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Metadata Schema for Managing Digital Data and Images of Thai Human Skulls

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Abstract: This research was aimed at developing metadata that meets international standards for the purpose of managing digital data and images of Thai human skulls for medical studies. The research was conducted by applying the Metadata Lifecycle Model of the Metadata Architecture and Application Team. The model comprises four steps: requirement assessment and content analysis, identification of metadata requirements, metadata schema development, and metadata service and evaluation. The research outcome was a metadata schema composed of four modules, seven data element sets, and 29 pieces of data, each of which had six sets of property descriptions. Metadata evaluation conducted by three specialists in the field of anatomy and forensic medicine and three experts in the field of information science and metadata through free retrieval based on the Continuum of Metadata Quality in four aspects revealed that the experts were satisfied with the quality of metadata at a very high level: 100% for completeness, accuracy, and accessibility, and 94% for conformance to expectations. The developed metadata contain details that can be used to describe the characteristics of human skulls, with consideration taken in the development of the language used, retrieval, access, data exchange, and sharing. Thus, this novel metadata schema can be of use in management of digital data and images of human skulls for the purposes of medical studies, i.e., human anatomy and forensic anthropology.

Keywords: human skulls; metadata schema; information object analysis; digital data; digital images

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1. Introduction

Studies on human skull studies were initially carried out in specific, individual fields, but over time researchers have begun to adopt a more multidisciplinary approach. Principles and methodologies have been applied with the use of tools or scientific equipment to study archaeological processes in parallel to the development of theoretical concepts and construction of methodologies in order to interpret/explain historical and cultural stories. This has led to studies and analyses of a wide variety of archaeological evidence in detail by means of standardized systems [1], thereby providing useful resources for intensive analytical studies of human skulls. Studies conducted under the archaeological perspective are directly related to at least two different disciplines, i.e., physical anthropology and gross anatomy in medicine [2].

Human skulls are important evidence that provides information physiologically linking the past and the present with significance in various aspects. Human skulls are the only type of evidence providing basic information about the gender and age of the dead, including their height and traces of uncommon characteristics that appear on bones or in the bone structure. These may indicate pathologies from general infection of bones or trauma from a certain cause. Studies of bone structure have led to an understanding of nutritional conditions in the past [2–4]. Analytical information of human skulls allows the interpretation of the lifestyle of a dead person. Traces found from the study of each part of the bone are regarded as evidence reflecting the behavior or actions of the person when alive. They relate to a certain behavior that the person routinely performed, thereby providing a clue as to what their occupation was [4].

In Thailand, a human skull is one type of archaeological evidence, according to Section 4 of the Archeological Site, Antiquities, Artifacts and National Museum Act, 1961 and the Amended Archeological Site, Antiquities, Artifacts and National Museum Act (Second Edition) [5]. The study of human skulls is an aspect of the study of physical anthropology and biology, since humans are a species of the animal kingdom. Studies of human origin and evolution and comparisons of humans in the past and present have been conducted to analyze specific characteristics in order to identify differences in human races [6]. When discovered tombs and their surrounding articles such as utensils and ornaments are investigated, researchers are able to solve puzzles related to historical people, environments, and cultures. These studies take into account archaeological, physical, anthropological, scientific and modern technological information; hence, details of basic human information, e.g., age at death, gender, height, race, ethnic group, possible social and cultural pictures of the past, lifestyles, and diseases, are obtained, enabling comparisons between prehistoric and present humans.

There are many learning resources and collections of bodies of knowledge in regard to human skulls. In Thailand, at present, the learning resources are anatomical museums, including Khondon Anatomical Museum; Faculty of Medicine Siriraj Hospital, Mahidol University; Anatomical Museum, Chulalongkorn University; Museum of Human Body, Faculty of Dentistry, Chulalongkorn University; and Anatomical Museum of Ajarn Kasem Kaewim, Songkhlanakarin Hospital. There are not many anatomical museums in Thailand, and a study by Chanpak showed that there is a constraint in terms of space for an anatomical museum to collect and exhibit articles, biopsies, and pieces of human organs. There are also constraints in terms of open hours for visits to these museums, distances, and rights to visit. Some anatomical museums have websites, but only some information is provided, while no virtual museum has been developed [7]. These research findings are in agreement with those of a study conducted by Princess Maha Chakri Sirindhorn Anthropology Center related to human skulls in Thailand. The research was based on a conceptual framework, theories, and methodology in physical anthropology and related fields such as human macro-anatomy, biological archaeology, and forensic anthropology. Information on human skulls has been compiled in many forms, including documents, research reports, articles, textbooks, and realis. There are many constraints in access to human skull realis, i.e., in terms of active usage, open hours, and rights of usage [8]. Advances in information technology, however, enable users to gain access to such information virtually, at any time by means of the internet. This is linked to the museum management dimension that emphasizes digital collections of human skull information that effectively solve the limitations.

