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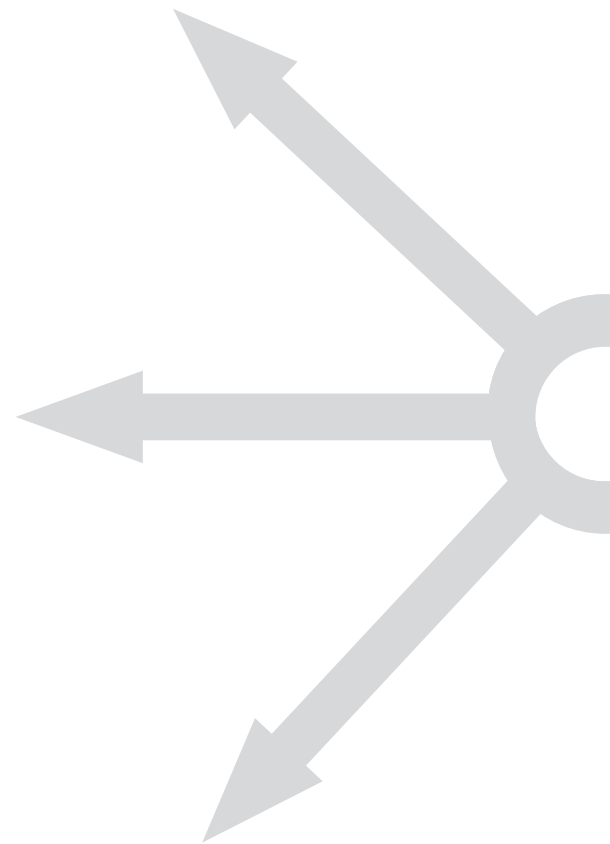
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Skeletor: system for recording and analysing articulated human skeletal remains

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Bioarchaeological analyses have the potential to generate a large amount of various data that require an efficient system for input, storage, access and analysis. In Croatia, the recording procedure for the analysis of articulated human skeletal remains is mostly done using paper forms. As data collected during this procedure varies in type, complexity and levels of categorization, the subsequent digitization usually covers only a small part of it. This significantly slows down the analysis process, makes access and processing of data difficult, and its long-term preservation questionable. As within the discipline, well-developed and subject-specific databases are usually unavailable or unaffordable, this paper presents an easy-to-use system for recording and analysing articulated human skeletal remains in a digital environment using predesigned recording forms and tables. The main goal of this system is to improve the current recording procedure, i.e. to enable simpler and faster access to recorded data through the use of relatively simple and well-known software, to speed up and simplify the bioarchaeological analysis, and to enable compatibility with other archaeological field data within the archive.

Keywords: *human skeletal remains, bioarchaeological dataset, spreadsheet data, recording forms, report table, summary tables*

Introduction

The recording procedure for bioarchaeological analysis¹ of articulated human skeletal remains is to the great extent, a standardised procedure that follows different but well-established guidelines. These enable the collection of data on different characteristics of human skeletal material found

in archaeological contexts. As this procedure has the potential to generate a large amount of various data, it requires an efficient data recording system. That is why the recording procedure is conducted using predefined recording forms intended for the collection of structured data.

¹ This work has been supported by the Croatian Science Foundation under the project “milOrd – Development and Heritage of the Military Orders in Croatia” (HRZZ, IP-2019-04-5513). In the scope of the project, which is, among other things, focused on the analysis of large

amounts of human skeletal material found during archaeological excavations, a system for recording and analysing of data collected by bioarchaeological analysis has been developed.



An overview of several systems for recording data on human skeletal remains used in Croatia showed that the recording procedure for bioarchaeological analysis is mostly done using recording forms printed on paper. These are designed to include all data on the skeletal remains of one individual and represent the form in which the data is permanently stored. As bioarchaeological data considerably varies in type, complexity and levels of categorization, when subsequent digitization is carried out, it covers only a small part of it. This significantly slows down the analysis process, makes access and processing of data difficult, and its long-term preservation questionable. The situation is also accompanied by a limited level of accessibility and insufficient reuse potential. Within the discipline, well-developed and subject-specific databases are usually unavailable or unaffordable, as is their maintenance and continuous upgrade,² so the unavoidable question becomes the design of an appropriate system for recording articulated human skeletal remains in a digital environment which can overcome the observed issues. In this context, the system must be suitable for the digitization of existing bioarchaeological data and at the same time provide the possibility of direct input of data during bioarchaeological analysis. System setup and usage should be customised for non-expert computer users with moderate computer skills. Furthermore, such endeavour must be encompassed with the awareness of different problems caused by rapid technological development due to which digital formats or software solutions for data management very easily become obsolete (Brickley 2017: 8).

