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a multidisciplinary study of non-adult diet and disease from medieval and early modern southern Estonia

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Children of the Grave: a multidisciplinary study of non-adult diet and disease from medieval and early modern southern Estonia

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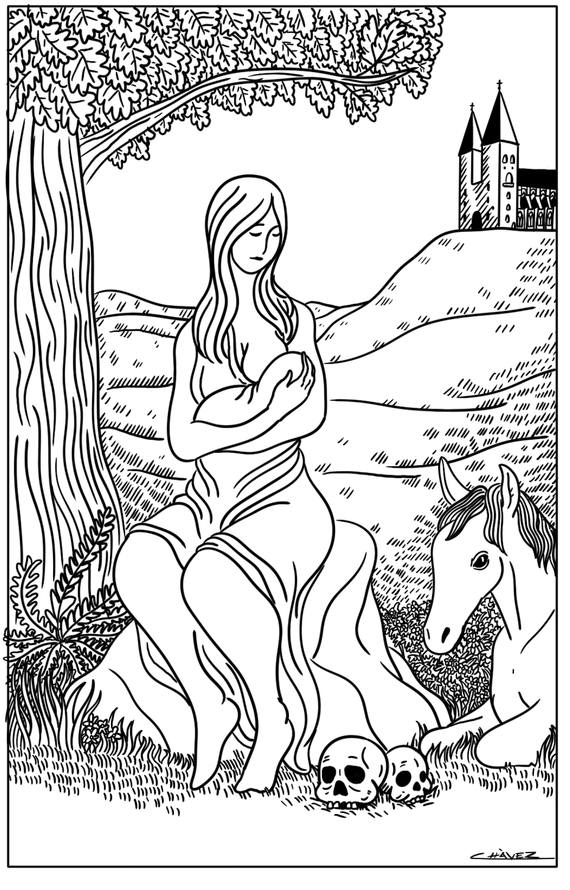
“...it soon grew clear that the hour of emancipation for that little prisoner of the flesh was to arrive earlier than her worst misgivings had conjectured. And when she had discovered this, she was plunged into a misery which transcended that of the child’s simple loss. Her baby had not been baptized.

(...) ‘Be you really going to christen him, Tess?’ The girl-mother replied in a grave affirmative. ‘What’s his name going to be? ‘SORROW, I baptize thee in the name of the Father, and of the Son, and of the Holy Ghost.’ She sprinkled the water, and there was silence.

(...) So passed away Sorrow the Undesired — that intrusive creature, that bastard gift of shameless Nature who respects not the social law; a waif to whom eternal Time had been a matter of days merely, who knew not that such things as years and centuries ever were; to whom the cottage interior was the universe, the week’s weather climate, new-born babyhood human existence, and the instinct to suck human knowledge”.

– Thomas Hardy
Tess of the D'Urbervilles (1891)



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V Morrone, A., Tõrv, M., Piombino-Mascali, D., Saupe, T., Sepp, H., Valk, H., Malve, M., & Oras, E. 2022. Children of the grave: Investigating non-adult feeding practices in medieval and early modern Estonia through stable isotope analysis. *PloS One*, in press. (ETIS 1.1.)

Author contribution: conceptualization, data curation, formal analysis, methodology, resources, data validation, writing of the original draft, review and editing, visualization.

1. INTRODUCTION

During the unfolding of this doctoral project, I had the opportunity to apply a photographic method called Reflectance Transformation Imaging (RTI) to samples of baby bones. This technique consists of taking multiple pictures of an object, illuminating it from different angles, then merging them into a final high-resolution image. Via dedicated software, the light and shadow can be adjusted to enhance important features, highlighting and rendering the surface details of the bone.
A large Reflex camera was placed on top of a dome filled with LEDs, and light was spread all over the tiny bones while the camera shot dozens of photos: one shot for each angle of light; one shot for each shade of darkness. While merging all these photos and observing the final picture, I realized that this technique is the perfect metaphor for my whole doctoral work.

Just as RTI spreads light on a child's bone from all available angles, so too I can explore past childhood from all available perspectives, merging them into a final definitive picture. Like RTI has different rendering modalities allowing changes of the shadowing and highlighting to reveal particular surface changes that usually go undetected, I have different means to highlight particular aspects of past childhood that have been often overshadowed in earlier bioarchaeological studies.

We could never imagine a human community without the frolicking, laughing and whining of babies and toddlers. As in the present, in the past children were not just silent and marginal members of society. They walked, played, often worked, and occupied most of the time of their caregivers, playing an active role in the everyday life of past human groups. The role of children in shaping past communities is a topic of increasing interest in current bioarchaeology, especially since they were often neglected in historical sources and narratives. The skeletal remains of non-adults provide numerous insights into the complexity of their personal and social lives, starting with their birth and continuing through their development and growth. In the last decade, several studies have provided insights into aspects such as non-adult activities and social role (Halcrow & Tayles, 2008; Inglis & Halcrow, 2018; Gowland & Halcrow, 2020; Halcrow & Ward, 2020; Halcrow et al., 2020; Hodson, 2021), health (Lewis, 2007, 2017), diet, and feeding practices (Dupras & Tocheri, 2007; Wheeler, 2012; Bourbou, 2018). However, the bioarchaeology of children is currently underdeveloped in the Baltic countries, lacking a coherent line of research covering different aspects of non-adult life and death in this part of Europe.

This thesis aims to begin filling this gap in children's studies in Eastern Baltic archaeology, adopting historical, archaeological, scientific, and even philosophical points of view. New imaging techniques were tested on their tiny bones, contributing to a better display and understanding of pathological patterns in osteological materials. Their skeletal remains were thoroughly examined using osteoarchaeology and paleopathology to detect infectious and metabolic diseases. Their bones were subjected to stable isotope analyses to address physiological stress and diet, as well as to pinpoint their breastfeeding and weaning thresholds. The critical interpretation of these multiple results aided in understanding complex interactions between childcare in different socio-economic contexts, local traditions in dietary selection, treatment of minorities, and nutritional stress in the mother-child nexus. This finally resulted in a multifaceted academic journey following the common thread of childhood in the past.

This thesis presents the first multidisciplinary study specifically dedicated to non-adults in Estonia and the Eastern Baltics. With a special focus on medieval and early modern Livonia, this work creates a starting point for the development of the bioarchaeology of children in this area of Europe.

1.1. Aims and research questions

The aim of this thesis is to provide a large-scale overview of childhood health, social role, staple diet, and feeding practices through the 500-years of medieval and early modern Livonia (13^{th}–17^{th} centuries AD), a historical region corresponding mostly to present-day southern Estonia and northern Latvia (Fig. 1). This was achieved first with a theoretical approach, then subsequently through the multidisciplinary use of paleopathological methods, novel imaging techniques, and biomolecular analyses.

Figure 1. Map of the eastern Baltics from c. 1400. The gray areas indicate bishoprics, while the white areas represent the territories under the Teutonic Order. Map: © Pluskowski et al. (2019).

This thesis is crafted around five papers, answering the following research questions:

1. What is the state of art of childhood bioarchaeology in the Baltic states? (Paper I).
2. What are the philosophical implications of the paleopathological study of non-adult remains in the light of the Osteological Paradox? (Paper II)
3. Which new imaging methods can be used to study non-adult bone pathology? (Paper III).
4. What has been the impact of the intense upheavals occurring in medieval and early modern Livonia on the weakest and most marginalized members of society? (Paper IV). In particular:
   a. How did the historical episodes of famine and epidemic recorded in written sources affect the physiological health of pregnant women and their off-spring?
   b. How were the prematurely deceased treated in these communities?
5. What were the staple non-adult diet and feeding practices in medieval and early modern Estonia? (Paper V). In particular:
   a. Did children access food sources differently than the adult population?
   b. Were there any differences in diet and feeding practices among children of different ages, or in rural versus urban contexts?
   c. For how long were Estonian children breastfed, and at which age did the weaning process begin and end?

1.2. Dissertation outline

This thesis is constituted by two main parts. The first explores childhood in the past from a historical and theoretical point of view. The first paper, ***Giving a voice to the little ones: The bioarchaeology of children in the Baltics*** (*Archaeologia Lituana*), is a detailed review of historical, archaeological and osteological studies dedicated to children in the Baltic area, in order to identify the state of the art, reflect on the reasons for the neglect of non-adult material in archaeological studies, and propose new research perspectives. The second article, ***The Song of the Science Mermaid: A Philosophical Trilogue on the Osteological Paradox*** (*Acta Baltica Historiae et Philosophiae Scientiarum*), dives deep into the philosophical implications of paleopathological studies. With a colloquial approach and a dialogue format, the theoretical issues encountered by bioarchaeologists while reconstructing past health are explored, specifically including the inevitable problems in the interpretation of disease patterns in child remains.

The second part lies on much more concrete grounds, exploring new methods and combining different scientific techniques in the study of non-adult remains.

Application of Reflectance Transformation Imaging (RTI) to surface bone changes in paleopathology (*Anthropologischer Anzeiger*) is a methodological paper in which evaluation of a novel photographic technique on osteological material is presented. This user-friendly method has proven to be particularly useful to observe subtle lesions in non-adult bones and was successfully used to display perinatal pathology in the fourth paper of this thesis, ***Hunger, disease, and subtle lesions: Insights into systemic metabolic disease in fetal and perinatal remains from 13th- to 15th-century Tartu, Estonia*** (*International Journal of Osteoarchaeology*). This article presents the paleopathological analysis of a deviant mass burial of babies discovered outside St Jacob's cemetery walls in Tartu, in which metabolic disease patterns were recorded, and the treatment of unbaptized babies was discussed in the light of historical famines and epidemics in Livonia. The final step of this journey into childhood in the Baltics is dedicated to non-adult diet. ***Children of the grave: Investigating non-adult feeding practices in medieval and early modern Estonia through stable isotope analysis*** (*Plos One*) investigates the staple diet in children from rural and urban southern Estonian cemeteries through bulk stable isotope analysis. It aims to explore differences among rural and urban population groups, and to detect the thresholds of breast-feeding and weaning for the first time in Estonia and the Eastern Baltics.

Building on the papers listed above, the dissertation will start with a historiographical review of the study of children in archaeological contexts, then proceed with the study of the missing children through various perspectives, including theoretical/philosophical discussions, and methodological novelties. After presenting the osteological materials and the methods adopted, the main results of this work will be discussed to understand what stories immature remains can tell us adopting several techniques in archaeological science, how these means were able to compensate for each other's flaws, and finally what further narratives about children's lives and deaths we expect to be able to unfold in the future.

2. HISTORY OF RESEARCH

2.1. Brief history of the archaeological and anthropological study of children

Child bioarchaeology can be defined as the study of non-adult remains from archaeological contexts (Lewis, 2007; Halcrow & Ward, 2020). The first bioarchaeological investigations of children followed the same research methods as applied to adults and were crafted to classify physical features of the skeleton. Among these, the macroscopic and metric characteristics of the skull received most of the attention (Halcrow & Ward, 2020; Halcrow et al., 2020). Until the 1990s, immature individuals were systematically marginalized from bioarchaeological research, although a few papers covered issues such as the scarce representation of children in ancient cemetery contexts, and their high mortality rates in the past (Mays et al., 2017).

With these premises, the anthropological research on the youngest members of ancient communities flourished over two principal lines of thought. The first was initiated by the paramount analysis by Philippe Ariès on the conceptualization and treatment of children in medieval contexts (*Centuries of childhood: a social history of family life*, 1962). In this work, infants and children were labeled as passive subjects of society, nearly invisible in the archaeological records and mostly part of a feminine and domestic reality, strictly intertwined within female gender roles (Baxter, 2008). According to Ariès, the present-day concept of infancy did not exist until the Early Modern Age, and prior to then, parents completely lacked empathy and affection towards their offspring, dressing them and treating them like miniature adults. This detached approach would have represented a defense mechanism against the overwhelming infantile mortality (Ariès, 1962). Successive publications built on the topic (De Mause, 1974; Stone, 1977; Pollock, 1983), while others started criticizing this traditional point of view (Attreed, 1983; Hanawalt, 1986, 1993; Swanson, 1990; Shahar, 1990).

The second research trend was inspired by feminist movements in the 1970s, evolving with the *gender theory* in the 1990s. A major interest was directed towards “invisible” population groups, transferring the child from an exclusively womanly dimension to a more active position in the community; children started to be considered parts of the social life, actively contributing to the transformation of their environment (Lillehammer, 1989; Derevenski, 1994; Baker, 1997; Kamp, 2001). One of the first authors focusing on the role of children in archaeology was Lillehammer (1989), who suggested a multidisciplinary use of funerary archaeology, ethnography, and osteology as means for understanding the complex interactions between children, adults, and their physical environment (Lillehammer, 1989). Her pivotal work was continued by several researchers (Coulon, 1994; Scott, 1999; Beausang, 2000). In particular, the studies of children in Anglo-Saxon England by Sally Crawford have widely discussed this topic (Crawford, 1991, 1993, 1999, 2000, 2007). It was therefore only after the mid-20th century that non-adults effectively entered the anthropological record.