The skull is the human bone structure that forms the human head and face in a complex form. Studies of human skulls are very useful, especially in regard to proof of identity. If there is adequate information from any part of the skull, scientific forensics will be able to analyze the correlation of the parts or components of the skull with various characteristics, such as sex, age, race, and ethnicity [8]. If systematic management of the data and images of human skulls are available and are based on various technologies, for instance, metadata, information corpuses, or an information system, the analyses and computation of information will yield tremendous benefits. However, research on human skulls in order to learn about the components of the skull, the number of bones, their names, and characteristics that compose the content of the skull are already available in textbooks or in the form of anatomy information. A system that compiles information in the aspect of information science comprises context or the information about the owner of the skull. This system necessitates collection of an adequate number of real cases, which is very complicated due to the source (a hospital) and consent of the owner. Additionally, with the missing content and context, it is impossible to analyze the structure or the information derived from the relation between the content and the context.

Metadata are a set of information developed structurally in order to describe in detail a set of information resources. Such descriptions cover the content, context, and structure, as well as the relations between the components used to describe the information resources. Metadata are produced for benefits in retrieval and management of information resources [9,10]. The metadata of each type of information are derived from a set of metadata elements established to explain the details of the information resource, for example, the title, the person responsible for production, the year of production, the content characteristics, and the format of the data file. In addition, the principles in format setting, value displaying, and encoding are established for the data in each component so that the computer can interpret the results. The principle and encoding approach is called the metadata schema [11]. Presently, a metadata schema has been developed using international standards to enable management of different types of data based on the characteristics of each information resource [12].

Studies of standard metadata for management of medical information demonstrated a widely known standard, i.e., Digital Imaging and Communications in Medicine (DICOM) [12]. This is an international standard for managing images in medicine and related data that establish the format of data to facilitate exchange of quality data useful for clinical purposes (https://www.dicomstandard.org/about-home, accessed on 2 February 2021). The standard was developed by the National Electrical Manufacturers Association (NEMA). The DICOM standard is composed of four modules: (1) series—explaining a patient's images; (2) patient—explaining the patient; (3) image—explaining the images in detail; and (4) study—explaining the study or the test conducted with the patient [13]. Tirado-Ramos, Hu, and Lee noted that the DICOM standard is used to manage digital images in medicine. It explains specific information of a real object with the aim of exchanging the information of the objects with similar properties. Therefore, the DICOM standard compiles the characteristics of medical images obtained from CT-Scan, e.g., file name and image characteristics, including size, color, and resolution [13]. However, the DICOM standard cannot be used to manage data related to human physiological or anatomical aspects since it does not provide the management of details related to content. Moreover, other existing metadata standards include the Dublin Core Metadata Element Set [14], used to describe books and documents; the Metadata Object Description Schema (MOD) [15]; the Visual Resource Association (VRA Core) [16], used to describe visual arts, such as paintings, sculptures, and architecture; Categories for the Description of Works of Art (CDWA), used to explain arts, architecture, and cultural objects; and Performance Arts Metadata [17]. It is obvious that the existing metadata standards have been developed to manage different types of information resources, reflecting physical differences, varied content, and user needs [18]. Moreover, none of these standards focus on describing and linking the appropriate semantic data to medical data, especially human skull data, which are used for anatomical and forensic medical studies.

The management of human skull data in the field of information science can be studied based on information object analysis, which, according to Gilliland, involves the fact that an information object has three components, namely, (1) content data, (2) context data, and (3) structure data [19]. This is the basic concept used in data description for storing and retrieving information in various forms. The development of metadata, in particular, is necessary for describing information objects in a digital form [20]. This research thus applied this concept in analyzing information objects to analyze human skull data. Then, a metadata schema was developed to describe human skulls in order to store human skull data in the digital format. This metadata schema is different from existing ones, as it was specifically developed for describing the data of human skulls and the data derived from living human CT scan images and data. Moreover, the unique data on human skulls can be stored and calculated for forensic analysis and can be further used to verify human identity. It may also be useful for libraries and museums in the production of data corpus or for learning platforms for medical studies in the future.

2. Objectives

The aim of this research is to answer the following research question: how can internationally standardized metadata used to describe information and images of Thai human skulls store information and Thai human skull images for the purpose of medical studies?

The information and Thai human skull images used as examples in this research were obtained from the study "Craniometry Study of Skulls in Northeastern Thai Adults" by Tuamsuk, Nonsrichan, and Sirisilp [21]. The authors of this research permitted use of the information presented in their study, which was approved in terms of human ethics in research based on the Declaration of Helsinki and Good Clinical Practice Guideline (ICH GCP), as per the authorization document No. HE641189, issued on 29 March 2021. The research by Tuamsuk, Nonsrichan, and Sirisilp was conducted on 246 skulls of living Thai people from CT scan images obtained by means of a craniometry study. The study compiled significant information complete with multi-dimensional skull images that can be used in study programs in the field of human anatomy. The other outcome of this study is the development of the cranial index, which is helpful in identity analysis of people in the field of forensic anthropology [21].