In accordance with the stated issues, under the name SKELETOR (<http://milord.iarh.hr/index.php/en/activities-and-results/skeletor>), an easy-to-use system for

recording and analysing articulated human skeletal remains in a digital environment was designed using Microsoft Excel (© Microsoft Corporation 2022a) spreadsheet software (Appendix 1: SKELETOR_FORMS.xlsx; Appendix 2: SKELETOR_META.xlsx). This software was chosen as an environment for the system design because it is the most commonly used software for tabular data and probably the easiest input tool with powerful functions for analysing data. Although it is spreadsheet software not designed for database management, it is simple and fast and is adequate for the type and the amount of data at hand. Long-term access to data is ensured by its storage in comma-separated values (.csv) or delimited text (.txt) file formats which are preferred file formats for long-term archiving of spreadsheet data, i.e. quantitative tabular data with metadata (Niven 2011; Göldner et al. 2013; Gerth and Schäfer 2017; Trognitz 2017). At the same time, it allows the possibility to print sheets on paper for hard-copy archiving or converting the data to other file formats, e.g. .pdf or different raster formats.

The data

The initial step in the process of a system design was the review of a dataset that arises from the bioarchaeological analysis. To enable the data input process, a list of all the information that is recorded during the analysis of human skeletal remains was prepared. The final list contained 823 query fields divided into seven basic categories. Based on the number of fields in each category, in one Excel workbook, five digital recording forms were designed, which compared to the tabular entry significantly facilitate the input of data. All data entered in the recording forms are automatically transposed to the sixth worksheet in a form of a table with 823 fields arranged in an equal number of columns. To each of 823 fields, unique labels created mostly as acronyms of individual bioarchaeological categories and subcategories were assigned (Table 1). These labels serve as headers of the columns for easier navigation through data in tabular form. To understand the usage of labels and also facilitate the data input process the system is accompanied by a set of explanatory metadata (Appendix 2: SKELETOR_META-METADATA; SKELETOR_META-LABELS)

During the input process data are entered into five pre-designed recording forms. In the first form (Appendix 1: SKELETOR_FORMS-I_FORM) general information on the site and archaeological context are provided. They are entered at the top of the first form and then automatically copied to all recording forms in the same work-

² Maybe the best known software for recording data on human skeletal remains is Osteoware® (© Smithsonian Institution 2020), a free-ware developed by Smithsonian National Museum of Natural History. Although it can meet all requirements of bioarchaeological analysis and at the same time is equipped with a user-friendly interface, it demands continuous professional maintenance and upgrade. It primarily runs on Microsoft Windows OS and at the moment, it was last upgraded for Windows 7™ in 2010 (see Dudar 2010: 2). The situation is somewhat different with the databases created using commercial software. The example is the database for documentation of commingled and fragmentary remains (Osterholtz 2019), which uses fragment based approach in the recording process but gives the possibility to record articulated human remains (Osterholtz 2019: 79). Built on the FileMaker software, a commercially available application that enables nonexpert users to create and modify relational databases (Osterholtz 2019: 79), it is an easy-to-use system equipped with user-friendly interface. At the same time, its long-term maintenance and support depend directly and exclusively upon the proprietor.