The most direct means to conduct these analyses are non-adult remains themselves. With this purpose, important milestones specifically based on the anatomy and physiology of the immature skeleton were developed from the 2000s onwards. The globally-used reference volume by Scheuer & Black (2000), *Developmental juvenile osteology* (and later editions – Schaefer et al., 2009; Scheuer & Black, 2004; Cunningham et al., 2016), the guide for the identification and recovery of immature human remains in archaeological contexts (Baker et al., 2005), and the recent volume by Han et al. (2017) on the anthropology of the fetus are among these. Two recent publications by Mary Lewis, *The bioarchaeology of children* (2007) and *Paleopathology of children* (2017), were specifically dedicated to children in archaeological and forensic contexts. From here, the bioarchaeology of non-adults steadily progressed, becoming a well-recognized and appreciated branch of research. A growing number of studies allowed exploration of the everyday lives of children in different times and places.

Currently, the two principal lines of research in the field are: **a)** biomolecular studies employing aDNA and especially stable isotope analysis for reconstructions of diet, feeding practices, and migration patterns; **b)** paleopathological analyses (Mays et al., 2017). Moreover, in the last five years studies further explored the health and disease of the youngest individuals, such as fetuses and perinates (Han et al., 2017; Hodson, 2021). Aspects such as their age at death estimation, birth experiences, prenatal pathology, and ethics in the studies of fetuses are currently considered in the field (Hodson, 2021).

Future research on non-adults will most likely cover essential aspects such as sex determination, development of new, more precise age estimation methods, more accurate paleodemographic analyses, and improved techniques for paleopathological investigation, including advances in biomolecular studies (Lewis, 2007, 2018).

2.2. The Eastern Baltics: osteology and paleopathology

Since some of the aforementioned researchers contributed to the development of osteology in more than one Eastern Baltic countries, this chapter will follow a chronological structure. As in other areas of Europe, the early development of Baltic osteology started with the assemblage and analysis of anatomical collections, mainly with the aim of studying ancestry, ethnic features, and historical issues.

From the very beginning, the employment of scientific methods has been crucial in Estonian and Baltic archaeology. The very first attempts to analyze human skeletal material in Estonia took place at the end of the 19th and beginning of the 20th century, when the Professor of Anatomy at the University of Tartu (UT) **Aleksander Rosenberg** (1839–1926) analyzed animal bones from the Pärnu river, as well as human skeletal remains from the Neolithic burial site of Kõljala (island of Saaremaa, Estonia) and the stone-graves at Lagedi near Tallinn (Kriiska & Lõugas, 2006, 270). Rosenberg has been considered one of the most knowledgeable researchers of his time with regard to animal and human osteology. His work on archaeological human remains was followed by the research of other eminent researchers, such as Richard Weinberg (1904), who described the Corded Ware Culture skeleton found in Käo (central Estonia) and the human bones from the Pärnu River, and Carl Fürst (1914), who studied the Corded Ware Culture skeleton from Kõljala (Saaremaa).

In the same period, the Polish anthropologist **Julian Tałko-Hryncewitz** started assembling *crania* collections dated prior to WWI in Lithuania, describing lesions related to trepanation in some cases (Tałko-Hryncewicz, 1921; Tałko-Hryncewicz & Hoyer, 1921). This material survived WWII, and systematic excavations were renewed in the 1960s, leading to the storage of over 15,000 skeletons from the Mesolithic to the early modern period in the Faculty of Medicine of Vilnius University (Jankauskas & Gerhards, 2012). The procedure was slightly less organized in Latvia and Estonia, where human remains of archaeological significance were under the responsibility of the archaeologists who unearthed them. Hence, they were stored in universities, museums, or national institutes of history (Jankauskas & Gerhards, 2012).

Moving to the 1930s, **Juhan Aul**, the founder of Estonian anthropology and later Professor at the UT examined skeletons from the Sope and Ardu pit graves of the Late Neolithic Corded Ware Culture, as well as the stone-cist graves of Muuksi (Northern Estonia) (Kriiska & Lõugas, 2006, 273). In addition, the medical doctor and amateur archaeologist **Adolf Friedenthal** also contributed to the development of the field. Friedenthal excavated several stone graves in northern Estonia, analyzing the human remains discovered (Friedenthal, 1931, 1932). The anthropological study of archaeological human remains at the UT Institute of History and Archaeology continued in the 1940s with the work of one of Aul's students, **Karin Mark**, who dedicated her research to paleoanthropology (Mark, 1956), osteometric analysis of the skull, and especially ethnogenesis (Mark, 1970a, 1970b, 1972), focusing on Stone Age, medieval and early modern human remains (Mark, 1962, 1965; Kriiska & Lõugas, 2006, 275).

The birth of the systematic study of paleopathology in the Baltics is closely tied to the work of the Latvian radiologist **Vilis Derums** (1899–1988), who developed an inventory of 6,729 skeletons after his return from exile in the Soviet Gulag labor camps in the 1950s. Derums was the first researcher in the Soviet Union who diachronically analyzed skeletal remains from one geographical region, using materials from the Stone Age to the early modern period. These materials were studied from different perspectives, including pathology, osteometrics, and histology. Infectious disease, trepanations, joint disease, dental disease, ankylosing spondylitis, and traumas were among the skeletal pathologies described (Derums, 1963, 1964, 1966, 1968, 1978, 1979, 1980, 1987; Derums & Miltinsch, 1988). Although several diagnoses may be currently considered obsolete, his work was indeed pioneering for the development of physical anthropology in the Baltic countries and plays a continuing role in regional education and research in paleopathology (Kriiska & Lõugas, 2006, 275; Jankauskas & Gerhards, 2012).

At the end of the 1960s and the beginning of the 1970s, **Galina Sarap** and **Leiu Heapost** at the Institute of History of the Estonian Academy of Sciences continued studying odontology, serology, and the biological profiles of several archaeological human subjects (Kriiska & Lõugas, 2006, 275). Moving into the 1970s and 1980s, it is worth mentioning the Lithuanian odontologist Irena Balčiūnienė, who dealt with jaw and oral pathology such as caries and enamel hypoplasia (Papreckienė & Česnys, 1981, 1983).

From the 1990s onwards, the study and development of paleopathology in the Baltic area cannot be unbound from the massive work of the Lithuanian biological anthropologist **Rimantas Jankauskas**. Lithuanian paleopathological research in the 1990s followed two main trends: the release of specific case studies, and paleo-epidemiological studies of disease, with an osteobiographical approach (Jankauskas & Gerhards, 2012). Disease patterns related to infectious diseases such as tuberculosis (Jankauskas, 1998, 1999; Faerman & Jankauskas, 2000), treponematosis (Jankauskas, 1989, 1991, 1994), metabolic disease (Jankauskas & Schultz, 1999; Jankauskas, 2003; Jatautis et al., 2011), skeletal dysplasias and malformations (Jankauskas, 2001), tumors and joint lesions (Jankauskas, 1992), oral pathology (Palubeckaitė et al., 2006; Miliauskienė & Jankauskas, 2015), ear diseases (Sakalinskas & Jankauskas, 1991, 1993), trauma (Jankauskas & Zakaras, 1993; Jankauskas, 1995; Teegen et al., 1997), and stress markers (Palubeckaitė & Jankauskas, 2000, 2001; Palubeckaitė et al. 2002) were reported. The bioarchaeological approach applied in these studies produced interesting results regarding the lifestyle of Mesolithic and Neolithic populations (Butrimas & Jankauskas, 1998; Palubeckaitė et al., 2006), and medieval/postmedieval communities (Jankauskas 1995, 2002; Jankauskas & Urbanavičius, 1998). In addition, this approach was also directed to the forensic examination of Soviet-regime victims (1944–1947), executed by the KGB in prisons and buried in clandestine mass graves (Jankauskas et al., 2005; Jankauskas, 2009).

In the last thirty years, Estonian research groups from Tallinn University and the University of Tartu have studied human skeletal samples not only from the Stone Age to the modern period, but also from contemporary populations (Allmäe et al., 2019). In Estonia, research at the Institute of History during the 1990s resulted in a monograph about the physical anthropology of Estonians (Mark et al., 1994), and in the work of several new anthropologists: **Raili Allmäe** focused on human bones from prehistoric to historical urban and rural sites; **Ken Kalling** has studied human skeletons from St. John's Church in Tartu (1995, 1997), the churchyard of St. John's Church in Viljandi (South Estonia), and the stone grave in Viimsi (North Estonia, 1993); **Jonathan Kalman**'s research was based on stone graves and covered paleopathological topics such as trauma analysis (especially cranial), as well as post-mortem manipulation of bodies and partial burials in Estonian prehistoric sites (Kriiska & Lõugas, 2006, 283). In 2000, Kalman reconstructed a case study of a 30–40-year-old man from Kaberla (North Estonia) killed in a military battle in the 14^{th}–15^{th} century (Kalman 2000a); he also examined the skeleton of a 8–9-year-old child suffering from syphilis buried in the same Kaberla cemetery in the late 17th century (Kalman 2000b). **Jana Limbo-Simovart** has studied dental pathology in several sites, especially focusing on enamel hypoplasia (Limbo, 2004, 2011, 2013). The main research areas in this period were population studies of Estonian communities and neighboring countries (Allmäe, 1998, 1999, 2003; Heapost, 1998, 2000, 2002, 2006, 2007, 2016; Kalling & Heapost, 2013; Mark & Heapost, 2014), cremation analyses (Allmäe, 2004, 2014a), forensic anthropological cases from the 20th century (Allmäe & Limbo-Simovart, 2015; Allmäe et al., 2017), as well as paleodemographic studies (Allmäe, 1998, 2014b). Bioarchaeological case studies (Allmäe, 2006, 2008a, 2010; Peets et al., 2010, 2012), as well as the insights into stature and sexual dimorphism issues (Allmäe, 1995, 1997, 2000, 2008b; Heapost, 2003), have been numerous as well.

Moving to the present day, the Lithuanian research group is still extremely active, and in recent years has directed attention to biomolecular techniques for the detection of human pathogens such as typhus and trench fever (Raoult et al., 2006), disease, and trauma (Kozakaitė, 2011, 2018; Kozakaitė & Jankauskas, 2013; Kozakaitė et al., 2018a,b; Brindzaitė, 2020; Kozakaitė et al., 2019, 2020, 2022), and especially to mummy studies, with the establishment of the *Lithuanian Mummy Project* (Morrow et al., 2014; Piombino-Mascali et al., 2014a-d; Panzer et al., 2015; Piombino-Mascali et al., 2015, 2016, 2017a, 2017b, 2022).

In Latvia, systemic paleopathological studies were recently carried out by **Guntis Gerhards** and colleagues, who focused on trauma analysis (Gerhards, 2007, 2008), secular stature variations (Gerhards, 2005, 2006), infectious disease (Gerhards et al., 2017), malnutrition and metabolic disease (Pētersone-Gordina et al., 2013, Pētersone-Gordina, 2018), dental disease (Pētersone-Gordina & Gerhards, 2011; Pētersone-Gordina et al., 2018), and biomolecular studies (Ščėsnaitė-Jerdiakova et al., 2015; Capligina et al., 2016; Kazarina et al., 2019, 2021a, 2021b; Pētersone-Gordina et al., 2020, 2022a,b). International collaborations were undertaken by Lithuanian and Latvian research groups, and skeletal data from these countries have been also included in the database of the Global History of Health Project.

In recent Estonian paleopathological research, specific case studies were dedicated to traumatic injuries (Malve, 2019a,b, 2020a), syphilis (Kalman, 2000c; Malve, 2011; and the biomolecular study by Majander et al., 2020), infectious disease (Malve, 2020b), oral pathologies (Limbo, 2004, 2011, 2013), and stress markers (Limbo, 2006, 2008a, 2008b, 2009; Allmäe & Limbo, 2010). The pathological analysis of most of the materials stored in the UT and used in this doctoral study have been published by **Martin Malve** and colleagues from the UT, mostly in the form of excavation bioarchaeological reports in the context of specific archaeological sites (Malve & Valk, 2008; Malve et al., 2011, 2012, 2019; Roog & Malve, 2012; Valk et al., 2011, 2019; Lõhmus et al., 2011; Laneman et al., 2015; Lissitsina et al., 2015; Malve, 2015, 2016, 2020a, 2020b). Several of these projects were the object of UT MA theses, starting from Martin Malve and his osteological study of the cemetery of Tartu Dome Church (2010). Anu Lillak studied Estonian square stone graves (tarand) including the osteological analysis (Kivirüüt, 2014), Liivi Varul investigated the stone graves of Jõelähtme (Varul, 2016), and Maris Niinesalu-Moon conducted the osteological analysis of commingled remains from 6th–9th-century Saaremaa (Niinesalu, 2020).

2.2.1. Bioarchaeology of children in the Eastern Baltics

Paper I is an extensive literature review of the bioarchaeology of children in the Baltic countries, which elucidated several aspects of past childhood research in Estonia, Latvia, and Lithuania. Numerous publications indirectly contributed to this research line, providing precious information about the youngest sections of Baltic prehistoric, medieval, and early modern communities in the context of wider population studies. However, we are still lacking a systematic study specifically focused on children in the region. This chapter will present the current state of the art according to the geographic area, following the structure of Paper I.