3. Methodology

The current research was conducted by applying the Metadata Lifecycle Model of the Metadata Architecture and Application Team (MAAT) [22]. The model comprises four steps: (1) requirement assessment and content analysis, (2) identification of metadata requirements (3) metadata schema development, and (4) metadata service and evaluation. The methodology was based on the research and development approach, as illustrated in Figure 1.

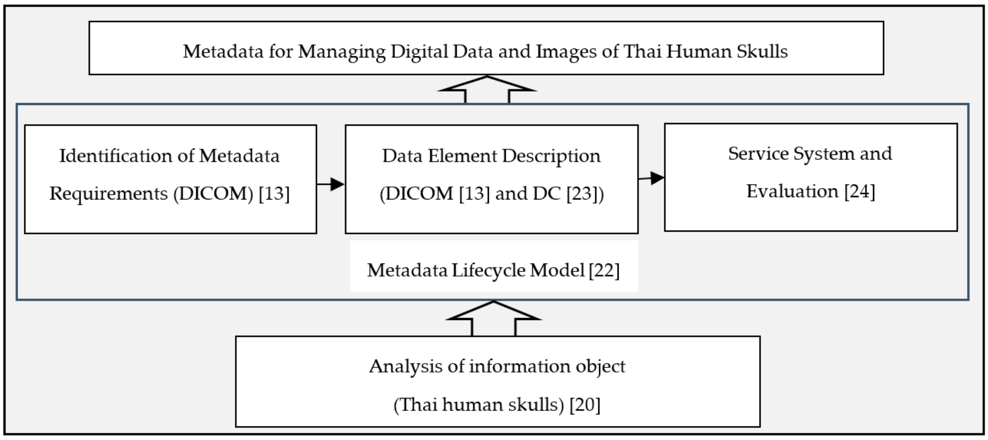

Figure 1. Research conceptual framework [13,20,22–24].

3.1. Needs Assessment and Content Analysis

The information used in this study was obtained from the research study "Analysis of the Human Skull Data Using Information Object Analysis Concept" by Yosakonkun, Tuamsuk, and Tuamsuk [25], which was a quality research study based on content analysis, information object analysis, and interviews with medical specialists in anatomy, forensic medicine, and forensic anthropology, with the aim of evaluating the need for metadata development. The analytical results of the research by Yosakonkun, Tuamsuk, and Tuamsuk, based on information object analysis, can be concluded as follows [25]:

Content means the information existing in human skulls. Human skulls are composed of 14 pieces of bone: frontal bone, parietal bone, temporal bone, occipital bone, sphenoid bone, ethmoid bone, zygomatic bone, maxillary bone, Lacrimal bone, palatine bone, nasal bone, inferior nasal conchae bone, vomer bone, and mandible bone. Each bone has the following significant and specific information for the anatomical and forensic anthropological studies: (1) histogenesis of bone—there are 2 types of histogenesis, intramembranous ossification and intracartilaginous ossification [26]; (2) bone shape, which can be classified into 5 shapes: long bone, short bone, flat bone, irregular bone, and sesamoid bone; (3) landmark—there are 43 landmarks on a human skull, which are the points used to measure the size and shape of the skulls used in anatomy and forensic anthropology, identified by number, name, and definition on the basis of previous research works [21,27].

Context refers to the information not existing in the skull but rather indicates the background of the skull or the information of the owner of the skull image. The CT scan provides CT date, birthdate, age, sex, race, height, weight, body mass index (BMI), province of residence, and CT scan images.

Structure refers to the information or set of information that indicates the relations between content and content, content and context, or context and context. The structure in this research was aimed at managing human skull information to develop metadata for that could be useful in forensic anthropological analyses. The structure consists of craniometric length and cranial index; see Figure 2 [21].