NO.	CATEGORY	DESCRIPTION	FORM NO.	FORM ID	LABELS CONSTRUCTION SCHEME						
					FIRST PART			SECOND PART			
					CATEGORY	SUBCATEGORY	SUFFIX	PREFIX	TYPE	SUFFIX	
1.	GENERAL	Information on the site and archaeological context			G	N/A	N/A	N/A	N/A	N/A	(query text or its abbreviation)
2.	INVENTORY	Inventory and completeness of individual bones	1.	I_FORM	I	Cranium, Trunk, Upper limb, Lower limb	N/A	Complete, Left, Right, Single, Unsided, Any	2 letter code	2 letter code	Proximal, Medial, Distal, Lateral + Joint
3.	SEX	Sex determination			S	Cranium, Hip	N/A	Complete, Single, Any	2 letter code	2 letter code	N/A
4.	AGE	Age determination	2.	SA_FORM	A	Cranium, Hip	N/A	Complete, Any	2 letter code	2 letter code	N/A
5.	MEASUREMENTS	Measurements of individual bones	3.	M_FORM	M	Cranium, Upper limb, Lower limb, Hight calculation	N/A	Left, Right, Single	3 letter code	3 letter code	N/A
6.	TEETH	Presence of teeth and changes in the teeth	4.	T_FORM	T	Status, caries_Occlusal, caries_Buccal, caries_Lingual, caries_Interproximal, caries_Root, caries_alveolar_Abscess, caries_Calculus, caries_alveolar_Resorption, dental_Wear, LEH (H)	maXilla, maNdible	Left, Right	1 to 3 letter code	1 to 3 letter code	LEH: Crown, number 1 to 3
7.	PATHOLOGIES	Presence of pathologies	5.	P_FORM	P	Fractures, osteoArthritis, schmorls_Defect, Perioistitis, Cribra_orbitalia, Ectocranial_hypo, LEH (H), Syphilis, TBC (T), Leprosy, Rickets, scurvy (K), Other	N/A	Complete, Left, Right, Single	1 or 2 letter code	1 or 2 letter code	Number, Side_Bone, Presence, Completeness, Type

Table 1. Seven categories of data divided into five different recording forms with label construction scheme for 823 query fields.



book. The main part of the first form is intended for recording the inventory and completeness of all bones of the individual skeleton: all cranial bones, trunk including vertebrae, ribs, sacrum, coccyx, sternum, manubrium, xyphoid, upper limb including scapula, clavicle, bones of the hand, humerus, radius and ulna, lower limb including pelvic bone, patella, talus, calcaneus, bones of the foot, femur, tibia and fibula. Most of the bones are separated by the side – left and right, while the long bones are further divided into epiphyses or joints (proximal and distal) and diaphyses (proximal, middle and distal third).

In the second recording form (Appendix 1: SKELETOR_FORMS-SA_FORM), the data about the sex and age of the skeleton are provided. Sex is estimated only for individuals older than 18 years of age. Based on the morphology of the cranium and pelvic bones, following criteria by Buikstra and Ubelaker (1994: 16-21), sex is estimated to be male, female, probably male, probably female or undetermined.

Age in adults is estimated by several criteria, according to changes in pubic symphysis (Brooks and Suchey 1990), auricular surface (Lovejoy et al. 1985: 21-26), and cranial suture closure (Meindl and Lovejoy 1985: 61). Adults are placed in one of the three age categories established by Buikstra and Ubelaker (1994: 36): young adults (18 to 35 years), middle adults (35 to 50 years) and old adults (50+). However, when a narrower determination is possible they are assigned to an age group of 5 or 10-year age bands. Subadults are divided into four age categories proposed by Baker et al. (2005: 10), and slightly modified: fetuses (less than full-term), infants (0 to 1 year of age), children (2 to 11 years of age), and adolescents (12 to 18 years of age). When a skeleton is not well preserved, the age category is assigned either to the adult or subadult group.

The third recording form (Appendix 1: SKELETOR_FORMS-M_FORM) contains measurements of the cranium and long bones including humerus, radius, ulna, femur, tibia and fibula. All measurements are taken according to the Martin-Saller system (Martin and Saller 1957). Skeletal height is reconstructed from measurements of the height of each long bone used in the regression equation or from a combination of measurements of the height of the femur and tibia (Trotter and Gleser 1952; 1958).³ Since the definition of the tibia

length is standard condylar-malleolar length and Trotter in her equation for stature estimation omitted the malleolus (Jantz et al. 1995: 758; Jantz et al. 2020: 2094), all calculations based on the tibia length should be taken with this consideration in mind. In the system, if certain criteria are met, that is if the age and sex of an individual are estimated, this calculation is done automatically.

