medicine, Assistant Professor of Veterinary Radiology). The remainder of the Steering Committee will be comprised of veterinarians representing the four other partner zoological organizations, Dr. Philip Hamel (Veterinary Radiologist), Dr. Robson Giglio (University of Florida, Assistant Professor of Diagnostic Imaging). ***Supporting Doc 11*** - *Steering committee composition*.

Based on initial discussion with software developers and evaluation of similar endeavors involving multiple zoos, we anticipate database design, development, and testing will require 6-12 months. The second year will focus on importing and cataloging historical imaging data from the six primary collaborating institutions with the database becoming functional for testing and use. The third year of the project will focus on launching external accessibility and use features to additional zoos and aquariums. Communication regarding the launch of external portal in the third year will allow for continued growth of collaborators and users, as well as continued evaluation and refinement. ***Supporting Doc 12*** provides preliminary technical specifications and quotes for development.

Activity 1 – Database Planning (Sep 2021 – Dec 2021): The leadership team (Adkesson, Kinney, Hostnik) will meet in Chicago with virtual connections as needed to create initial specifications for database development and prepare for design meetings (Activity 2) with meeting agendas, logistics, and final attendee lists. The leadership team will establish prioritization targets for species, imaging modalities, and anatomic regions of interest that will maximize the immediate usefulness of the database to the zoo community. These lists will serve as a preliminary framework for refinement during Activity 2. A post-doctoral fellow will be hired as a "Database Manager" during this time period and the steering committee representatives for participating zoos and aquariums will be defined.

Activity 2 – Database Design Meeting (Jan 2022): Key stakeholders will come together for a multi-day design and planning workshop. The workshop will be comprised of steering committee representatives, project personnel, software consultants, information technology support specialists, radiologists involved with similar databases for human medical data, and additional veterinary radiologists aligned with the project goals. A professional meeting facilitator will ensure this team fully defines the specifications for building the database, evaluates imaging transfer and anonymization protocols, establishes initial fields for query, evaluates placeholder fields for future growth capabilities, standardizes data submission forms, and evaluates options for external dissemination of studies via a web portal. Prioritization and process goals will be finalized, as well as target numbers for reference datasets.

Activity 3 – Selection of a Software Developer (Feb 2022 – May 2022): Results from Activity 2 will be used to develop specification documents. The Database Manager will meet with software design companies to solicit bids and the leadership team will select a vendor.

Activity 4 – Database Software Development (Jun 2022 – Sep 2022): Following selection of a vendor, the Project Manager will coordinate the development of the finished database product with the software company. This will require substantial coordination between multiple stakeholders. The Database Manager will ensure appropriate progress occurs in a timely manner via weekly meetings with the design team. Monthly steering committee meetings will commence at this time using a virtual platform (e.g. Zoom) with an annual in-person meeting to provide progress updates and allow for feedback as work progresses; additional stakeholders from Activity 2 will be included as appropriate.

Activity 5 – Importation of DICOM Data into PACS (Oct 2022 – Dec 2022): High level clean-up of DICOM data will be performed for each collaborating institution to create uniformity in coding of primary fields such as modality, species name, and patient identifiers. Any non-conforming studies will be manually reviewed by the Database Manager and supporting personnel to correct omissions or errors in metadata. DICOM data will then be migrated to a central PACS server and metadata will be imported into the database. Testing will be implemented to ensure that links are maintained as data is manipulated.

Activity 6 – Cataloging and Reference Study Selection (Jan 2023 – Aug 2024): The Database Manager will begin filtering data to select representative reference studies by species based on parameters determined during the design meeting. For each species, a pre-determined number of representative studies (defined in Activity 2) for each parameter (e.g. patient sex, patient age class, etc.) will be identified for DR and CT/MRI. Additional coding for body region (e.g. thorax, abdomen, extremity, head), health status, and missing metadata (e.g. age, sex) will be pulled from medical records. Veterinary student assistants will aid in assessing, organizing, and coding studies under supervision. CZS already maintains an extensive veterinary education program will add two preceptorship positions each year to work specifically on this project (***Supporting Doc 13*** *- Veterinary student program overview and sample documents)*. The Database Manager will perform an initial review of the studies to evaluate normality based on a high-level, generalized checklist created by the project's veterinary radiologists. Once the established target number is reached for each species and parameter, assessment of similar studies will be deprioritized until initial review is completed on all species.