As a corollary to the analysis of human skeletal remains, the demographics and lifestyle of non-adult individuals in **Lithuania** were explored through the analysis of toys, footwear, and manufactured items (Sarcevičius et al., 1999; Blaževičius, 2019; Blaževičius & Jatautis, 2016). A number of paleodemographic studies reported a marked underrepresentation of children in Lithuanian burial sites, which was attributed to taphonomy, cultural traditions, low-quality or incomplete archaeological examinations, as well as birth rates and migration (Jatautis & Mitokaitė, 2013; Blaževičius & Jatautis, 2016; Jatautis, 2018). Among the bioarchaeological reports, several took into account the non-adult sections of the population within the general population studies (Jankauskas, 2002; Jankauskas et al., 2006; Kozakaitė et al., 2019; Brindzaitė, 2020), and isotopic analyses provided information about the non-adult diet at individual and population levels (Antanaitis-Jacobs et al., 2009; Piličiauskas et al., 2017a,b; Whitmore et al., 2019; Bliujienė et al., 2020; Skipitytė et al., 2020). Furthermore, numerous studies dedicated to nonspecific stress indicators shed light on the health and dietary status of Lithuanian children. Among these, several capillary analyses of linear enamel hypoplasia and cribra orbitalia in medieval and early modern populations allowed exploration of the relationships between stress markers and child survival (Barakauskas, 1997; Palubeckaitė & Jankauskas, 2000, 2001; Palubeckaitė et al., 2002, 2006; Jatautis et al., 2011). Non-adult health was also investigated through the analysis of infantile skeletal growth patterns and stature variations in children from medieval populations, comparing them to modern local populations and to other Baltic contexts (Šereikiene & Jankauskas, 2002, 2004).

Regarding specific case studies, paleopathological investigations were focused on endocranial meningeal reactions (Jankauskas & Schultz, 1995) and metabolic disorders (Jankauskas & Schultz, 1999). Of particular interest for the understanding of the treatment of children in early modern Lithuania is the case study reporting striking evidence of child abuse in Alytus (Kozakaitė et al., 2018b). In the context of the *Lithuanian Mummy Project,* the radiological study of one infantile case highlighted the presence of rickets (Panzer et al., 2015). In addition, the genome of an ancient strain of variola virus was sequenced and reconstructed from samples gathered from a Lithuanian child mummy, allowing the reconstruction of the recent history of smallpox (Duggan et al., 2016). It is therefore evident that recent Lithuanian bioarchaeological research has started to include child remains. As the Vilnius research group grows, further work specifically focused on non-adults will be conducted. In particular, the MSc thesis of Rūta Brindzaitė is specifically dedicated to children in medieval and early modern Lithuania, and further material on this topic will become available soon.

Although researchers in **Latvia** have recently shown increased interest in social archaeology, non-adult skeletal remains have not gained full attention yet (Vilka, 2014). However, some recent research papers have been focusing on prehistoric child burials, either exclusively (Vilka, 2012, 2013, 2015; Zariņa & Zariņa, 2012), or as part of socio-cultural studies (Radiņš, 1999; Bandare, 2002; Šnē, 2002). In particular, **Ajia Ērkšķe** (née Vilka) (2014) analyzed child burials from the Middle and Late Iron Age (5th–12th century AD), investigating their positions as members of the society playing an active role in the collective, ideological, and mythological life of their communities. Furthermore, she highlighted the importance of interdisciplinary studies combining archaeological, osteological, biomolecular, and ethnographic material to answer important questions about children in prehistoric and historic societies (Vilka, 2014). Ērkšķe also reported a general underrepresentation of children in numerous coeval cemeteries, a recurrent topic in Latvian archaeological sites. The same was noted by Gerhards (2002) and Zariņa (2009), and recently investigated more thoroughly by Ērkšķe (Ērkšķe, 2020). Here, the author presented an exhaustive discussion of the intrinsic, extrinsic and cultural factors leading to similar cemetery patterns and providing examples from Latvian Iron Age cemeteries.

Regarding the bioarchaeology of children in Latvia, several publications indirectly contributed to this line of research. Variations in the stature of different segments of the Latvian population were addressed, also including growth variations in children (Gerhards, 2005, 2006). Numerous aspects of child demography may be indirectly inferred from the results of the bioarchaeological investigation of specific burial areas (Gerhards, 2000; Zariņa, 2006; Rudoviča et al., 2011; Gerhards et al., 2017). Recent publications have specifically addressed the health status of medieval and early modern Latvian populations and discussed the effects of particularly difficult historical periods on Livonian children. Among these, Zariņa et al. (2016) combined the paleopathological investigation of cribra orbitalia with stable isotope analysis and trace element concentrations in children from an early modern cemetery in Jekabpils, to explore physiological and nutritional stresses experienced during childhood. The work of Pētersone-Gordina and colleagues was dedicated to the integration of paleopathological data regarding stress indicators in teeth and bones with isotopic data for dietary reconstruction and migration studies (Pētersone-Gordina, 2018; Pētersone-Gordina & Gerhards, 2011; Pētersone-Gordina et al., 2013, 2018, 2020, 2022a,b).

Bioarchaeology in **Estonia** also lacks a specific research focus on children, and the youngest members of society have been mostly considered part of standard archaeological and bioarchaeological investigations. Children in medieval and early modern communities have been investigated by historians focusing on birth, family ties, scholarization, gender roles, and disease (Veispak, 1986; Põltsam-Jürjo, 2003, 2017, 2018; Mänd et al., 2012; Kröönström & Põltsam-Jürjo, 2019). From a bioarchaeological perspective, information about non-adults can be mainly extrapolated from excavation reports of specific sites (Kalling, 1995, 1997; Allmäe, 1998, 2003, 2010; Kalman, 1999; Heapost, 2007). In particular, fieldwork reports by Malve and colleagues from the UT always provide a paleodemographic and paleopathological analysis of the whole population, including children (see Chapter 2.2.). Additional examples are the papers dedicated to stone-cist graves in Kaseküla (Western Estonia) and Rebala (Northern Estonia), in which AMS dating of human remains revealed the use of these burials for infant remains in the Late Bronze Age, Pre-Roman Iron Age, and Late Iron Age (Laneman, 2012, 2021). Information concerning the health and lifestyle of Estonian children may also be gained from the numerous capillary analyses of stress markers (mainly enamel hypoplasia) performed on Estonian populations in the early 2000s (Limbo, 2006, 2008a,b, 2009; Allmäe & Limbo, 2010). More recently, the MA thesis of student Mari-Anne Liblik focused on dental pathology in the population of St Jacob's cemetery in Tartu, including child oral disease (Liblik, 2017).

Most of the publications covered basic anthropological matters such as craniometric characteristics of children and juveniles (Allmäe, 1995), stature estimation (Allmäe, 1997), and anthropological features of modern children (Heapost, 2017; Õun et al., 2019). Of particular interest is the case study reported by Allmäe (2006) regarding a 10^{th}–13^{th} century single-family burial site from Maidla, which discusses the reasons for the underrepresentation of children in this and in other coeval cemeteries, providing a thorough discussion of the factors affecting fertility in ancient populations (Allmäe, 2006). A striking paleopathological case study focusing on two children from the Tartu dome church was reported by Malve (2011), confirming the presence of congenital syphilis in medieval Tartu. Finally, a recent paper by Oras and colleagues from different research groups was dedicated to the multidisciplinary analysis of two Egyptian child mummies displayed at the University of Tartu art museum (Oras et al., 2020).

The first publication specifically focused on the paleopathology of children in the perinatal age categories in Estonian bioarchaeology is included in this dissertation (Paper IV), constituting the starting point for the development of child bioarchaeology in this country. The interest in the topic is currently growing in the UT research group, as new researchers enter the field and follow the trend. The most recent example is the MA thesis of Linda Vilumets on North-Estonian non-adult individuals (2022).

2.3. Stable isotope analysis for dietary reconstruction in the Eastern Baltics

In recent years, a number of studies have used carbon and nitrogen stable isotope data to reveal dietary habits and socio-cultural expressions of diet in Eastern European populations. The Stone Age has been the most thoroughly studied period in the Baltic area, and is the topic of the majority of published materials. The medieval and early modern periods were more recently investigated. The next two chapters will follow a geographical framework, as above.

In **Lithuania**, isotopic data was used to investigate dietary patterns in Neolithic and Bronze Age (Antanaitis-Jacobs & Ogrinc, 2000; Antanaitis-Jacobs et al., 2009; Piličiauskas et al., 2017a,b, 2020), Late Roman (Bliujienė et al., 2020), medieval, and early modern material (Page, 2014; Schotten, 2015; Whitmore et al., 2018; Skipitytė et al., 2020). In particular, Holder et al. (2017) reconstructed the dietary profile of Napoleon Bonaparte's Grand Army, who took part in the Russian Campaign of 1812 in Vilnius. Furthermore, several studies were focused on Polish material from the medieval Polish-Lithuanian Commonwealth (Reitsema, 2013; Reitsema et al., 2010).

In **Latvia**, stable isotope analysis (SIA) for dietary reconstruction is linked to the work of Stockholm University researchers **Gunilla Eriksson** and **Kerstin Lidèn**, which was mainly focused on Stone Age material (Eriksson, 2003, 2006; Eriksson & Zagorska, 2003; Eriksson et al., 2003; Eriksson & Lidén, 2013). Stable isotope data (including radiocarbon dating) from Latvian material was also studied in a cooperation between local researchers and scholars from the Center for Baltic and Scandinavian Archaeology, to gain insights into Stone Age subsistence strategies (Lübke et al., 2016; Meadows et al., 2016, 2018; Brinker et al., 2020). The first dietary stable isotope data from the Iron Age in Latvia has been published in Pētersone-Gordina et al. (2022a); this paper reported significant differences in childhood diet between male and female individuals, indicating that gender might have been a key factor for dietary differences in children (Pētersone-Gordina et al. 2022a). Further isotopic studies have been performed on prehistoric, medieval and early modern material including children, and will be discussed in the next paragraph.

With regard to **Estonia**, one of the first interdisciplinary works using stable isotope data is the paper by Lõugas et al. (1996), dedicated to resource utilization along the Estonian coast during the Stone Age. Estonian research using SIA on human bone recently resulted in multidisciplinary studies such as that of **Mari Tõrv** (2018) who dedicated her doctoral dissertation to the combination of archaeothanatology and SIA in the study of the mortuary practices of hunter-gatherers in Estonia. Further studies include isotopic dietary reconstructions of early modern and early Bronze Age material (Malve & Aguraiuja, 2014; Tõrv & Meadows, 2015), multiproxy studies also including SIA (Oras et al., 2018), and mobility studies using strontium, carbon, and oxygen stable isotopes (Price et al., 2016, 2020; Oras et al., 2016). One important publication focused on medieval remains has been Lightfoot et al. (2016), a case study investigating ethnicity and social status through isotopic dietary reconstruction, in which data from various burial locations in the area of Tallinn were compared. The most recent publication in the field is the paper by Aguraiuja-Lätti and Lõugas, focused on the dietary reconstruction of medieval and early modern Estonian populations from the cemeteries of St Barbara (Tallinn) and Kaberla (North-Estonia), with an emphasis on differences between urban and rural human communities (Aguraiuja-Lätti & Lõugas, 2019). Although it was not specifically focused on Estonian material, it is worth mentioning the academic work of **Ülle Aguraiuja-Lätti**, who performed SIA on Bronze Age material at the Universities of Tartu and Edinburgh (Aguraiuja, 2011, 2017), and is currently working on material from Tallinn and Northern Estonia.

2.3.1. Stable Isotope Analysis of children in the Eastern Baltics

To date, no specific biomolecular study has been dedicated to children in the Eastern Baltics. However, in **Lithuania** child feeding was covered in wider dietary studies of late Roman (Bliujienė et al., 2020), and medieval/early modern human groups (Whitmore et al., 2018; Skipitytė et al., 2020). There are also some general isotopic studies for dietary reconstruction that have revealed weaning patterns for Swedish and Latvian prehistoric populations (Eriksson, 2004; Eriksson & Lidén, 2013; Eriksson et al., 2003; Lidén et al., 2012; Howcroft, 2013; Howcroft et al., 2012a, 2012b, 2014).