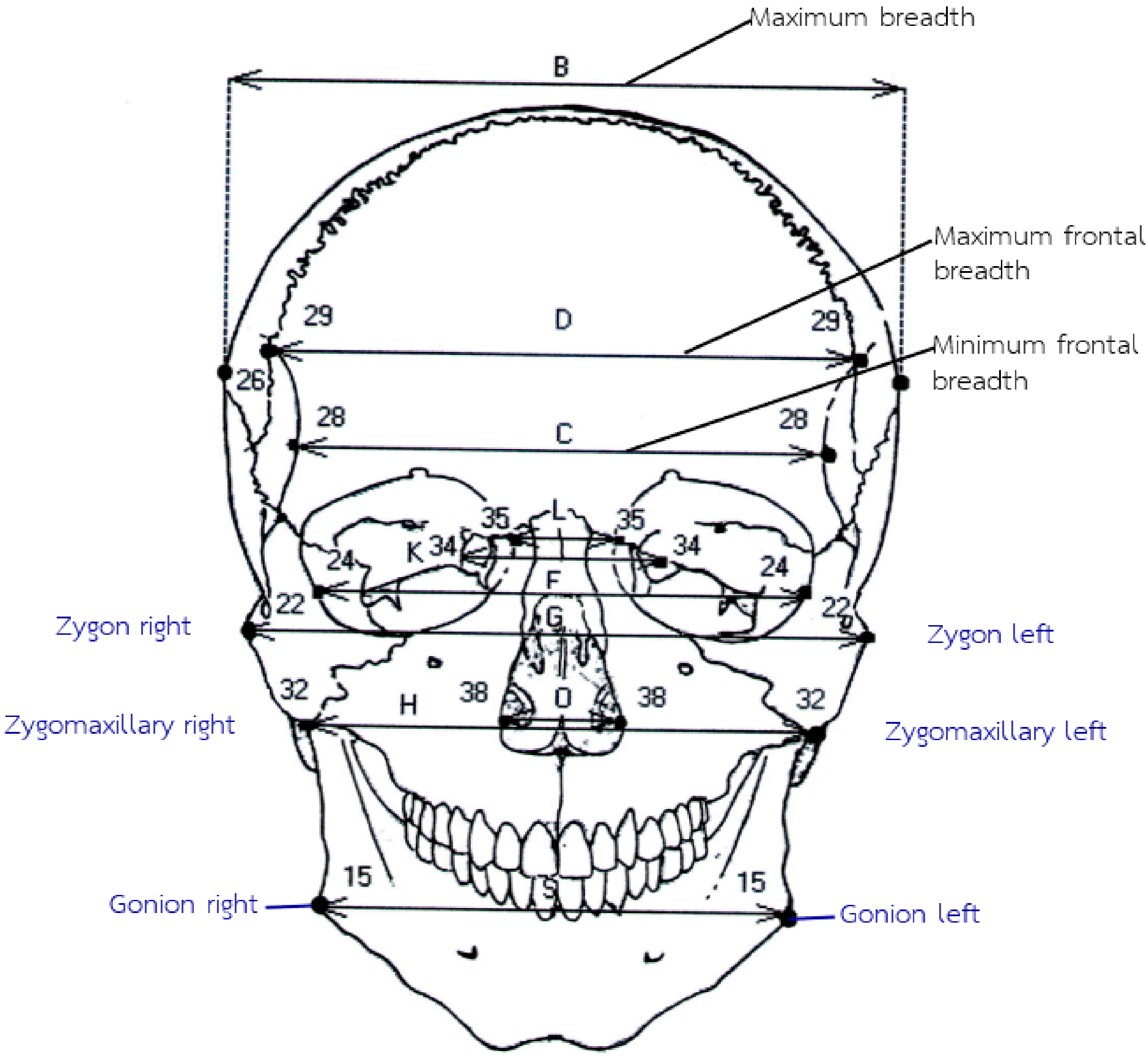

Figure 2. Example of landmarks on human skulls identified by the reference numbers (in blue) and the line of craniometric length (in black) [21].

3.2. Identification of Metadata Requirements

The researchers used the results of the first-step analyses of human skull information to draft the conceptual framework of metadata for Thai human skulls, arranging the data element sets based on the DICOM standards (DICOM→) of NEMA [13]. The information was classified into four modules, with seven data elements based on the characteristics of information derived from information object analysis (Table 1).

Table 1. Conceptual framework of the metadata structure.

Module	Module Description	Data Element	Data Based on Information Object Analysis
Series	Data set on the content of human skull	Element 1: Bone	Content data
		Element 2: Landmark	Content data
Patients	Data set on the patient whose skull was CT scanned	Element 3: Patient	Context data
		Element 4: Craniometric length	Structure data
Images	Image of CT scan of the patient's skull	Element 5: Image	Context data
Study	Data set on the study (cranial index of the patient's skull)	Element 6: Cranial index	Structure data
		Element 7: Standard index	Standard data

Because the DICOM standards [13] are specific to the images of human skulls with the data sets focusing on patient and image data, the researchers adapted the concepts of Dublin Core Metadata to manage information objects [23] in order to describe the details of data elements for human skulls. The properties of each data element of Dublin Core Metadata [23] generally consist of four details: (1) element name, (2) label, (3) definition, and (4) comments, among which, name, definition, and comments were used in this research.

3.3. Metadata Schema Development

This step involved the production of a data element description in the metadata. The description regards the properties of data in order to build a common semantic understanding and demonstrate the uniqueness of each set of metadata. This can be read by the machine-understandable metadata. Single-word naming was conducted for syntactic specification, which is necessary for further coding or program writing in different languages, such as Extensible Markup Language (XML) [23].

Details of the information elements in this research were set based on the management standard of some information of Dublin Core Metadata [23] and DICOM [13] for those associated with a large amount of the patient and image information, as there is no information standard directly related to human skulls. The property of each piece of information in Dublin Core Metadata [23] comprises the 4 following items at least: (1) element name or name of data, (2) label, (3) definition, and (4) comment or description of the format or characteristics of information. Moreover, other properties can be added depending on each piece of data and usage. For example, URL means that the information is on a website that is linked to a respective source or that provides further details, while References means the reference source of the data. The data in the DICOM standard, on the other hand, are mostly the data used to manage medical-related images, the details of which have not been clarified. Thus, only the name that corresponds to this research was used in order to arrive at the same standard, and single-word naming was conducted in accordance with Dublin Core Metadata (Table 2).