Normal studies will receive final review by one of the veterinary radiologists who have committed to the project (***Supporting Doc 6***). Radiologists will focus on particular taxa to ensure uniformity and familiarity. The leadership team will coordinate with ACVR ZEWDIS to recruit additional support as needed and communicate progress. Abnormalities will be coded in the database at a basic level (e.g. organ system, pathologic grouping) to provide contextual reference as they are encountered. As an example, a CT scan may illustrate normal abdominal organs (coded "normal, abdomen"), while also containing a traumatic fracture of the skeleton (coded "abnormal, skeleton, trauma, fracture, femur").

Following review, studies will be anonymized by erasing metadata from the DICOM file except for an encrypted, uniquely generated study identification number. Patient information stamped as an overlay on the images will be digitally redacted using software tools (e.g. PixelMed Publishing). A digital watermark identifying the ZARD as the source of the image will be added to all images.

Activity 7 – Web Interface Development (Jun 2022 – Jun 2024): As a sizable dataset of reference studies becomes available in the database, the development of the web-based interface platform will commence. This portal will allow queries by species with filters for modality, body region, sex, and age class. Retrieved results will provide a link to an HTML5 DICOM viewer that enables standard functionality for image viewing (pan, zoom, rotate, flip, window level, invert, and measurement), as well as some advanced functionality for CT viewing such as Hounsfield unit measurement and multi-planar reconstruction (***Supporting Document 14*** – *Example HTML interface and letter of support*). A selected subset of feature studies will also be visible through a browser-based, high-performance 3D image viewing platform (***Supporting Doc 15*** *- Example HTML interface and letter of support*; see also *https://vizua3d.com/products*). For species where reference data is considered deficient, a flag will appear advising the user of the deficiency and encouraging the submission of reference study data. The web portal will be developed such that users can submit a form containing patient data details and DICOM files for incorporation into the database following review.

Activity 8 – Web Platform Promotion and Launch (Ongoing throughout; intensive Sep 2023 – Aug 2024): The database will be promoted externally throughout development to ensure awareness within the zoological profession. As database design is determined in the first year, the Leadership Team and Database Manager will begin to deliver presentations at professional conferences to encourage study and data management standardization by other organizations to allow easy future contribution into the database. In March 2024, six additional zoos selected from those offering letters of support will begin beta testing the

database as novel users, followed by a full launch by June 2024. Project staff will further promote the database in 2024 with presentations and workshops at scientific conferences. Workshops will help drive further database growth through inclusion of new partners and focus on maximizing their ability to effectively use the database to its functionality. A second goal will be to simplify data transfer into the ZARD, by instructing participants on imaging data standards, nomenclature for data entry, metadata editing, PACS management, DICOM transfer tools, and other topics to help curate their DICOM files and PACS management.

The end of this stage will also include a wind-down of the Database Manager's position as automated importation of new studies into the database will commences through the web platform. Veterinary radiologists will continue to review all studies prior to full release into the database.

Evaluation Process: We will evaluate the success of our project through on-going formative and summative techniques, as well as qualitative and quantitative measures, that encompass feedback from all engaged parties.

Evaluation for Activities 1-3: Success will be evaluated based on the development of a detailed specifications document for software design that encompasses complete data inclusions goals, end-user platform parameters, data standards, future capabilities, and technical specifications. The facilitator will assist in summarizing pre- and post-meeting assessments to ensure design goals are met. Selection of a software developer and execution of a contract will be the final outcome.

Evaluation for Activity 4: The contracted software developer will be evaluated based on conformance to design specifications and timelines as outlined in reports from the Database Manager.

Evaluation for Activity 5: We will carefully evaluate the number of non-conforming studies requiring manual entry on a biweekly basis. Monthly reports will be provided to the Steering Committee. Parameters established as part of the technical specifications for the software developer will establish a maximum limit for non-conforming data. Excess studies beyond this threshold will prompt revision of software algorithms to increase efficiency of transfers.

Evaluation for Activity 6: The number of species and representative studies included in the final database as normal reference studies will serve as an evaluation metric. Quantitative analysis will be performed on biweekly basis to evaluate progress and conformance to the overall project timeline.