In Latvia, studies integrating paleopathology and SIA have been limited to some interesting case studies. In particular, Zariņa et al. (2016) combined stable isotope analysis with the study of cribra orbitalia in children. The study reported significantly lower $\delta^{15}N$ values in individuals with cribra orbitalia compared to those unaffected, suggesting greater consumption of lower trophic level foods. The authors concluded that the prevalence of the disease may have been related to dietary deficiencies in this population (Zariņa et al. 2016). **Elina Pētersone-Gordina** at Durham University performed the abovementioned ground-breaking research integrating paleopathological and isotopic data in the investigation of nutritional and physiological stress (Pētersone-Gordina, 2018; Pētersone-Gordina et al., 2020, 2018). The latest paper by this author also applied strontium isotopes to investigate possible adult and child migrants in the cemetery of St Gertrude in Riga (Pētersone-Gordina et al., 2022b). The most recent contribution to non-adult SIA in Latvia is the study by Henderson et al. (2022), in which stable carbon and nitrogen isotope analyses of sequential samples of dentine were used to explore differences in diet relating to weaning age, social roles and food sharing between children and adults in a Mesolithic/Neolithic population from the cemetery of Zvejnieki (Northern Latvia). The study reported a difference in $\delta^{15}N$ between adults buried with and without pendants, highlighting a certain variability in social status or food procurement roles within the group. More importantly, the authors argued that infants were “exclusively” breastfeed until ca. 6–12 months of age (Henderson et al., 2022).

Investigations focusing specifically on non-adult diet and combining dietary studies with health and pathology are currently missing in **Estonia**. The first article specifically dedicated to non-adult diet and feeding practices in medieval and early modern Estonia is Paper V, which also reveals the duration of breastfeeding and age of weaning in medieval and early modern Estonia for the first time.

3. METHODOLOGICAL FRAMEWORK

3.1. Why are we researching children?

In the last decade, increasing interest was shown towards the archaeology of childhood, including the scientific study of their skeletal remains. The bones of non-adults represent an endless source of information regarding their personal life, social interactions, dietary habits and caregiving, and are impacted by economic and social factors that may have exposed them to disease or traumatic experiences. There are several differences (and advantages) in the study of non-adult skeletal remains compared to adult individuals, and these will be summarized below.

First, **age estimation** is more accurate for immature remains, since the skeletal changes occurring in a rapidly growing body are numerous, easily detectable, and can be associated with narrower age ranges (Lewis, 2007; Scheuer & Black, 2000). The refinement of universal methodologies and the development of more accurate techniques for age estimation in children is an enduring research topic in bioarchaeology, because narrower age ranges allow for more accurate population reconstructions and for a deeper understanding of the position of children in the community (Halcrow & Tayles, 2008). This is particularly true for historical societies where available written sources provide information regarding birth, childcare, legal issues, and marital age. Each of these aspects could be understood more thoroughly through a more precise age estimation, which would enable linking a sound biological age to the social age of the time. Together with the evaluation of the funerary customs, this may lead to more nuanced interpretations of the archaeological context.

The study of child remains is also highly informative from a paleopathological point of view. In particular, the study of **stress indicators** (*i.e.* cribra orbitalia, growth disruptions, Harris lines, and enamel developmental defects) offers interesting opportunities to assess their physiological disruptions in growth (Halcrow & Tayles, 2008). Stress indicators generally develop during childhood, and bone lesions tend to remodel and disappear with age. Hence, the true prevalence of similar lesions can be more accurately assessed in non-adults (Lewis, 2007, 2017). The same can be stated for metabolic disorders such as scurvy or rickets, since the physiology of the immature bone causes a more severe reaction in response to nutrient deficiencies (Lewis, 2017). The comparison of pathological data gathered from adults (the population survivors) and children (the non-survivors) may therefore clearly highlight the occurrence of differential treatments, diets, or health conditions in different age groups, among cemetery samples and different populations.

Immature remains also retain essential information about their communities from the dietary perspective. The **stable isotope analysis** of non-adult bone collagen is not only informative about their staple diet, but also about breastfeeding and weaning strategies (Fuller et al., 2006; Dupras & Tocheri, 2007; Howcroft et al., 2012b; Waters-Riszt et al., 2022). This provides insights into the choices and traditions of their caregivers, also in the contexts of family planning and organization of everyday life (Herring et al., 1998; Kendall, 2016).

As a final consideration, the social aspects of the **bioarchaeology of care** and treatment of minorities have recently gained particular attention, especially in the light of gender archaeology and studies of pregnancy/labor (Tilley & Schrenk, 2017; Halcrow et al., 2020). The analysis of the role of children in archaeological contexts allows exploring traditions and cultural tendencies modeling their care (Muller, 2017; Oxenham & Willis, 2017; Niere et al., 2020; Bohling et al., 2022), marginalization (Hansson et al., 2019; Martin et al., 2020; Svensson et al., 2020), gender roles/rank (Lidén et al., 1997; Lidén & Götherström, 1999), and abuse (Kozakaitė et al., 2018), finally reaching topics such as children's burials and funerary treatments (Ludlow & Hackett, 2019). In a similar way, their remains often enter the forensic record as unfortunate results of abuse, war, negligence, but also homicide or suicide (Lewis, 2007, 2017; Love et al., 2011).

It therefore becomes clear that previous studies and ongoing research highlighted the importance of childhood bioarchaeology for revealing aspects of non-adult everyday life and health, also shedding further light on numerous social aspects of past societies such as feeding customs and marginalization. Several of these aspects would remain invisible without a holistic bioarchaeological approach to non-adult remains. Ignoring this abundant and fragile dataset would result in the loss of crucial understanding of past populations; for this reason, this topic is currently gaining attention in the field.

3.2. Terminological issues

One of the most complex problems in the study of non-adult remains, especially when planning a comparison between different archaeological contexts, is the unstandardized use of terminology used in identifying children, especially with regard to their age (Lewis, 2007; Halcrow & Tayles, 2008). A typical example is the term *infant*, which correctly indicates individuals under one year of age, but is frequently used to define children up to five years of age (Lewis, 2007, p. 1; Halcrow & Ward, 2020). Another example is the term *subadult* (any individual under 17 years of age), which is considered problematic since it subtly implies that immature individuals are somehow inferior in respect to adults (Lewis, 2007, p. 2; Sofaer, 2006, p. 121). Hence, many researchers prefer using the term *non-adult*[1], which is also the word used in this thesis.

Terminology-related problems become even more apparent when considering the variable age categories used in population studies, since comparing different demographic profiles using different categories for different populations is a

[1] In fact, even this term was subjected to critique, implying that the individual is somewhat different from the norm (different from adult) (Halcrow & Tayles, 2008). However, here it is used in a biological sense, with no hierarchical implication between older and younger individuals.

highly complicated task. In addition, in most cases the *biological* age estimated from skeletal features matches neither the *chronological* age (the years since birth), nor the *social* age, which is the combination of behavioral and social norms linked to a certain age according to the cultural traditions of the population (Gowland, 2006; Sofaer, 2006; Lewis, 2007, p. 2; Halcrow & Tayles, 2008). This can be due to errors in selecting the correct methods for age estimation, to pathological conditions resulting in age underestimation, or simply to cultural bias. Our current idea of a child does not necessarily match how a child was perceived in the past, or even in different geographical areas (see reviews by Kamp, 2001; Perry, 2007; Rebay-Salisbury & Pany-Kucera, 2020).

The problem of a correct age category definition is of crucial importance for historical and paleodemographic studies. For instance, transferring an individual from a social category to another may completely transform the demographic profile of a population and alter the historical-archaeological interpretation (Kamp, 2001; Lewis, 2007; Perry, 2007). A common mistake is using and comparing age categories without any reference to the society of origin, adopting an excessively modernist perspective. A 14-year-old Estonian girl today has a completely different social perception compared to a girl of the same age in the medieval period (who most likely had been working for years) or simply in another area of the world, even though we are considering the same biological development. A possible way to overcome this issue is by adopting a highly multidisciplinary approach, associating clearly defined and globally accepted age categories with the information retrieved from archaeological contexts, funerary archaeology, and historical sources. An example of the fundamental contribution of the archaeological context in the interpretation of child age categories can be found in the study by Kalaitzi (2010). The paper reports the historical and iconographic analysis of child representations on tombstones of Classic and Hellenistic periods in Macedonia. The iconographic study has been crucial for the reconstruction of the social identity of the child and provided a reasonable starting point for the setting of non-adult age classes for future use, including anthropological studies (Kalaitzi, 2010). Another example is the archaeological study by Berseneva (2006) concerning the non-adult burials of Iron Age Sargat cultural groups in the Trans-Urals and Western Siberia. In this work, symbolic markers of age in child burials were recorded, attempting to determine a social framework for children in the Sargat society (Berseneva, 2006). The integration of the biological age categories estimated through anthropological methods with similar social/symbolic age markers greatly benefits the bioarchaeological analysis.

In the frequent cases in which the material lacks archaeological context or grave goods, the only way to minimize this uncertainty is to use globally accepted categories in the absence of more precise age estimation techniques, at least producing comparable results. The information regarding non-adult social age retrievable from burials and historical sources related to the materials of this study is quite scarce. Hence, to obtain comparable results, in this thesis the age categories proposed by Lewis in the globally used volume *The bioarchaeology of children* (2007) are adopted (see Chapter 5).

3.3. Missing children: non-adult underrepresentation in archaeological contexts

One of the most common stereotypes in bioarchaeology is that non-adult remains "dissolve", or "disappear" from cemetery contexts. The belief that child remains are always too few to be statistically significant for proper research has often led to their systematic neglect from general population studies. Although effective limitations to their preservation do exist, it has been confirmed that infantile remains survive very well in burial conditions ideal for the preservation of adult skeletons and can therefore be retrieved in sufficient number to allow investigation of their mortality and morbidity (Buckberry, 2000; Lewis, 2007; Manifold, 2012, 2015).

However, it is undeniable that in numerous archaeological contexts a clear underrepresentation of children is observed (Buckberry, 2000; Pinhasi & Bourbou, 2008; Manifold, 2012, 2015), and this has been commonly reported in the Baltic area as well (Heapost, 1993; Roog & Malve, 2012; Blaževičius & Jatautis, 2016; Ērkšķe, 2020). So…where have all the children gone? The intrinsic, extrinsic, and cultural factors affecting the availability and preservation of immature remains will be explored below.

3.3.1. Intrinsic factors

Intrinsic factors are related to different biological aspects of the structure of the human bone and to the physiological processes occurring in the body, which can affect the taphonomic processes. They are therefore linked to the chemico-physical features of the bone tissue, such as composition, dimension, shape, density, and porosity (Gordon & Buikstra, 1981; White & Hannus, 1983; Child, 1995, Guy et al., 1997; Bello & Andrews, 2006).

The overall structure of the immature skeleton is quite different with respect to an adult individual. The number and morphology of the bones are variable according to the growth stage, starting from a minimum of 156 at birth, to ca. 332 bones around the age of six when epiphyseal centers form, to the general 206 bones of the adult skeleton (Lewis, 2018; Scheuer & Black, 2000). The majority of the skeletal elements at birth show complex morphologies, sometimes quite different compared to their adult counterparts. Therefore, they can be easily overlooked or mistaken for pebbles or animal bones, especially if broken or taphonomically altered. The lack of experience and understanding of fetal and infant anatomy, and the few specialists specifically investigating these population groups, have resulted in a systematic neglect of these age groups in bioarchaeological studies (Hodson, 2021).

One of the main intrinsic factors is the age of the individual, since non-adult bones are not only smaller, thus more easily scattered over long distances by flora and fauna, but also less dense and more rich in organic components compared to adult remains (Guy et al., 1997). This can facilitate their decomposition, especially in acidic or very alkaline soils (Gordon & Buikstra, 1981; Walker et al., 1988). The mineral composition of immature bones is also age-dependent, with the lowest levels observable shortly after birth, and a stable increase in mineral content from the second year of life. It is therefore expected that the retrieval and preservation of child remains in different excavation contexts would vary according to age classes and burial environment (Lewis, 2007).

The differential preservation of immature bones also depends on the skeletal element. The most vulnerable bones are those showing a larger percentage of spongy tissue (i.e. sternum, vertebral bodies, ribs, long bone epiphyses), as well as the bones of hands and feet. On the other hand, the elements richer in cortical bone (i.e. neurocranium, mandible, long bone diaphyses), are more likely to survive taphonomic processes (Waldron, 1987; Pinhasi & Bourbou, 2008; Manifold, 2012). The differential preservation of some skeletal areas in respect to others is also influenced by the way they are deposited in the grave, which heavily depends on cultural traditions (Roberts & Connell, 2004).

The porosity and mineral density of human bone are further factors playing a major role in the skeletal degradation. Possible alterations of these characteristics due to pathological conditions (i.e. osteoporosis, metabolic disease, or traumas) may lead to increased fragility of the skeletal elements, resulting in a premature dissolution of the material (Ortner, 2003; Turner-Walker, 2008; Pinhasi & Bourbou, 2008).

3.3.2. Extrinsic factors

Numerous characteristics of the physical environment involved in diagenetic processes can be listed as extrinsic factors: chemical composition of the underground and rain waters, pH and texture of the soil, oxygen levels in the area, flora, and fauna (Manifold, 2015).

In addition to the chemico-physical action of plants and animals, which are driven towards decomposing human remains and able to scatter them over large distances, the multiple effects of anthropic activities should be considered. Agricultural and construction works, as well as environmental pollution, are all potentially damaging factors able to cause extensive destruction (Turner-Walker, 2008; Manifold, 2012). It is clear how immature bones are even more at risk of being scattered over large distances or broken, given that they are smaller, more numerous, and lighter than adult elements.