Table 2. Properties of the data elements applied in this research, adapted from DICOM Library [28].

DICOM Tag	DICOM Name	Metadata of Thai Human Skull
(0010,0020)	Patient ID	PatientID
(0010,0030)	Patient's Birth Date	PatientBirthDate
(0010,0040)	Patient's Sex	PatientSex
(0010,0010)	Patient's AgeF	PatientAge
(0010,1030)	Patient's Weight	PatientWeight
(0010,1040)	Patient's Address	PatientAddress
(0018,9329)	CT Image Fame Type Sequence	CTImage
(0018,9329)	View Position	ViewPosition

3.4. Metadata Service and Evaluation

The metadata developed were produced as a storage and retrieval system in the form of a digital collection of Thai human skulls, using PHP language to write the MySQL Program as the databases and Open Archives Initiative—Protocol for Metadata Harvesting (OAI-PMH) [29] as the standard to assist in the compilation of metadata of the information in Open Archives. The system enables searching of and access to the metadata of all resources in the digital information corpus of skulls and can be the prototype for testing the management of information and digital images of Thai human skulls. Access is available at: http://localhost/thai_skull/ (accessed on 12 April 2021).

Metadata evaluation was conducted by three specialists in the field of anatomy and forensic medicine and three experts in the field of information science and metadata. The system was experimented on via free retrieval, and the metadata were evaluated using the evaluation form developed from the concept of the Continuum of Metadata Quality developed by Bruce and Hillmann [24]. The evaluation was then performed on four aspects, namely, completeness, accuracy, accessibility, and conformance to expectations. Informants were requested to complete evaluations forms, from which data were collected. The results showed high satisfaction with some suggestions for metadata revision, including the options for adding data elements for future development such as skull image views and demography data of patients.

4. Results

The outcome of the current research is the development of a metadata schema for the management of digital data and images of human skulls with the following particulars:

4.1. Structure of Metadata Schema

The structure of the metadata schema comprises 4 modules, 7 data element sets, and 29 pieces of data. Each piece of data contains 6 property items (Table 3).

4.2. Description of Metadata Schema

Below are the descriptions that can be used to describe digital data and images of Thai human skulls (Table 4).

4.3. Metadata Evaluation

Metadata evaluation conducted by three specialists in the field of anatomy and forensic medicine and three experts in the field of information science and metadata through free retrieval based on the Continuum of Metadata Quality [24] in four aspects revealed that the experts were satisfied with the quality of metadata at a very high level, 100% for completeness, accuracy, and accessibility, and 94% for conformance to expectations.

4.4. Linked Open Standard

The metadata schema for managing digital data and images of Thai human skulls was converted into RDF (Resource Description Framework) format to allow the metadata to be openly interchanged and used for other similar sets of data (Figure 3).

Table 3. Structure of metadata schema for Thai human skulls.

Module	Data Element	Data	Property
Series	1. Bone	1.1 BoneName_English 1.2 BoneName_Thai 1.3 BoneHistogenesis 1.4 BoneTissue 1.5 BoneShape	Name Definition Format Comment Example References
	2. Landmark	2.1 LandmarkID 2.2 LandmarkName 2.3 LandmarkDescription	
Patients	3. Patient	3.1 PatientID 3.2 CTDate 3.3 PatientBirthDate 3.4 PatientAge 3.5 PatientSex 3.6 PatientRace 3.7 PatientHeight 3.8 PatientWeight 3.9 PatientBMI 3.10 PatientAddress	
	4. Craniometric length	4.1 CraniometricLengthID 4.2 CraniometricLengthName 4.3 CraniometricPointToPoint 4.4 CraniometricLengthDescription 4.5 CraniometricLength	
Image	5. Image	5.1 ViewPosition 5.2 CTImage	
Study	6. Cranial index	6.1 CranialIndexName 6.2 CranialIndexValue	
	7. Standard index	7.1 SkullType 7.2 StandardIndexValue	

Table 4. Description of metadata schema of Thai human skulls.