Evaluation for Activities 7-8: A successful outcome will be a web-based platform ready for beta testing by at least six additional institutions by March of 2024 that includes cataloged reference images for 95-100% of the highest priority species defined during Activity 1 and 2. Website analytics (visits, pages per session, session duration, click-through rate, returning user rates, event tracking) will help refine the ZARD website in the first three months after public launch, as well as metrics on database use, studies viewed, and studies contributed.

End of Grant Evaluation: Following completion of Year 3, we will submit a final narrative report to IMLS that documents the success of the grant. We will provide quantitative figures on the studies included in the final database, audience reach, and ZARD target audience use. Through targeted surveys, workshop and presentation evaluations, and web platform requests for feedback, we will also gather qualitative information on project success. Utilizing both qualitative and quantitative measures we aim to illustrate the impact of the database on zoo animal health and the resulting positive change related to collection stewardship and sustainability.

2b. Risks to Project and How They Will Be Mitigated

The quantity of data in terms of the number of the studies included in the initial project scope is large. The quality of studies is also variable, as older studies contain less diagnostic information due to inferior imaging equipment that offered poor resolution and detail. Both considerations pose some risk to the successful execution on the proposed timeline, but will be mitigated by careful data management and prioritization. Automated scripts in the initial data migration process will code studies such that the best studies by species are reviewed first. Prioritization will be placed on species prone to medical concerns, those with little available reference material, and those with high conservation and institutional value. A layered taxonomically oriented approach will also be superimposed, such that taxa for which there are few representative species will be

prioritized over species for which there is abundant reference material from closely related species (e.g. aardvarks will be emphasized over zebras, given the similarities between zebras and horses). Appropriate classification of studies as normal (healthy) versus abnormal is another risk, but this risk is mitigated by the involvement of the multiple radiologists in support of this project.

By involving multiple parties in the stakeholder workshops at the beginning of the project timeline, we will mitigate technology and staffing risks. Having all key parties involved with specification development and testing will ensure that problems are quickly identified and remedied. The database manager will oversee the process closely, as well as execute data entry, but will be supported by a strong and engaged leadership team that is able to allocate time resources as needed to ensure the success of the project.

Through careful planning, we will aim to minimize any software and interface development delays. Unexpected issues and considerations will undoubtedly arise and contingency funding and time has been included to address these as they arise. These delays will have minimal impact on cataloging of data and selection of reference studies for the database, allowing project work to progress as problems are mitigated.

2c. Personnel for Project Planning, Implementation, and Management

Michael Adkesson, DVM, Dipl. ACZM, ECZM, Vice President of Clinical Medicine, will be the Project Director and will provide oversight at 12.5% of his time. A full-time Database Manager will be hired to coordinate database and web platform development, provide data quality analysis and communication, catalog studies, and maintain the project website. John Pauley, Hospital Operations Manager, will oversee CZS PACS server management and daily operations of the CZS radiology consulting service at 10% of his time. He will be assisted by Bethany Micheletti, Hospital Administrative Assistant, at 15% of her time. F. William Zeigler, Senior Vice President, Animal Collections & Care, will ensure CZS time and resource allocation for successful project completion at 2.5% of his time. Serving as paid consultants will be Eric Hostnik, DVM, MS, Dipl. ACVR, ACVR-EDI, and PJ Hamel, DVM, MPH, Dipl. ACVR, both of whom will serve on the leadership team and will provide radiology consulting. Matt Kinney, DVM, Dipl. ACZM will volunteer his time on the leadership team. Finally, veterinary students in CZS internship programs will assist with imaging study assessments and cataloging.

2d. How Partners Will Be Engaged

CZS is recognized for its development of collaborative programs involving multiple zoological institutions and external partners. Past IMLS grants illustrate our ability to develop collaborative engagement of partners, including MG-30-17-0006-17, MG-30-15-0046-15, and LG-26-10-0057-10. In addition, this project will capitalize on methods effectively developed by the highly successful Great Ape Heart Project (GAHP) to engage multiple zoological partners and stakeholders to build project momentum. The GAHP used IMLS support (awards LG-26-12-0526-12 and MG-30-15-0035-15) to build a sustainable, collaborative database developed from medical information collated from multiple zoological organizations. We will engage GAHP leadership for advice on this project, which they fully support (***Supporting Doc 16*** - *GAHP letter of support*).