In the specific context of archeological investigation, bone material can be lost during each step of the excavation process. This can start as soon as during the preliminary identification, in which child remains (often buried in shallow graves) are often destroyed by surface scraping or using mechanical excavators. Further damage may occur during the archaeological excavation, influenced by weather issues, site structure, and the lack of time and resources typical of rescue excavations. The experience of the archaeologist becomes particularly crucial when dealing with non-adult remains, since more care and attention are needed to retrieve and recover each tiny skeletal element of an immature skeleton (Duday, 2005; Lewis, 2007). The treatment of the remains during recovery and storage are just the last steps of a long process of potential degradation and fragmentation of the skeletal remains (Lewis, 2007).

A positive example of the importance of proper treatment of non-adult remains is the osteological material I had the opportunity to study in this doctoral thesis. The presence on-site of several archaeologists with long-term experience in osteology permitted recovery of complete immature skeletons, including tiny tooth crowns and ossification centers, even in the case of fetuses and perinates. The correct storage practices in the UT Department of Archaeology labs contributed to the proper preservation of the remains, which were highly suitable for paleopathological and biomolecular analyses.

3.3.3. Cultural factors

The cultural factors implied in the preservation of children in archaeological sites depend on the attitudes of different societies towards premature death, including their traditions and funerary customs (Lewis, 2007; Ērkšķe, 2020). In most cases, immature remains do not disappear from the archaeological record because they "dissolve" in the ground, but simply because they were buried elsewhere or treated differently.

Several examples reporting the choice of particular locations for infant burials (within the same cemetery or considerably far from it) are retrievable from the archaeological literature, starting with the case study from medieval Tartu presented in Paper IV of this dissertation. Here, fetuses and perinates were found in four mass graves and two double burials located outside St Jacob's cemetery walls, separated from the rest of the community. Similar scenarios can be found in medieval and early modern cemeteries all over Europe (Crawford, 1993, 2007; Murphy, 2011; Simone Zopfi et al., 2011; Millet & Gowland, 2015; Hausmair, 2017; Craig-Atkins et al., 2018).

Other examples are the numerous "children's corners" observable in British cemeteries, usually located in the Western sections of the churchyards (Crawford, 1993, 2007; Stroud & Kemp 1993). Excavations conducted in early medieval English and Scottish churchyards have shown a common tendency towards burying infants and babies along the Eastern walls of the church, under the eavesdrops. The rainwater dropping from the holy building was thought to indirectly baptize the little ones, generally victims of abortion or stillbirth (Crawford, 1993, 2007; Craig-Atkins et al., 2018; Hausmair, 2017). The clustering of children in specific areas due to practical or ritual reasons may result in interesting paleodemographic interpretations, but only when they are found and highlighted. Since most of the times we are dealing with rescue excavations, often cemeteries are not entirely unearthed. If the excavated area does not include the "children's corner", these individuals will never enter the population demographic profile (Lewis, 2007).

Another essential factor affecting the scarce representation of children is the burial depth. Very often non-adult burial pits are much shallower compared to adult graves, simply due to the practicality of digging a smaller tomb at lower depths (Crawford, 1993). The study by Bello et al. (2006) on the cemetery of Estève-Le-Pont (southern France) reported that infantile burials were between 0.1 and 0.3 m deep, while adult cuts reached even 1.4 m in depth, identifying a remarkable pattern in the funerary organization of the area (Bello et al., 2006). Similar patterns were reported for several other archaeological contexts (Ingvarsson-Sundström, 2003; Manifold, 2012). The shallow burial depth automatically increases the vulnerability of the little bodies to animal action and vegetal conditions, various environmental impacts, and especially superficial excavation through mechanical excavators or archaeological work (Lucy, 1994; Ingvarsson-Sundström, 2003; Bello et al., 2006; Manifold, 2012).

Even more numerous are the archaeological contexts in which children are intentionally buried far from the main cemetery. The remains of infants and perinates have been frequently found in domestic areas and under the house floors from the Neolithic to the Graeco-Roman periods (Scott, 1999; Ingvarsson-Sundström, 2003; Kostanti, 2017). It was common practice during the Roman Era to bury babies under 40 days of life within villages or settlements, since they were not yet considered as human beings, and were therefore allowed to be buried outside the necropoles (Scott, 1999). The same was observed in ancient Greek contexts, leading to the hypothesis that neonates were recognized as members of the community only after a certain time after birth, perhaps reflecting a defense mechanism against high infantile mortality (Fox, 2012). The choice to bury fetuses and neonates within ceramic containers such as *amphorae, enchytrismòs,* or tiles, usually located outside the community necropoles, was common practice in the Mediterranean region from the Graeco-Roman to the early modern periods (Gaio, 2004; Themos & Zavvou, 2010; Nizzo, 2011; Simone Zopfi et al., 2011; Licata et al., 2018; Fedeli et al., 2019, Morrone et al., 2021). Burials of babies and infants in ceramic vessels were rarely reported for Eastern Europe, and often reported as "deviant". Sporadic examples can be seen in Early Bronze Age Bulgarian Thracia (McSweeney & Bacvarov, 2017), and medieval Poland (Gardeła & Duma, 2013; Kowalski et al., 2021).

Special attitudes towards the burial of neonates and infants were observed also in more recent contexts, strictly intertwined with Christian baptism (Hausmair, 2017). In medieval and early modern Europe, baptism had to be performed soon after birth to achieve soul salvation, and death before this event resulted in the exclusion of the newborn from proper burial in consecrated ground, a common scenario in medieval Welsh (Lally & Moore, 2011), French (Perez, 2015), and Polish (Gardeła & Duma, 2013) cemeteries. This practice was observed for the whole medieval period and even until the 19th century, as testified by the renowned Irish *cillíni*: isolated mounds in which unbaptized babies, but also marginalized individuals such as prostitutes, suicides, lepers, and syphilitics were buried (Finlay, 2000; McKerr et al., 2009; Murphy, 2011). In Estonia, an interesting example is represented by the clustering of infant burials in reused prehistoric stone graves from the Bronze and Early Iron Age (Laneman et al., 2021). This was observed for children dated between 400 and 650 AD in the Jaani stone graves at Väo (northern Estonia), as well as for infants from the 8^{th}–11^{th} and the 15^{th} centuries AD in Kaseküla and Rebala II stone-cist graves (Laneman, 2012; Laneman et al, 2021). The authors suggested that this particular age group was probably excluded from a common burial ground, ending up in a thousand-year-old or even older stone grave (Laneman, 2021). The first published Estonian example regarding babies buried outside a medieval urban cemetery is described in Paper IV of this thesis.

A last mention goes to the information loss caused by the curation of skeletal material. It was common practice in the past to collect only specific skeletal elements (i.e. the skull) instead of the whole skeleton; hence, immature skeletons were often not entirely preserved in museum collections, and were frequently relocated in the commingled remains (Buckberry, 2005; Lewis, 2007). This was also reported in Scandinavia (Sellevold, 1997), and in the Baltic area before the development of physical anthropology (Jankauskas & Gerhards, 2012; Chapter 2).

3.4. Child paleopathology

Understanding the paleopathological framework of non-adults is crucial for the reconstruction of numerous aspects of past populations. These aspects span from the health of mothers in case of babies and infants, to differences in dietary treatments according to age classes. There are substantial differences in the study of pediatric disease compared to adult individuals. The physiology of growing bones results in differences in consistency, mechanical resistance, turnover rates, and porosity compared to those of an adult (Lewis, 2018). Consequently, the effects of particular pathological processes will be displayed differently in immature bones, creating skeletal changes that in some instances are subtle and difficult to detect (Paper III), and in others require the identification of specific patterns to reach a reliable diagnosis (Paper IV). The ability to distinguish similar differences requires the osteologist to have a thorough specialization in the anatomy and pathological reactions of immature skeletal remains.

A typical example is represented by **metabolic diseases**. These are disorders associated with the processes through which the body extracts nutrients from the diet, and often are the results of malnutrition, deficiencies in the absorption/ production of specific nutrients, or secondary effects of congenital and chronic diseases (Ortner, 2003; Lewis, 2018). Scurvy, rickets, and anemias are among the most commonly studied metabolic diseases in ancient populations, as they are sensitive indicators of their stress levels and cultural choices. Due to the physiology of growing bones, the bone changes attributable to metabolic diseases are usually more evident in children compared to adults. For instance, childhood rickets (vitamin D deficiency) affects immature bones very rapidly because large quantities of new bone are quickly deposited, resulting in widespread lesions and severe bone deformation in children. These effects are quite different from the subtle changes of osteomalacia in mature bone, where slower turnover rates result in very long formation times (Mays et al., 2006; Mays & Brickley, 2018; Veselka et al., 2015). Similarly, the pathological pattern associated with scurvy (vitamin C deficiency) often appears more widespread in children compared to adults; since the periosteal membrane in growing bones is much less attached to the underlying cortical bone, the frequent and painful hemorrhages caused by scurvy affect much wider body areas in children. Consequently this results in wider skeletal regions showing reactive pathological lesions (Ortner, 2003; Ortner et al., 2001; Snoddy et al., 2016, 2017, 2018). All of these widely studied metabolic diseases, including their co-occurrences, have been addressed and thoroughly described in Paper IV.

The development of skeletal lesions attributable to anemic states is also enhanced in childhood. Stress indicators such as *cribra orbitalia* and porotic hyperostosis are observable as evident cribrosities on the orbits and ectocranial surfaces. These lesions are thought to be formed in response to an excessive production of bone marrow in the skull diploë to compensate for the deficiency in red blood cells typical of carential, hemolytic, or congenital anemias (Stuart-Macadam, 1991; Ortner, 2003; Lewis, 2018; Lewis & Roberts, 1997; Walker et al., 2009). Similar lesions form more easily in immature skulls since their neuro-cranial bones are rich in hematopoietic bone marrow, but are much less likely to occur in anemic adults, who normally have much more cranial space to fill with new pathological marrow (Stuart-Macadam, 1991; Walker et al., 2009). For this reason, finding cribrous lesions in adult individuals is always indicative of child-hood stress, offering a valuable example of "survivors" in a cemetery population.

The analysis of immature remains allows a detailed examination of **non-specific stress markers** such as developmental enamel defects (enamel hypo-plasia), growth disruptions (Harris lines), and *cribra orbitalia* at an age closer to their development, within narrow age categories (Lewis, 2000, 2018). The combi-ned study of similar lesions greatly contributes to the reconstruction of past popu-lation health and disease, starting from the youngest sections of the community. The study of non-adults (the non-survivors) allows valid comparisons with those adults who did survive childhood, permanently recording the signs of stress in bones and teeth.

Conversely, high turnover rates in children result in more rapid remodeling of the diseased elements, hindering the detection of pathology and trauma even after short periods of time. An example is the appearance of **traumatic injuries** in children. The high plasticity of immature bones means that they are less prone to complete fracture, but instead often undergo partial breaks ("greenstick fractures"), buckling, or bowing deformities that are difficult to identify in dry bone (Lewis, 2000, 2007, 2018).

Periosteal reactions are also quite problematic in child remains, even though they are among the most common lesions detectable in bioarchaeology. The dis-tinction between subperiosteal bone production (SBP) of pathological origin and physiological new bone formation resulting from rapid growth is a major limi-tation in bioarchaeology. This issue occurs especially when dealing with fetal and perinatal individuals (Hodson, 2021; Lewis, 2018). The available macroscopic methods for assessing pathological lesions are currently inadequate or imprecise. Therefore, interpreting evidence of pathological changes in fetal–infant individuals becomes both subjective and variable, with little standardization and hindered comparability between studies (Hodson, 2021).

Finally, a more recent and unexplored research topic is represented by **endocranial lesions**. Their appearance, which was described also in Paper IV of this thesis, varies between flat and smooth bone neoformation, and much more severe lesions showing deep vascular impressions (Lewis, 2004, 2007, 2018). Their etiology is still quite uncertain, and their presence was connected to numerous pathologies (*i.e.* traumas, tumors, specific and nonspecific meningitis, congenital syphilis, metabolic diseases such as scurvy, infectious diseases, congenital diseases), making them a valid example of nonspecific stress indicators (Lewis, 2004, 2007, 2018).

3.4.1. Theoretical issues in reconstructing past living conditions: the Osteological Paradox

The paleopathological investigation is carried out via differential diagnosis (Glossary), and the problems in performing this process correctly depend on the very nature of bone tissue. Bone response to physiological stress is relatively nonspecific, since the skeletal tissue reacts in a limited number of ways: differences in shape, abnormal bone production, and abnormal bone loss, usually, but not always, as a result of bone destruction (Ortner, 2011). Hence, different disorders may result in very similar skeletal lesions. An example in children are the periosteal reactions mentioned above and discussed in Paper IV. Conversely, not all pathologies leave a trace on the skeleton, and not all individuals who have been ill will show signs on their skeleton (Ortner, 2011).