Dental status is recorded in the fourth recording form (Appendix 1: SKELETOR_FORMS-T_FORM) following criteria by Buikstra and Ubelaker (1994: 49). Caries lesions are observed by their position and standards proposed by Powell (1985). Abscesses are scored using criteria established by Roberts and Manchester (2007: 70), calculus according to the Brothwell system (Brothwell 1981: 155), alveolar resorption to the DeWitte method (DeWitte 2012: 407), and dental wear by Smith scoring (Smith 1984: 45). Linear enamel hypoplasia (LEH) is documented on the maxillary first incisors and canines as well as mandibular canines. Measurements include the crown height and the measurement from the distance of the cemento-enamel junction to the linear defect (Buikstra and Ubelaker 1994: 57).

The fifth and final recording form (Appendix 1: SKELETOR_FORMS-P_FORM) is intended for recording pathologies following the standards proposed by Buikstra and Ubelaker (1994: 107-123). Firstly, fractures are divided into antemortem or perimortem while possible fractures are noted as well. A total number of affected bones and their side are registered as well as a detailed description of each fracture. Degenerative osteoarthritis is noted considering the side of all major joints (shoulder, elbow, hip and knee) and vertebrae (cervical, thoracic and lumbar). Schmorl's nodes are evidenced on the thoracic and lumbar vertebrae. Nonspecific periostitis is observed as an active or healed process on both cranial and postcranial bones. Cribra orbitalia is recorded for each orbit in the form of active or healed lesions or not present at all. Ectocranial porosity of the cranial vault is simply noted as present or not. LEH is previously recorded in the fourth dental sheet so in this one its status is transferred as present or absent. Infectious diseases (syphilis, tuberculosis and leprosy) and metabolic disorders (rickets and scurvy) are registered as present or not present following criteria proposed by Ortner (2003). For a detailed description or a comment on present pathologies, an input section for free text entry is provided.

³ The equation for stature estimation is population and age-specific and can be applied only on white population aged 18 to 35 years (Trotter and Gleser 1952). Since Trotter and Gleser (1952) noted the correlation between ageing and stature they applied a correction formula. Galloway (1988), Chandler and Bock (1991) and Giles (1991)

suggested that these changes are becoming significant only after the age of 40 or 45 years. As Giles (1991) showed that only at the age of 60 a 1.2 cm for males and 0.7 cm for females must be subtracted from calculated stature, it was decided to use the Trotter-Gleser formula for all age categories without a correction formula.