Key stakeholders and partners will be engaged from the onset with the database design meeting and formation of the Steering Committee. Collaborating partners will receive monthly reports from the Database Manager and participate in monthly update meetings on a virtual platform, as well as an annual in person meeting. Website communications and updates will also serve to keep all parties engaged.

2e. Project Timeline

The three-year project will begin in September 2021. Year One will involve database planning, including virtual leadership team meetings and a multi-day design and planning workshop. We will select a software developer in early 2022 and will begin database software development and monthly steering committee meetings in summer 2022. Year Two will involve importation of DICOM data into and testing of systems. Cataloging and reference study selection will begin in Year Two and continue into Year Three. The final project year will also involve web interface refinement, promotion, and launch of the web platform.

We will evaluate the success of our project through on-going formative and summative techniques, as well as qualitative and quantitative measures, that encompass feedback from all engaged parties.

2f. Time, Financial, Personnel, and Other Resources Needed

CZS is requesting a grant of $689,419 over three years for this project. The request includes salaries and benefits for Dr. Adkesson, the Database Manager, Mr. Pauley, and Ms. Micheletti; costs for database software and web platform development; necessary hardware and equipment; a portion of radiologist fees for Dr. Hostnik and Dr. Hamel; and, promotional, training, and marketing costs. Finally, CZS has a federally negotiated indirect cost rate of 67.80% and we are requesting $123,,406 in indirect costs during the three years. CZS will contribute salaries and benefits for Mr. Zeigler, a portion of consulting fees for Dr. Hostnik and Dr. Hamel, and the remaining $434,391 of indirect costs as cost share.

2g. Tracking Progress Toward Achieving Intended Results

Progress will be tracked against the overall project timeline to ensure activity target dates remain on schedule. The Project Director will meet weekly with the Database Manager. The Leadership Team will meet twice a month (virtual platform) to discuss progress, timelines, and upcoming deadlines. The Database Manager will prepare monthly reports for the Steering Committee. The outwardly facing website will also containing a 'percent complete' tracker to allow external audiences to visualize progress made in terms of species and studies within the database. The Steering Committee will meet annually in person for one day to assess and track progress. This will precede a national zoo related conference to minimize travel costs.

2h. Sharing Project Results

Upon availability of funding, the project will immediately launch a website and begin promotion within the zoological profession. Twice monthly updates to the website, progress notes, links to press and media, and other related content will be publicly accessible. Following Activity 2, we will begin semi-annual updates to the membership of AZA AHC, AAZV, IAAAM, and EAZWV. Communications will provide regular updates on database development and decisions related to DICOM and PACS data standardization with a goal that other zoos adopt these standards to allow efficient future transfer of studies into the database. Through these direct member communications, we can guarantee that 100% of AZA member organizations in North American will be aware of the database and encouraged to use it and actively contribute to its future growth.

The leadership team will also deliver professional presentations at the annual conferences for the organizations noted above to discuss the project status, design and data decisions, data standardization, and preparations for future data contributions by other institutions. These presentations will promote both the use of and contribution to the database by highlighting the database specifications and capabilities. In addition to the previously described purpose of the workshops at scientific conferences, these workshops will also be an opportunity to share more detailed information on the results of the project and solicit input on future growth directions (e.g. addition of abnormal images representing disease states, linkage to additional patient medical data, and other research initiatives).

All images retrieved from the project will be watermarked with a source identifier attributable to the database. Requests for access to images in the database for research or publication purposes will be evaluated by the steering committee to ensure appropriateness and recognition of the database.

3. PROJECT RESULTS

3a. Intended Project Results and How They Will Address Need, Problem, or Challenge Identified

The establishment of the ZARD will fill a gap in available veterinary reference material for species maintained in zoos, aquariums, and wildlife organizations. This searchable database will launch with thousands of diagnostic imaging studies as a foundational resource to provide case-matched comparison studies that enhance veterinary care. This result will (1) improve the health and well-being of animals in zoological institutions by cultivating an imaging database that enables veterinarians to more proficiently evaluate health

and devise evidenced-based treatment plans and (2) increase scientific understanding of non-domestic animals while leveraging diagnostic images to archive detailed digital studies of animals in zoological collections.