With these premises, we are inevitably driven to one of the main theoretical issues encountered by the paleopathologist, known as the Osteological Paradox. The term derives from a fundamental publication by Wood et al. (1992), which triggered a debate that is still vigorous after thirty years (and quite far from being solved) (see the critiques at the end of the original paper, and Wright & Yoder, 2003; Siek, 2013; DeWitte & Stojanowski, 2015; Milner & Boldsen, 2017; Buikstra et al., 2022). The underlying principle is the fact that a cemetery sample will never be representative of the living population in a particular historical period. As a consequence, multiple paleoepidemiological models could be equally plausible in the reconstruction of the pathological profile of a population. This greatly hinders our ability to produce inferences about the health conditions of past populations starting from the frequencies of particular skeletal lesions, resulting in biased interpretations. Wood et al. (1992) list three essential problems affecting the historical reconstruction (Fig. 2): **(1)** *Hidden heterogeneity in frailty*, meaning that each individual is unique in his/her susceptibility to stress and disease, consequently varying the risk of death. This means that not all individuals experiencing the same risk of exposure will show signs of a disease, and those who do could display different degrees of severity in their lesions (Wright & Yoder, 2003; DeWitte & Stojanowski, 2015). **(2)** *Selective mortality*. Cemetery samples are already a biased sample of the original population because they represent the dead! The deceased reflect the highest risk of death for each age category, and therefore the prevalence of their lesions will never be representative of the living conditions of the population at any given time (DeWitte & Stojanowski, 2015; Wood et al., 1992; Wright & Yoder, 2003). A combined example of these two concepts may be the random skeleton with no pathological lesions typically found in the field: this may have been a "healthy" person (perhaps victim of an accident or soft tissue trauma), but at the same time one of the frailest individuals in the whole population, who died before displaying any signs of disease. **(3)** *Demographic nonstationarity*. Cemetery samples often come from populations that experienced migration or temporal variations in fertility and mortality. If the population is not stationary (of constant size, and with age groups equally distributed), the age categories of the sample will not reflect the real mortality rates of the community, but would rather be more sensitive to extrinsic changes and be more affected by fertility patterns (Wright & Yoder, 2003; DeWitte & Stojanowski, 2015; Milner & Boldsen, 2017).

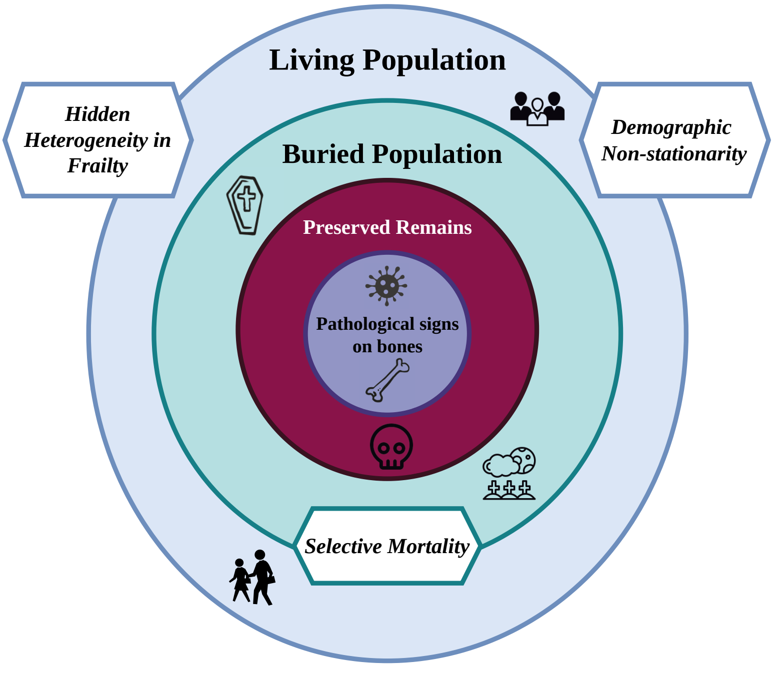


Figure 2. Graphic scheme showing the amount of information obtainable from human skeletal remains with regard to paleopathological reconstructions, and its relationship to the constituents of the Osteological Paradox. Hidden heterogeneity in frailty and demographic non-stationarity affect the living population experiencing disease, while selective mortality creates bias mostly in the buried population. Graphic scheme by Alessandra Morrone.

And so, how to deal with the Osteological Paradox? Already in the original paper, Wood and colleagues (1992) strongly suggest expanding the existing research on heterogeneity in frailty, risk of death, and the effects of disease on human physiology. But most importantly, they suggested a strictly multidisciplinary approach in research, applying numerous archaeological sciences and paying great attention to the historical and cultural contexts of the material. The combination of humanities and natural sciences leads to multiple alternative interpretations of the osteological data, increasing the probability of obtaining plausible inferences (Wright & Yoder, 2003; Milner & Boldsen, 2017).

The Osteological Paradox is a topic that provides food for thought also from the philosophical point of view. In Paper II of this dissertation, a thorough discussion regarding its implications was provided from the Philosophy of Science perspective. Philosophy of Science deals with the nature of scientific knowledge, its purposes, and its characteristics. Questions regarding the nature of science, whether science provides true information about the world, and whether it is possible to believe in scientific theories when these are based on unobservables, are covered by this field of philosophy. Similar questions are crucial in the recent debate between **scientific realism** and **antirealism**: the former side claims that what is described by our scientific theories is truthfully (or approximately) known. In this view, realism considers non-observable entities and phenomena as valid explanations for observable entities and phenomena. Hence, it postulates the existence of unobservable entities (atoms, electrons, or past events). The antirealist side claims the opposite, *i.e.*, that our factual knowledge is restricted to what is experienced by human senses, and therefore scientific theories do not offer a true description of reality.

Using the philosophical means of the informal dialogue (here, a trilogue between three speakers), the statistical/demographic problem of the Osteological Paradox was presented with this new perspective. Is it possible to claim that the results of paleopathological studies are true? Can we believe that they are describing what really happened in the past and are not only abstract tools and speculation?

The Paradox was discussed in the light of the debate between scientific realism and antirealism, focusing on the so-called *problem of underdetermination of theory by data* (Turner, 2011; Currie, 2018), which can be considered as a philosophical equivalent of the Osteological Paradox. In a nutshell, the problem implies that there is potentially more than one reliable explanation for the same phenomenon, undermining the scientific realist concept of *truth*. After exploring the obstacles that this problem poses in front of the historical researcher, the distinction between "how-possibly" models and "how-actually" models (Bokulich, 2011, 2014, 2016) was presented.

Philosophical models can be adopted to drive inferences about the past starting from the traces we gain from archaeological sciences. In paleopathology, the role of models is to interpret the patterns observable on the skeleton: a model narrates the story of the past life and disease of an individual. Taking my sample of babies (see Paper IV) as a case study, the non-specific lesions encountered (abnormal porosity, SBP) can be explained with several differential diagnoses, such as normal growth, infections, vitamin C deficiency, vitamin D deficiency, or a co-occurrence of deficiencies (Fig. 3). In this way, the lesions on the skeletons represent the observable phenomena, while the differential diagnoses considered represent the models adopted to describe them. The alternative explanations produced in the scientific process can be seen as "how-possibly" models (Bokulich, 2014). These models are developed when new phenomena are observed. Although the effective cause of a particular phenomenon is unknown, the models can explain some part of its development and reality, independently of whether they have been tested or not. Following this philosophical view, "how-possibly" models are not merely useful instruments, but an effective explanation of reality.

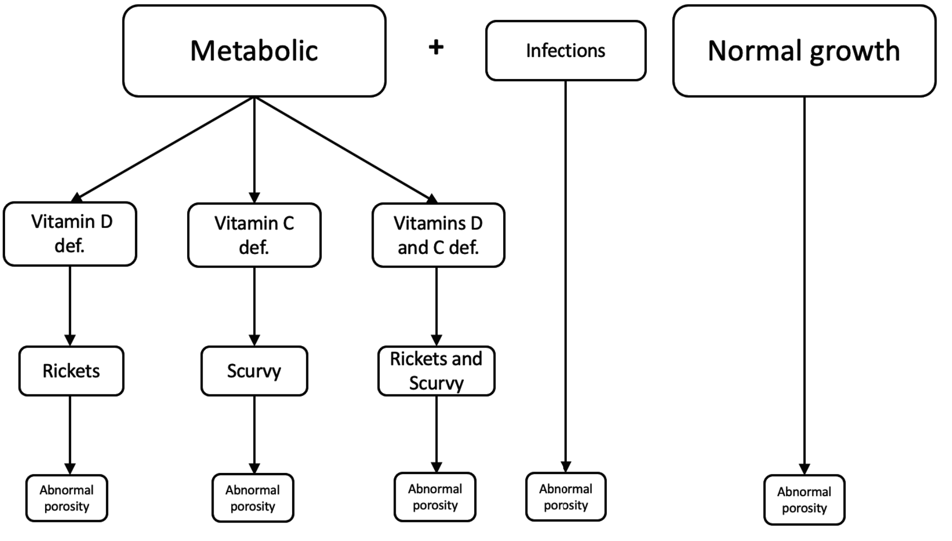


Figure 3. Graphic scheme summarizing the "how-possible" models (differential diagnoses) dealing with the observable phenomenon (abnormal porosity). The scheme shows the different levels of abstraction constituting the explanations of the target system, which follow a hierarchical structure. Graphic scheme by Lisa Zorzato.

Different levels of abstraction can grasp different levels of explanation (Fig. 3): at the lowest level, we have the skeletal markers for SBP and abnormal porosity. At the most abstract level, we have the "how-possible" alternative differential diagnoses (normal growth, metabolic diseases, infections). The fact that there are more "how-possible" models complicates the task of testing them with the available evidence, which is a major claim of the anti-realist view. However, in all these cases, a link between the models/diagnoses and the target system/lesions is evident, and the models do share with the target system some aspects of the physical reality. Therefore, the "how possible" models are not just sterile speculation but show a consistent internal structure well grounded in reality.

Summarizing the reasoning proposed in Paper II, although paleopathological studies do not always reach an empirical result, the scientific methods adopted support the realist point of view. According to the realist perspective, the issues presented by the *problem of underdetermination* do not constitute a limit, since the progress of science is an undeniable and *cumulative* process. If scientific theories are true (and we have compelling reasons to believe they are), knowledge will grow and offer more advanced theories in the years to come, each time arriving one step closer to the truth. Having a range of alternative explanations constitutes a standard procedure in every science (if conducted properly), and the absence of an immediate answer is an embedded aspect of scientific progress. Bioarchaeology continues to evolve integrating new biomolecular, radiological, and microscopic techniques to provide new empirical proofs for the reconstruction of past disease. This somehow fulfills the requests for an omnivorous approach presented by Wood and colleagues (1992). The support of technology and advance of knowledge will eventually confirm one solution among all the others. When this happens, a selection and funneling towards the more plausible theories naturally occurs, and the "how-possibly" model will turn into a "how-actually" model, a true description of the past. This reasoning constitutes the end of the trilogue, which provides the historical scientists with reasons to believe in their ability to conceive of true and reliable scientific models to interpret the historical past.

3.5. Isotopic approaches to the study of non-adult diet and stress

3.5.1. Stable isotope analysis for dietary reconstruction

Stable isotope analyses (SIA) of human skeletal tissues are generally used to reconstruct the bulk protein intake of the past human diet. All chemical elements are composed of atoms, which consist of positively charged protons (+) and neutrons (0) surrounded by a cloud of negatively charged electrons (–). The chemical properties of a specific element are determined by its atomic number, which indicates of the number of protons. While the number of protons does not change, the number of neutrons in different atoms of the same element may vary, resulting in different atomic masses of an element. Isotopes are atoms of an element that differ from one another in the number of neutrons in the atom nucleus. Some isotopes are unstable and subject to radioactive decay (for instance, ^{14}C). Others do not change, meaning that the ratio of one isotope to another stays constant over time; these are known as stable isotopes (Sealy et al., 1995; Katzenberg, 2008). Different isotopes show similar chemical properties, but their difference in mass results in different kinetic properties, and therefore they take part in physiological reactions at different rates. This leads to different ratios of one stable isotope compared to the other in the products of a chemical reaction compared to the reactants, a process known as fractionation (Katzenberg, 2008).

Stable isotope abundance ratios are expressed against the ratios of the same isotopes in international standard materials. They are measured in parts per thousands (‰), and reported with the delta notation as follows:

$$\delta xZ = \frac{Rsample - Rstandard}{Rstandard} \times 1000 ‰$$

Here, Z is the analyzed element, x the atomic mass of the heavier isotope, and R is the ratio of the mass of the heavier isotope to that of the lighter isotope.

3.5.1.1. Carbon

Carbon has three naturally occurring isotopes: while ^{12}C and ^{13}C are stable, the ^{14}C isotope is radioactive. Stable carbon ratios are usually negative (–), since most biological tissues contain less ^{13}C than the standard material (the PeeDee Belemnite (PDB), a marine limestone fossil). Stable carbon analysis is used to investigate the ecological background of the diet, such as different plant types constituting the staples (C3, C4 plants), and organisms from marine and terrestrial ecosystems (Schwarcz & Schoeninger, 1991; Ambrose & Krigbaum, 2003; Knudson & Stojanowski, 2008; Katzenberg, 2008).