Module 1—Series	This Module Specifies the Data Regarding Bones and Landmarks on the Human Skull
Element 1: Bone	Element set of data on the bones of human skulls
Name 1.1	BoneName_English
Definition	English name of the bone
Format	Text
Comment	Use an English term as shown in an anatomical textbook
Example	Frontal bone
References	-
Name 1.2	BoneName_Thai
Definition	Thai name of the bone
Format	Text
Comment	Use a Thai term as shown in the Dictionary of Thai Medical Terms or Thai textbook of Anatomy
Example	กระดูกหน้าผาก (Thai language for Frontal bone)
References	-
Name 1.3	BoneHistogenesis
Definition	The origin or development method of the bone

Table 4. *Cont.*

Module 1—Series	This Module Specifies the Data Regarding Bones and Landmarks on the Human Skull
Format	Text
Comment	There are two methods: 1. intramembranous ossification and 2. intracartilaginous ossification
Example	Intramembranous ossification
References	-
Name 1.4	BoneTissue
Definition	Characteristic of the bone's tissue
Format	Text
Comment	There are two characteristics: 1. compact and 2. spongy
Example	Compact
References	-
Name 1.5	BoneShape
Definition	Shape of the bone
Format	Text
Comment	There are five shapes: 1. long, 2. short, 3. flat, 4. irregular, and 5. sesamoid
Example	Flat
References	-
Element 2: Landmark	Element set of data on the landmarks on human skulls
Name 2.1	LandmarkID
Definition	Identification number of the landmark on the human skull
Format	Text
Comment	There are 43 landmarks on the human skull. Typically, a landmark ID starts from number 1 to 43. As the paired landmark appears on the left and right sides of the skull, the letter L or R shall be added as appropriate.
Example	2
References Name 2.2	- LandmarkName
Definition	Name of the landmark on the human skull
Format	Text
Comment	Name of all 43 landmarks on the human skull. For the paired-landmark appearing on the left and right sides of the skull, the letter L or R shall be added as appropriate.
Example	Glabella
References	-
Name 2.3	LandmarkDescription
Definition	Description of the landmark on the human skull
Format	Text
Comment	A description of each landmark
Example	Most anterior midline point on the frontal bone, usually above the nasofrontal suture
References	-
Module 2—Patients	This module specifies the data regarding the patients whose CT scan of skulls were studied in this set of data.
Element 3: Patient	Element set of demographic data of the patient
Name 3.1	PatientID

Table 4. *Cont.*

Module 1—Series	This Module Specifies the Data Regarding Bones and Landmarks on the Human Skull
Definition	Identification number of the anonymous patient
Format	Number
Comment	A patient ID starts from number 1 to an n case.
Example	1
References	-
Name 3.2	CTDate
Definition	Skull CT scan date of each patient
Format	Date
Comment	dd/mm/yyyy (A.D. year)
Example	24 September 2009
References	-
Name 3.3	PatientBirthDate
Definition	Patient's birth date
Format	Date
Comment	dd/mm/yyyy (A.D. year)
Example	13 February 1966
References	-
Name 3.4	PatientAge
Definition	Age of the patient as of the CT date
Format	Number
Comment	Input the age of the patient as of the CT scan date in numeric format
Example	43
References	-
Name 3.5	PatientSex
Definition	Gender of the patient
Format	Text
Comment	Input M for male and F for female.
Example	M
References	-
Name 3.6	PatientRace
Definition	Race of the patient
Format	Text
Comment	Input a race of the patient. Note that all patients in the data set of this research are Thai.
Example	Thai
References	-
Name 3.7	PatientHeight
Definition	Patient's height
Format	Number
Comment	Input the patient's height in centimeter
Example	167
References	-

Table 4. *Cont.*

Module 1—Series	This Module Specifies the Data Regarding Bones and Landmarks on the Human Skull
Name 3.8	PatientWeight
Definition	Patient's weight
Format	Number
Comment	Input the patient's weight in kilogram
Example	71.5
References	-
Name 3.9	PatientBMI
Definition	Value of body mass index (BMI) of the patient
Format	Number
Comment	Input value of the patient's BMI
Example	25.53
References	-
Name 3.10	PatientAddress
Definition	The place of patient's address.
Format	Text
Comment	The place of patient's address, in this data set is the name of the province of Thailand. Input an English name of the province according to the official name.
Example	Khon Kaen
References	Names of places and province of Thailand in English. http://www.thailaws.com/download/thaidownload/provinces_eng.pdf (accessed on 4 April 2021)
Element 4: Craniometric length	Element set of data regarding craniometric length of the patient
Name 4.1	CraniometricLengthID
Definition	Identification number of the craniometric length
Format	Text
Comment	There are 26 craniometric lengths. The alphabet from A to V is used to identify each craniometric length.
Example	D
References	-
Name 4.2	CraniometricLengthName
Definition	Name of each craniometric length
Format	Text
Comment	Input name of each craniometric length
Example	Maximum front breadth
References	-
Name 4.3	CraniometricPointToPoint
Definition	Landmark point-to-point ID that specified each craniometric length.
Format	Text
Comment	Input the landmark ID from the starting point to the point of each craniometric length
Example	29L–29R
References	-