With the highest caliber of veterinary care, zoos and aquariums are best able to provide strong stewardship of their living animal collections, thus ensuring population sustainability into the future and the ability to deliver on their missions. With a web interface, the database will be globally accessible by veterinarians to facilitate information sharing and scientific discovery. The interface will function on mobile devices, also allowing patient side use in remote locations. The dynamic nature and open contribution portal from the web platform will highlight data deficient species and encourage continued growth and refinement of reference study data. The platform also creates a platform for future expansion to include detailed evaluation of abnormal diagnostic studies that will enable research into disease, evaluation of health at population levels, and integration with medical record keeping software.

3b. Changes in Knowledge, Skills, Behaviors, or Attitudes of Intended Audience

Equipped with easy access to reference materials, veterinarians engaged in zoological medicine will be able to more efficiently focus on diagnosis and treatment of disease, as opposed to scouring existing disconnected resources for scant reference material. This increased efficiency will enhance diagnostic accuracy and timely veterinary care. We intend for the ZARD to become the go-to reference source for diagnostic images of non-domestic animals. Veterinarians depend on ZIMS reference data for normal blood test parameters across taxa and utilize the software daily. We believe the ZARD will fill this same role for diagnostic imaging and will become an indispensable resource for clinicians on a daily basis. The database will serve a crucial role in the education of veterinary students, residents, and post-graduates as they learn to apply knowledge gained from domestic species to the other species found in zoological institutions.

3c. Models, Tools, Research Findings, and/or Services Resulting from Project/Adaptations by Others and Dissemination

As outlined, this project will produce a globally accessible reference database. The openly accessible nature of the database to veterinarians will allow encourage broad adoption and use. Support from the AZA, AAZV, IAAAM, and EAZWV will enable promotion to 100% of veterinarians working in AZA accredited zoos in North America and a near perfect awareness internationally. Through the promotional activities previously described, we will widely promote use of the database.

3d. How we will Sustain the Benefits of the Project

CZS is strongly committed to the excellence of its veterinary programs and leadership in the field of veterinary radiology for zoological species through its Center for the Science of Animal Care and Welfare. The CZS will continue to maintain the database in a static form following the completion of this grant by hosting the database, PACS server, and software architecture. The organization has dedicated annual capital funding from a private foundation that supports veterinary programs. Following completion of this IMLS grant to establish the database, the Steering Committee will continue to seek funding for development of additional advanced features that build upon this foundational database creation. We already have identified prospects for funding including the AZA Conservation Grants Fund, AAZV Wild Animal Health Fund, and the Morris Animal Foundation, as well as private foundation and individual donors affiliated with all of the ZARD partners. The future research potential of the database will create synergistic opportunities to expand functionality, support the database, and complete hypothesis driven research projects. Future collaborations with ZIMS and other organizations will also promote expansion and support.

The database's design with consideration for future expansion and research will ensure collaboration and support are easily integrated. Similarly, the web-based platform provides a portal that enables easy contribution of new studies by external users, such that the database will continue to expand dynamically over time.

Schedule of Completion - Year 1

	Year 1 (2021 - 2022)											
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Activity 1: Database Planning												
Activity 2: Database Design Meeting												
Activity 3: Selection of a Software Developer												
Activity 4: Software Development												
Activity 5: Importation of DICOM Data into PACS												
Activity 6: Cataloging and Reference Study Selection												
Activity 7: Web Interface Development												
Activity 8: Web Platform Promotion and Launch									Preliminary Work			

Schedule of Completion - Year 2

	Year 2 (2022 - 2023)											
	Sep	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**
Activity 1: Database Planning												
Activity 2: Database Design Meeting												
Activity 3: Selection of a Software Developer												
Activity 4: Software Development												
Activity 5: Importation of DICOM Data into PACS												
Activity 6: Cataloging and Reference Study Selection												
Activity 7: Web Interface Development												
Activity 8: Web Platform Promotion and Launch	Gradually increasing											

Schedule of Completion - Year 3

	Year 3 (2023 - 2024)											
	Sep	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**
Activity 1: Database Planning												
Activity 2: Database Design Meeting												
Activity 3: Selection of a Software Developer												
Activity 4: Software Development												
Activity 5: Importation of DICOM Data into PACS												
Activity 6: Cataloging and Reference Study Selection												
Activity 7: Web Interface Development												
Activity 8: Web Platform Promotion and Launch	Intensive											