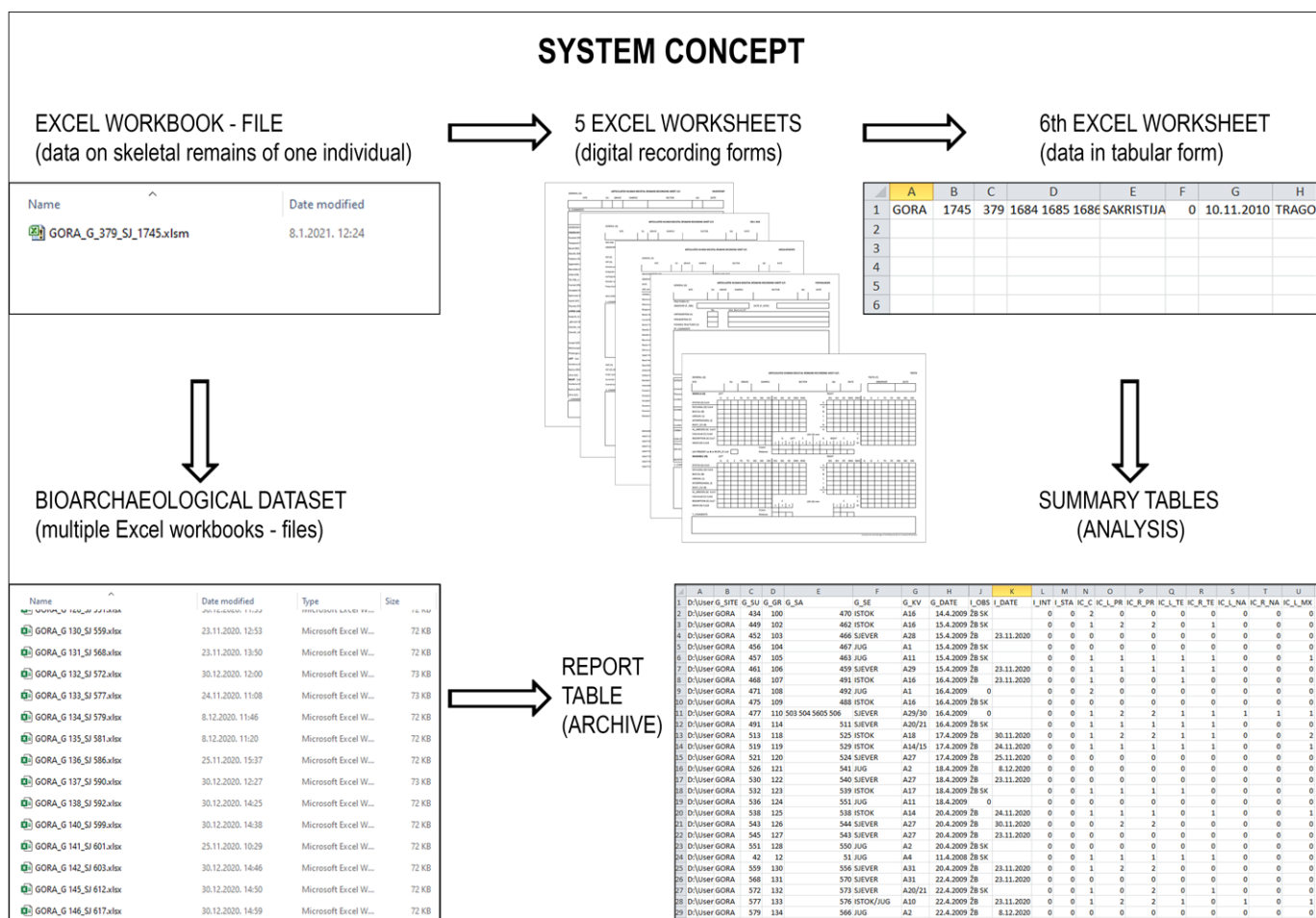


Figure 1. The scheme of a system concept.

The system

In a designed system one file, i. e. Excel workbook represents data on the skeletal remains of one individual. To facilitate the input of different types of data collected during the procedure of bioarchaeological analysis, the workbook contains five digital recording forms designed in separate Excel worksheets. During the input process, all of the data entered in the forms are automatically transposed to the sixth worksheet in a tabular form. All the worksheets in the workbook are protected which means that cells cannot be reformatted or deleted, the content in default cells cannot be edited, and the default design of the recording forms cannot be changed.⁴ It is

only allowed to modify input cells – which are surrounded by borders and thereby visually emphasized – and only certain predefined codes are allowed. That is why an integral part of the system is a metadata document that contains the list of allowed codes divided into 20 coding categories (Appendix 2: SKELETOR_META-CODES). Most of the codes used in the system are standardly used in bioarchaeological analysis and are taken from or modified after Brothwell 1981; Smith 1984; Lovejoy et al. 1985; Meindl and Lovejoy 1985; Powell 1985; Brooks and Suchey 1990; Buikstra and Ubelaker 1994; Roberts and Manchester 2007; De Witte 2012.

For example, in cells where the completeness of certain bones is recorded, the input of only three codes is allowed: 0 - meaning bone is not present, 1 - more than half of the bone with diagnostic features is preserved, and 2 - less than half of the bone without diagnostic

⁴ To prevent accidental changes of worksheet structure, the worksheets are password-protected. Unlocking is enabled by entering a password: milOrd



features is preserved. Where the number of preserved bones is recorded, only the maximum range of the possible number of bones is allowed, so for the left side ribs, only the numbers from 0 to 12 are allowed. Blank cells are allowed, because in the worksheet with tabular data such an entry is automatically recorded as 0 - missing.⁵ That is why the presence of a bone or a tooth but the absence of the observed pathology is recorded as 9 - absent, not present. The additional restriction concerns the usage of the comma. As the comma is the delimiter in the comma-separated values file, which is a future-proof archiving format intended for the long-term preservation of digital data in tabular form, its usage in the recording procedure is disabled.⁶

To maintain a proper dataset structure and to reduce the possibility of overwriting files, the file naming procedure must be defined in advance. Maybe the most appropriate are the filenames consisting of unique identifiers already used in the archaeological datasets, i.e. site, grave and stratigraphic unit IDs. After the data for every analysed individual has been entered, the result of the process is a bioarchaeological dataset for a particular site that has the form of multiple spreadsheets saved as .xlsx files and stored within one folder.