Table 4. *Cont.*

Module 1—Series	This Module Specifies the Data Regarding Bones and Landmarks on the Human Skull
Name 4.4	CraniometricLengthDescription
Definition	Description of each craniometric length
Format	Text
Comment	Input the description of each craniometric length
Example	Direct distance between the two frontotemporal areas is extended
References	-
Name 4.5	CraniometricLength
Definition	The length from landmark's point to point, measured in millimeter
Format	Number
Comment	Input numeric value of the craniometric length of each patient in millimeter
Example	106.12
References	-
Module 3—Images	This module specifies the data regarding the images of CT scan of skulls of patients.
Element 5: Image	Element set of the image of CT scan of human skull of each patient
Name 5.1	ViewPosition
Definition	Image view of CT scan of the patient's skull
Format	Text
Comment	There are 6 views of the image in this data set: 1. anterior, 2. posterior, 3. superior, 4. Interior, 5. lateral left, and 6. lateral right.
Example	Anterior
References	-
Name 5.2	CT_Image
Definition	Image of CT scan of the patient's skull
Format	.PNG file
Comment	Upload a CT scan image file. Link to location of the image file.
Example	-
References	-
Module 6—Study	This module specifies the data regarding the cranial index of the CT scan of skulls of patients.
Element 6: Cranial index	Element set of the cranial index of the human skull of each patient
Name 6.1	CranialIndexName
Definition	Name of each cranial index
Format	Text
Comment	Input name of each cranial index
Example	Cranial index
References	-
Name 6.2	CranialIndexValue
Definition	Value of each cranial index in percentage as a result of calculation
Format	Formular
Comment	Automatic input from the "CraniometricLength" data and then calculate according to the pre-set formula. The value is presented in percentage.

Table 4. *Cont.*

Module 1—Series	This Module Specifies the Data Regarding Bones and Landmarks on the Human Skull
Example	Maximum breadth × 100
	Maximum length
References	-
Element 7: Standard index	Element set of the standard index identifying the type of the human skull from cranial index value
Name 7.1	SkullType
Definition	Type of human skull that can be used to identify human identity in forensic anthropology
Format	Text
Comment	There are several types of human skulls, for example, ultradolichocranial, hyperdolichocranial, dolichocranial, mesocranial, brachycranial, hyperbrachycranial, and ultrabrachycranial skulls
Example	Dolichocranial
References	-
Name 7.2	StandardIndexValue
Definition	Value of each standard index for type of human skull in percentage
Format	Text
Comment	Percentage value or range of values for identifying the type of human skull
Example	80–85
References	-


```xml
<?xml version="1.0" encoding="UTF-8"?>
<rdf:RDF
    xmlns="http://www.metaphacts.com/resource/"
    xmlns:lookup="http://www.metaphacts.com/ontologies/platform/repository/lookup#"
    xmlns:User="http://www.metaphacts.com/resource/user/"
    xmlns:Help="http://help.metaphacts.com/resource/"
    xmlns:Platform="http://www.metaphacts.com/ontologies/platform#"
    xmlns:owl="http://www.w3.org/2002/07/owl#"
    xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
    xmlns:skos="http://www.w3.org/2004/02/skos/core#"
    xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
    xmlns:Admin="http://www.metaphacts.com/resource/admin/"
    xmlns:Default="http://www.metaphacts.com/resource/"
    xmlns:Repository="http://www.metaphacts.com/ontologies/repository#"
    xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
    xmlns:sh="http://www.w3.org/ns/shacl#"
    xmlns:Assets="http://www.metaphacts.com/resource/assets/"
    xmlns:ephedra="http://www.metaphacts.com/ontologies/platform/ephedra#"
    xmlns:sp="http://spinrdf.org/sp#">

<rdf:Description rdf:about="http://webprotege.stanford.edu/R5kP3YMGYmr4JUQ053xnmP">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
    <rdfs:comment xml:lang="en">Element set of data on the landmarks on human skulls</rdfs:comment>
    <rdfs:label xml:lang="en">Landmark</rdfs:label>
    <rdfs:subClassOf rdf:resource="http://webprotege.stanford.edu/R8Buz8UKULkxfVcNmYclzTn"/>
</rdf:Description>

<rdf:Description rdf:about="http://webprotege.stanford.edu/R70xvyTRUhKv9IH6feyHkBV">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
    <rdf:type rdf:resource="http://webprotege.stanford.edu/RCAw8qwoxeknLCCfbf9zNRE"/>
    <rdfs:comment xml:lang="en">There are 26 craniometric length.  The alphabet from A to V is used to identity each craniometric length.</rdfs:comment>
    <rdfs:label xml:lang="en">CraniometricLengthID</rdfs:label>
</rdf:Description>

<rdf:Description rdf:about="http://webprotege.stanford.edu/R724aIeiBzonrHeDRFG3pUn">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
    <rdf:type rdf:resource="http://webprotege.stanford.edu/R5kP3YMGYmr4JUQ053xnmP"/>
    <rdfs:comment xml:lang="en">A description about each landmark.
Most anterior midline point on the frontal bone, usually above the nasofrontal suture.</rdfs:comment>
    <rdfs:label xml:lang="en">LandmarkDescription</rdfs:label>
</rdf:Description>

<rdf:Description rdf:about="http://webprotege.stanford.edu/R76TB6X1Ez56s4TPTm85NyV">
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#NamedIndividual"/>
    <rdf:type rdf:resource="http://webprotege.stanford.edu/R5kP3YMGYmr4JUQ053xnmP"/>
    <rdfs:comment xml:lang="en">A name of each 43 landmarks on human skull. For the paired-landmark appears on the left and right sides of the skull, the letter
    <rdfs:label xml:lang="en">LandmarkName</rdfs:label>
</rdf:Description>
```


Figure 3. Example of metadata in RDF format.