The distinction between plant constituents is possible due to the fractionation process occurring within different photosynthetic pathways, leading to various $\delta^{13}C$ values in different plant species (Katzenberg, 2008). The C3 pathway is most common in plants from temperate climates (such as Estonia), and results in tissues showing lower $\delta^{13}C$ values, usually between –20‰ to –35‰ (Katzenberg, 2008). On the other hand, the C4 pathway is mostly found in tropical/subtropical plant species, of which maize and millet are common examples. This results in carbon isotopic values ranging from –9‰ to –14‰ (Katzenberg, 2008). Marine algae and plants normally range between C3 and C4 terrestrial plant values (Schoeninger & Moore, 1992).

Stable carbon values are indicative of the consumption of different foodstuffs, showing an increase of about 1–5‰ in isotope values in the consumer compared to the consumed foods (DeNiro & Epstein, 1981; Ambrose & Norr, 1993). Terrestrial and marine organisms display clearly different $\delta^{13}C$ values, mostly because marine plants absorb most of their carbon from dissolved bicarbonate, which has a higher $\delta^{13}C$ value than atmospheric CO_2. Marine food webs therefore show higher $\delta^{13}C$ values compared to terrestrial C3 food webs (Smith & Epstein, 1971; Schoeninger & DeNiro, 1984).

3.5.1.2. Nitrogen

Nitrogen has two naturally occurring stable isotopes: ^{14}N and ^{15}N. Atmospheric nitrogen enters the food chain through nitrogen fixation performed by bacteria and soil microorganisms (Ambrose & Krigbaum, 2003; Fornander, 2011). Most biological tissues incorporate more ^{15}N compared to the standard (AIR, i.e., atmospheric nitrogen), so the reported $\delta^{15}N$ values are usually positive (+). Nitrogen stable isotope values reflect the position of an animal in the food chain, as nitrogen values increase by 3–4‰ $\delta^{15}N$ relative to diet due to fractionation. The $\delta^{15}N$ values for terrestrial plants start from around 4‰, with marine plants usually showing higher values and the N_2-fixing plants reaching values next to 0‰ (Ambrose, 1991; Katzenberg, 2008). As the food web progresses, $\delta^{15}N$ values will show an increase from plants, to low-level consumers (e.g. herbivores), to high-level consumers (e.g. omnivores, carnivores) (Fig. 4).

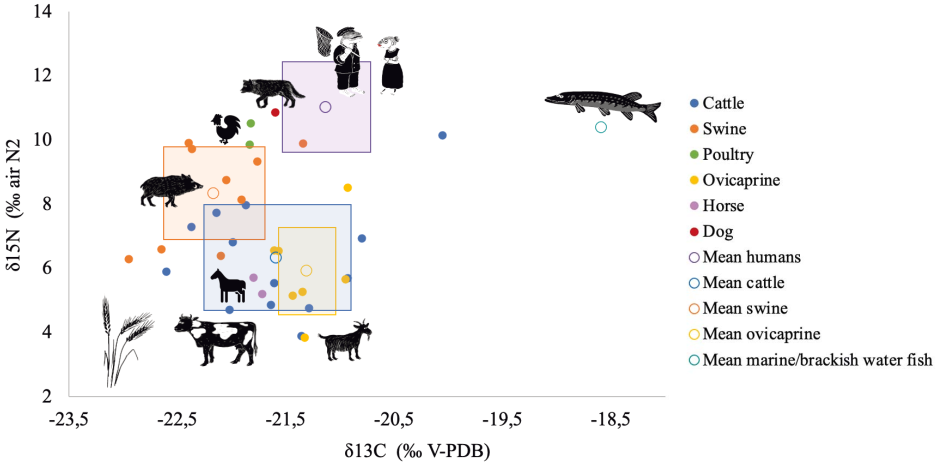


Figure 4. Overview of the isotopic analysis highlighting the sites and urban-rural relationship in the entire population studied in Paper V, including adults and juveniles. The scatter plot presents the $\delta^{13}C$ and $\delta^{15}N$ values of the samples for each cemetery along with local and coeval faunal data from Estonia (Aguraiuja-Lätti, original data; Aguraiuja-Lätti et al., original data; Malve, original data). Scatter plot by Alessandra Morrone, animal drawings by Jaana Ratas.

Nitrogen isotope values are also employed to distinguish between the consumption of marine/freshwater and terrestrial foods, since most aquatic species show higher $\delta^{15}N$ values with respect to terrestrial animals because of longer food chains (DeNiro & Epstein, 1981; Minagawa & Wada, 1984; Schoeninger & DeNiro, 1984; Minagawa et al., 1986; Ambrose & Krigbaum, 2003). Since nitrogen isotope values are affected by climatic and environmental variations, and there are significant differences in trophic level effects among different tissues and species, local baseline data is essential to provide valuable interpretations of the isotopic data (Hedges et al., 2004; Dalerum & Angerbjörn, 2005; Hedges, &

Reynard, 2007; Katzenberg, 2008). In this study, I am using existing animal baseline data from Estonia (Aguraiuja-Lätti, original unpublished data) to have higher confidence in the dietary reconstruction of the populations under examination.

3.5.2. Isotopic approaches to the study of breastfeeding and weaning

The study of breastfeeding and weaning through SIA has become an increasingly important line of research in bioarchaeology. The basic principle is that a breastfeeding infant is consuming the mother's tissues, showing a rise in nitrogen values of about one trophic level (2–3‰) compared to the mother (Fogel et al., 1989; Fuller et al., 2006). This was best observed in hair studies of modern populations (Fuller et al., 2006; de Luca et al., 2012). With weaning, this trophic effect should gradually decrease, with infant nitrogen values dropping to the mother's levels or below (Fogel et al., 1989). The same effect should be milder for $\delta^{13}C$ values, with a trophic level shift of around 1‰ (Fuller et al., 2006; de Luca et al., 2012).

Two ways of analyzing breastfeeding and weaning patterns are mainly performed in bioarchaeological studies. **a)** *Cross-sectional analysis* takes bulk bone samples (usually ribs) from children of different ages, compares them between each other and with adult values (specifically the women), and obtains a broad picture of the weaning duration in a population (see reviews by Jay, 2009; Humphrey, 2014; Tsutaya & Yoneda, 2015; King et al., 2017). This is the method adopted in this doctoral project and exemplified in Paper V. **b)** *Incremental (or life-history) analysis* is used to establish feeding practices at the individual level, with a high-resolution temporal scale. Here, non-remodeling tissues such as dentine are sampled in increments, revealing high resolution isotopic values for different formation times. On the other hand, different areas of growing bones show different turnover rates reflecting isotopic values incorporated before death (Waters-Rist et al., 2011, 2022; Beaumont & Montgomery, 2016; Morgan, 2013). Strategic sampling of dentine/bone increments provides a high resolution reconstruction of the nutritional history of children (the non-survivors) and adults (the survivors) (Bell et al., 2001; Dupras & Tocheri, 2007; Jørkov et al., 2007; Humphrey, 2010, 2014; Eerkens et al., 2011; Waters-Rist et al., 2011, 2022; Beaumont et al., 2013, 2015; Howcroft et al., 2012a, 2014; Morgan, 2013; Reynard & Tuross, 2015; Beaumont & Montgomery, 2016; Waters-Rist & Hoogland, 2018).

Recent application of incremental analysis has significantly contributed to the understanding of the effects of physiological stress and malnutrition on isotopic values (Katzenberg & Lovell, 1999; Morgan, 2013; Reitsema, 2013; Olsen et al., 2014; Beaumont & Montgomery, 2016) as will be discussed in the next paragraph.

The limitations of cross-sectional studies have been widely discussed, and mainly concern the equifinality of the isotopic interpretation, discussed below. Other issues include the precision of the aging techniques, poorly understood turnover rates, and physiological processes causing isotopic shifts between mothers and offspring (Dupras & Tocheri, 2007; Howcroft et al., 2012a, 2014; Beaumont et al., 2013, 2015; Reynard & Tuross, 2015; Kendall, 2016). Furthermore, estimating the weaning time inevitably assumes that the females in the population are representative of the mothers, and an overall homogeneity of the adult female diet as well as of their cultural norms in breastfeeding habits (Beaumont et al., 2013, 2015; Dupras & Tocheri, 2007; Howcroft et al., 2012a, 2014; Wood et al., 1992). This ignores individual variability and cultural practices dictated by social status, gender, or health conditions (Stantis et al., 2020). As a result of the Osteological Paradox, the children in the cemetery are non-survivors that may have not experienced the same feeding practices as the survivors, or whose deaths may have been caused by different weaning trajectories (Beaumont et al., 2013, 2015; Dupras & Tocheri, 2007; Howcroft et al., 2012a, 2014; Wood et al., 1992). Similar issues can be partially limited by adopting incremental techniques. A life history approach conducted on each individual allows focusing on several short periods of life, which correspond to the tooth/bone increments. The resulting isotopic data are therefore not only more numerous, but also at a higher resolution, allowing pinpointing of the moments in which dietary changes or stress episodes started (Dupras & Tocheri, 2007; Eerkens et al., 2011; Waters-Rist et al., 2011, 2022).

Despite these limitations, the cross-sectional approach remains the most useful and inexpensive manner of creating general models of population weaning strategies. Combined with incremental techniques, it has the potential to provide the most nuanced set of data for feeding practices studies (King et al., 2017).

3.5.3. Identifying physiological stress in isotopic studies

In the light of the pathological record, SIA is a useful tool in the interpretation of the paleoepidemiological data on both the population and individual levels. $\delta^{13}C$ and $\delta^{15}N$ values have been used to integrate pathological data from various contexts with information about everyday diet, thereby obtaining a clearer picture of the etiology and nutritional background of specific pathologies (Linderholm & Kjellström, 2011; Zariņa et al., 2016; Kinaston & Buckley, 2017).

SIA can be used not only to understand the effects of everyday diet on disease occurrence, but also as biological indicators of physiological stress. The basic principle is that, other than high trophic level diets, elevated ^{15}N values may also result from protein stress due to dietary deficiencies and pathological conditions. This generally results in the catabolism of existing body tissues that are already enriched in ^{15}N because of preferential excretion of the lightest isotope ^{14}N (Katzenberg, 2008; Katzenberg & Lovell, 1999; Reitsema, 2013; Olsen et al., 2014). In a nutshell, the body starts "eating" its own tissues.

This pattern was first observed in birds, (Hobson & Clark, 1992; Hobson et al., 1993), but the research was rapidly extended to humans. Among the studies investigating starvation or nutritional stress through SIA, some focused on stress related to pregnancy and morning sickness (Fuller et al., 2004, 2005, studies conducted on hair), starvation related to *anorexia nervosa* and famines (Beaumont &

Montgomery, 2016; Mekota et al., 2006, 2009), and pathological conditions in bone (White & Armelagos, 1997; Katzenberg & Lovell, 1999; Reitsema, 2013; Olsen et al., 2014). These publications have widely shown that during disease or nutritional stress, human tissues register such events in variations of their stable isotope values, resulting in elevated $\delta^{15}N$ compared to healthy tissues. $\delta^{13}C$ also exhibits a milder but significant increase (Katzenberg & Lovell, 1999; Reitsema, 2013; Olsen et al., 2014). A groundbreaking example is the work by Katzenberg & Lovell (1999), which compared the isotopic values of pathological and non-pathological bone to determine whether particular conditions (post-paralytic atrophy, healing fractures, active periostitis, and healing osteomyelitis) result in variations in bone protein stable isotope ratios. This study reported the greatest variation in bones with osteomyelitis from an individual who had AIDS. The authors interpreted these results as due to collagen being formed from the catabolism of existing proteins in the body under these conditions (Katzenberg & Lovell, 1999). Another interesting example is the paper by Beaumont & Montgomery (2016), in which the $\delta^{13}C$ and $\delta^{15}N$ profiles were obtained from incremental samples of individuals from a workhouse dating from the Great Irish Famine of the 19th century. The results of this analysis demonstrated that chronic nutritional stress indeed results in increased $\delta^{13}C$ and $\delta^{15}N$ values in both adult and immature individuals. This evidence therefore provides an alternative explanation beyond diet or environmental effects in case of anomalous $\delta^{13}C$ or $\delta^{15}N$ values in archaeological populations.