But the data stored in this manner are still not prepared for analysis. For that purpose, all data entered in five pre-designed recording forms are automatically transposed to the sixth worksheet named TABLE (Appendix 1: SKELETOR_FORM-TABLE) where they are given the structure of tabular data containing all bioarchaeological data on one individual. When the data on skeletal remains of all individuals are entered, merging the automatically generated records in tabular form enables the creation of the report table with all entered data or different summary tables suitable for data analysis (Fig. 1). It is important to know that the placement of headers with column labels at the top of the report or summary tables requires the inclusion of a TABLE worksheet from the metadata document (Appendix 2: SKELETOR_METADATA) in the merging process.⁷

As tables from all files have the same structure, the merging procedure for multiple workbooks is not complicated and can be executed in several ways. Advanced Excel users will probably choose to use the Power Query (© Microsoft Corporation 2022b), Excel's add-in with powerful tools for merging and sorting data.⁸

For beginners, maybe the easiest method for merging data is in an open access add-in called RDB Merge (© de Bruin 2010). This user-friendly add-in is designed for merging multiple .xlsx or .csv files into a report table, at the same time enabling the selection among columns available in the original files. The result of merging the specific range of columns is a summary table suitable for problem-specific analysis. When the data are transferred to tabular form basic quantitative analysis can be done using basic Excel tools like Find and Filter, while advanced users can use Formulas or PivotTables.

Conclusion

The system for recording and analysing articulated human skeletal remains named SKELETOR is primarily designed to improve the bioarchaeological recording procedure in a digital environment through the use of relatively simple and well-known software. This makes it suitable for use by non-expert computer users with moderate computer skills. At the same time, by enabling simpler and faster access to recorded data, it is intended to speed up and simplify the bioarchaeological analysis. Also, it is designed with a basic intention to contain compatibility with archaeological field data archived in a spreadsheet form and to contain capability for long-term data archiving. Furthermore, each recording form is suitable for print on A4 paper for hard copy archiving, as well as conversion to other file formats.

Nevertheless, it is important to note that the system is not perfect nor without flaws, and these can be recognised on several points. The first concerns the structure of the final dataset which has no data connectivity between data entered in the recording forms and

⁵ However, entering the code 0 in the digital form is recommended because it confirms that the bone is really missing, and that, for example, the category was not accidentally skipped.

⁶ Usage of comma is also disabled in the cells where free text entry for analyst's descriptive remarks is allowed.

⁷ Equally named worksheets in workbooks placed in the same folder simplify the merging process so before merging, metadata document should be copied with bioarchaeological data.

⁸ To older versions of Microsoft Excel, Power Query had to be separately added but from Excel 2016 it appears in the Data tab as Get & Transform Data group of commands (© Microsoft Corporation 2022b).

the merged data in the report table or summary tables. Therefore, upon completion of data entry, it is necessary to choose in which form the data will be kept during the analysis and storage in a local repository. It is therefore important to be aware that worksheets with recoding forms designed for data entry are much more suitable for the potential entry of new or modification of old data while for digital archiving, data in tabular form is preferable. Whatever option is chosen, during the period of data usage and local data storage, constant control over the changes in the final version of the dataset is required. Another shortcoming is the lack of built-in version control which would disable the storage of multiple versions of the same document with conflicting or outdated data. Same as previous, the third flaw is also connected with the possibility of human error. It commonly occurs when

coded data is used and is the result of incompletely controlled data entry. As the input of codes requires a high level of consistency, any mistake can result in problems or errors during querying and analysis (Niven 2011). At the same time, archiving coded data requires the storage of additional decoding documents whose loss can forever disable the understanding of the meaning of the codes (Niven 2011). However, the awareness of the listed problems, as well as the establishment of a clear workflow for changing, saving and overwriting documents with strict compliance to the predefined data entry instructions, can significantly reduce instances of human error and to a large extent guarantee the successful creation of a meaningful bioarchaeological dataset on human skeletal remains in a digital environment.

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