5. Discussion

Since DICOM is the standard for managing medical information, it does not involve content management or content related to anatomy, skeletal systems, or human skulls. The information in this research is both the content and the images of skulls that contain relatively high differences in details. However, the researchers based the study on conformance in the module name and element name, which followed the standard of DICOM or was at least comparable to it, thereby allowing the metadata to be of an international standard and useful for common use in the future. Comparative details are given in Table 5.

Table 5. Comparison between structures and names of modules in this research and DICOM standards.

Module Name	DICOM Standards	Metadata of Thai Human Skulls
Series	This module specifies the attributes that identify and describe general information about the Series within a study.	Data sets of human skull elements (this research only compiled bone information and landmarks, which are used for forensic anthropological analyses).
Patient	This module specifies the attributes of the Patient that describe and identify the Patient who is the subject of a study. This module contains attributes of the Patient that are needed for interpretation of the composite instances and are common for all studies performed on the Patient.	Attributes of the patient whose skull was imaged can be used to study information of a skull in series, and the skull index can be analyzed. This research compiled information of Thai people whose skulls were CT scanned for the purpose of research.
Image	This module specifies the attributes that identify and describe an Image within a particular series.	There are details regarding the CT scan image sets of Thai human skulls that were imaged for research purposes in the patient information set.
Study	This module specifies the attributes that describe and identify the Study performed upon the patient.	The data sets on the analyses of patient skulls, resulting from measuring the lengths of different parts of the CT scan images and calculations (for use in forensic anthropology analysis, which is emphasized in this research).
Equipment	This module specifies the attributes that identify and describe the piece of Equipment that produced a series of composite instances.	Not specified, as there are no data sets for equipment (no application).
References	https://dicomiseasy.blogspot.com/2011/12/chapter-4-dicom-objects-in-chapter3.html?m=1&fbclid=IwAR06QFpD34WVkqCppuUO57wfd0EfLnQ1oKDzBKEC4sXDEJMBRgjhUK3WJMU (accessed on 4 April 2021)	The results of skull data analyses in the research conducted by Tuamsuk, Nonsrichan, and Sirisilp [16] and interviews with doctors specializing in anatomy and forensic anthropology.

6. Conclusions

In conclusion, the development of metadata for the management of digital data and images of Thai human skulls was carried out on the principle that a human skull is an information object, which comprises a content, context, and structure, enabling an attribute setting for the skull according to the information management method to be used for the purpose of the description of information in many aspects. The data management approach discussed above is the basis for the development of equipment whose purpose is to store and search digital information [20], which is different from previous information resource management approaches. Formerly, emphases were placed on the collection of context information, principally including, for instance, name of author, topic, year of publishing, place of publishing, and publisher, without attention paid to the content and structure of the information resources that are also necessary for access [12]. Therefore, when the information is developed into metadata based on the approach that conforms to the international standards, i.e., setting the name, definition, format, and details of the information that can be used to describe the characteristics of human skulls, and when the language of access is taken into account for retrieval, access, and information exchange and sharing [23], the metadata become useful in managing digital data and images of skulls for medical studies. The fields that may benefit from this are human anatomy and forensic anthropology. The metadata schema was developed to describe human skulls in order to provide assistance in storing human skull data in the digital format. Although, this metadata schema used and adopted some elements from the existing metadata standards, including the DICOM and Dublin Core Metadata Element Set, it is significantly different due to the following reasons: (1) the metadata are developed specifically to describe human skull data; (2) the data are derived from living human CT scan images and data, and the unique data (such as landmarks and craniometric length) of each human skull can be stored and calculated for forensic analysis and can be further used to verify human identity. These metadata are in a novel form; the user will be able to use the information to study different elements of human skulls; and the information required for human identification is also available (empirical study) [30]. If the database system compiles a great amount of information and a high number of human skull images, they can be analyzed to demonstrate the appearance and relations with human characteristics in different aspects, such as races, domiciles, and ancestors.

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Nomenclature

Acronyms/Abbreviations	Full names
DICOM	Digital Imaging and Communications in Medicine
NEMA	National Electrical Manufacturers Association
CT Scan	Computerized Tomography Scan
Dublin Core or DC	Dublin Core Metadata Element Set
MOD	Metadata Object Description Schema
VRA	Visual Resource Association
CDWA	Categories for the Description of Works of Art
OAI-PMH	Open Archives Initiative—Protocol for Metadata Harvesting
RDF	RDF (Resource Description Framework)

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