Focusing on fetuses and perinates, anomalous isotopic patterns may reflect the health conditions of pregnant or nursing mothers (Bourbou, 2018; Bourbou et al., 2019, 2013; Waters-Rist et al., 2022). Metabolic diseases such as scurvy and/or rickets are likely to occur when low dietary diversity, quality, and/or quantity persist for extended periods of time[2] (i.e., famines, epidemics) (Buckley et al., 2014; Geber & Murphy, 2012; Snoddy et al., 2017). Similar stress episodes experienced by mothers may be reflected in the isotopic values of their newborns; physiological stress experienced by infants and children in the weaning age can also result in isotopic variations. The weaning process is not only an important threshold in life, but can also be considered as a critical period from a physiological point of view, since the introduction of supplementary foods can expose infants to pathogens and nutritional stress while their immune system is still developing (Goodman & Armelagos, 1989; Herring et al., 1998; Katzenberg et al., 1996; Wheeler, 2012). This may result in metabolic disorders and failure to adapt to the environmental conditions, often contributing to premature death (Dupras & Tocheri, 2007). Numerous recent studies have investigated infant

[2] The actual amount of time needed to develop skeletal lesions is extremely variable, since a plethora of factors affect bone turnover in babies and adults. Among these, the age of the individuals, their relation to birth (for instance, after birth it is higher in preterm babies compared to term babies) (Lapillonne et al., 2000; Szulc et al., 2000; Shiff et al., 2001), as well as the lifestyle and malnutrition of the mothers (Högler et al., 2003; Wu et al., 2004) all play a role in determining the time of lesion formation.

stress in isotopic reconstructions of breastfeeding and weaning (Bourbou et al., 2013, 2019; Beaumont et al., 2015; Bourbou, 2018; King et al., 2018; Waters-Rist et al., 2022), and my contribution to this research line is Paper V of this thesis.

3.5.4. The problem of equifinality in isotopic studies

SIA provides a "broad brush" picture of diet, meaning that the characterization of $\delta^{13}C$ and $\delta^{15}N$ values for specific dietary sources at particular times and locations may be explained with several, equally probable scenarios (Bogaard & Outram, 2013; King et al., 2017; Siebke et al., 2019). As occurs with paleo-epidemiological models, the Osteological Paradox (or, more philosophically, the *principle of underdetermination*) also applies to isotopic patterns, as similar values may reflect different food proportions. For instance, relatively high $\delta^{15}N$ values may be reached by consuming animal meat from higher food-webs, marine and freshwater resources, dairy products, or by physiological stress (Katzenberg, 2008; Bogaard & Outram, 2013).

Integrating SIA with bioarchaeological results may be the only way to better understand general and local diets (Bogaard & Outram, 2013). The evaluation of contextual information from different archaeological sciences (bioarchaeology, pollen analyses, zooarchaeology, paleoclimatology) and their integration with relatable historical sources allows identifying the best possible interpretations for the observed isotopic values.

Another essential theoretical point concerns establishing the timing of specific stress episodes in isotopic values. In the absence of historical documents, identifying famine and epidemic is not straightforward, as no clear isotopic signals for similar events can be concretely detected in human remains. There is no specific signal for "famine" written in bone. Any change in $\delta^{13}C$ and $\delta^{15}N$ values resulting from starvation and leading to a fast death will not be measurable in bone collagen due to the slow turnover rate and averaging of the data; in the individuals who did survive famine, collagen turnover would have eventually obscured any isotopic evidence for starvation, at least if they lived long enough (Beaumont & Montgomery, 2016; Morgan, 2013). In addition, during critical historical upheavals, episodes of famine, warfare, and epidemic often occurred in direct conjunction, and thus it may be difficult to discriminate between them (Beaumont & Montgomery, 2016; Morgan, 2013). Archaeological evidence such as short-term deviations from the usual diet (e.g., inclusion of unusual plants or modified butchery practices) obtainable from archaeobotanical and archaeozoological data, changes in demography of the cemetery population, or evidence for mass burial events should be always linked to osteological analysis. When written sources are unavailable, the combination of this information may provide a more nuanced background for the isotopic data (Beaumont & Montgomery, 2016; Morgan, 2013).

Focusing on non-adult studies, the effects of physiological complexity, and the direct impact of specific metabolic processes on isotopic values (e.g. positive nitrogen balance) are still not completely understood, especially when dealing with pregnancy and weaning (Fuller et al., 2006; Reitsema, 2013; Beaumont et al., 2013, 2015). Even if a peak in nitrogen values is observed, it is uncertain whether it reflects a maternal diet rich in high trophic level foods, physiological variations or disease in the mother, a breastfeeding signal, an episode of childhood stress, or perhaps a combination of these factors (see Paper V).

Several paleopathological studies associate stable isotope data to skeletal stress indicators, such as enamel hypoplasia and other dental disease, *cribra orbitalia*, or subperiosteal bone production (Zariņa et al., 2016; Pētersone-Gordina et al., 2018). The main issue here is that most associations between isotopic signatures and metabolic disorders can explain the etiology of these conditions only partially, through a broad average of the bulk components of the individual's diet. Unfortunately, the situation is much more complex, and nutrition is not the only factor involved in these skeletal conditions. Other causative factors include infections, parasites, genetics, and disease, and all of these can also affect the isotopic values of skeletal tissues (Reitsema, 2013).

As with the Osteological Paradox, similar problems cannot be avoided, but may be minimized by adopting the correct framework for population analysis (Wright & Yoder, 2003). Incremental techniques record life stages other than those immediately before death. In this way, different snapshots of diet and physiological stress (e.g., in infancy, childhood, early and late adulthood) can be obtained through strategic sampling (Reitsema, 2013). Studied in conjunction with non-specific stress indicators, childhood dietary data may help unravel the interaction between childhood nutrition, health, and survival (Wright & Yoder, 2003; Beaumont & Montgomery, 2016). The comparison of isotopic data between subjects of the same ages who were survivors (adults and older children) versus non-survivors (younger children) is a powerful tool to identify any differences in subsistence and stress in different population groups, providing further information for the historical reconstruction (King et al., 2017).

4. MATERIALS

4.1. The Context: historical overview of medieval and early modern Livonia

4.1.1. Health and disease

The medieval (13^{th}–16^{th} centuries AD) and early modern (16^{th}–18^{th} centuries AD) periods in current-day Estonia were strongly characterized by long-term political instability, economic uncertainty, and sociocultural changes, partially because the region was subject to different political powers. Before the 16^{th} century (ca. 1560), the territories of the present-day republics of Estonia and Latvia constituted a historical region under the name of Livonia, which was ruled by the Kingdom of Denmark between 1219–1346 and successively sold to the Livonian branch of the Teutonic Order in 1346. Continuing with the early modern period, between 1558 and 1645 Estonia was contested between Sweden, Russia, Denmark (ruling the island of Saaremaa between 1559 and 1645), and the Polish–Lithuanian commonwealth. Between 1645 and 1710 the country was subject to Sweden, and from 1710–1918 it was under Russia. Societal processes such as foreign conquests, development of urban settlements with typical European characteristics and multiethnic dwellers, and a major split between the foreign upper class (the *Deutsch*, i.e., Germans, who were ecclesiastic people, merchants, and the representatives of honorable crafts) and the local lower class (the *Undeutsch*, the locals or non-Germans, including practitioners of less honorable crafts and the poorest sectors of the population, mostly from the hinterlands) have been thoroughly described in historical records (Russow, 2006; Selart, 2015; Sillasoo et al., 2009). The differences between the urban population, multicultural and dynamic, and the rural realities, still enriched with local traditions and preconquest heritage, were marked and reported for several aspects of everyday life and death (Valk, 2006).

Numerous written sources report the direct effects of cultural development and warfare, resulting in distinct episodes of epidemic, famine, and malnutrition, which did not spare the Estonian territory (Jankauskas & Urbanavičius, 1998; Lang, 2006). Some of these events are recorded in the Chronicle of Henry of Livonia (1180–1227, Book IV), reporting a succession of plagues affecting the provinces bordering the Baltic Sea. The earliest mention of widespread plague is from the year 1211 (Book IV, Chapter XV, 7 – "*De pestilencia – (...) many men who, by fleeing, had escaped being struck by the sword could not escape the bitter death of the pestilence"*), continuing during 1212 (Chapters XV, 11 and XXV, 2). In 1223 the plague was reported in Viljandi and Sakala (Chapter XXVII, 2 and 3 – *"Since the heat was, indeed, exceedingly great and there was a multitude of beasts and men in the fort, and they were perishing from hunger and thirst, there was a great pestilence because of the excessively great stench of those who had died in the fort and the men began to get sick and die"*). These events continued during the whole 14^{th}–15^{th} centuries until 1710, targeting especially the crowded urban areas, and often forcing village dwellers to gather in towns (Jannsen, 1888). A simultaneous plague and devastating famine caused by severe weather conditions were reported in 1315 and described in one of the few preserved fragments of the Younger Livonian Rhymed Chronicle (mid-14th century) (Olivier, 2014). The situation was described as so dreadful that people were eating each other, with an estimate of at least 10% of the population perishing (Palli, 1996, 1997). However, this estimate was questioned since the textual sources are too scarce to offer any reliable estimation on the real percentages of population that perished during the famine (Raudkivi, 2010). A plague in Tallinn was reported in 1352–1353 (most likely the Black Plague, which reached Livonia around 1351), followed by another outbreak in the 1380s. In particular, the Chronicle of Detmar (written in Lübeck at the end of the 14th century) mentions a great pestilence in the Bishopric of Tartu in 1378, where only one sixth of the population is said to have remained alive (*"In demsulven iare was grot pestilencie in deme stichte van darpte, also dat kume de seeste minsche blef levendich"*) (Raudkivi, 2010). The impact of the Great Famine and the Black Death on Livonia had been devastating, leading to illness, countless deaths, and deviations from societal norms (cannibalism, abandonment of family members, etc.) (Raudkivi, 2010). However, unlike for Western Europe, for Livonia there is a great shortage of written sources to define the extent of the territory involved and the impact of famine and plague on the local communities. Moreover, the vulnerability of different sections of society, as well as their means to deal with the crisis, cannot be determined with certainty (Raudkivi, 2010).

Other smaller episodes, mostly connected with warfare, were recorded successively. The nature of the infections remains unknown, since every slightest outbreak was recorded as "pestilence" (Mänd et al., 2012). However, other diseases such as intestinal infections (including dysentery), tuberculosis, purulent throat and measles were reported in addition to the plague. From 1495, a wave of syphilis reached Livonia from Europe (Majander et al., 2020), and the presence of smallpox was also recorded in this period (Mänd et al., 2012).

It is notable that the spread of infections was strictly intertwined with conditions of severe famine. The 1315–1317 Great European Famine resulted in tragic consequences for medieval Livonia, followed by several years of crisis during the whole 15th century, caused by crop shortages and inflation. Warfare was among the factors leading to the destruction of local crops, livestock and farming equipment, contributing to the occurrence of famines as much as the worsened climatic conditions (Sillasoo et al., 2009; Raudkivi, 2010). A temperature drop during the years 1310–1350, coincident with declines in both cultivated land and herb pollen curves during the Little Ice Age was confirmed by archaeobotanical findings from several Estonian sites (Sillasoo et al., 2009).

With regard to the historical context described above, it becomes clear that the living conditions of the Livonian population, especially the non-adult groups, were severely affected by similar upheavals. Therefore, the multidisciplinary analysis of medieval and early modern cemetery material is an invaluable tool for the reconstruction of the impact of complex historical processes on the life and death of the non-adult sectors of the population.

4.1.2. The Livonian cuisine

The dietary habits of medieval and early modern Estonian populations can be inferred from a plethora of archaeological and historical sources (Mänd, 2005; Sillasoo & Hiie, 2007; Põltsam-Jürjo, 2013, 2018; Aguraiuja-Lätti & Lõugas, 2019). The staple diet was mainly composed of vegetables and legumes, the most common plants being barley, turnip, wild berries, and hazelnuts, depending on the season (Sillasoo & Hiie, 2007). Evidence for the consumption of common millet, oats, buckwheat, pea, figs, and cultivated black currants was also reported (Sillasoo & Hiie, 2007). The plant staples were then complemented with cheese, locally brewed beer, dried or salted fish, and bread (mostly we talk about rye and wheat breads) (Mänd, 2004). Our knowledge of festive foods is of course much more detailed, since several historical sources describe food, cooking, and food presentation at feasts and special gatherings (Mänd, 2004). Varieties of fresh meats and fish, ham, imported wines, nuts, and fruits along with spices were considered standard festive foods throughout the Middle Ages and Renaissance, in Livonia as well as in Northern Germany, Prussia, and other regions around the Baltic Sea (Mänd, 2004, 2005).

These similarities were determined by the natural environment, and then further promoted by the Hanseatic trade. This allowed importation of several foreign products in Livonia, resulting in a wider food choice in the city as compared to the village. The wealthy German upper class enjoyed higher quality resources and exotic imported foods, such as spices, herbs, cheese, game, wine, almonds, and imported fruits (raisins, dates). However, it appears that dietary staples (bread, meat, fish) were quite similar for all social groups, with the lower classes integrating them with more vegetables, butter, and fermented dairy products (Mänd et al., 2012; Aguraiuja-Lätti & Lõugas, 2019).

The medieval city dweller obtained the necessary food from one's household, as the preparation of bread, mead, beer, and meat/fish was mainly carried out at home (Mänd et al., 2012). Small garden plots, as well as pigs and poultry, were grown inside and near the town walls, while livestock was raised in grasslands outside the city boundaries. Fish was common in both upper and lower classes and frequently consumed during fasting, with herring, salmon, and Atlantic cod being the main imported fish in urban and rural areas; freshwater fish (bream, pike, perch, carp) was also bred in town moats (Mänd, 2005; Orton et al., 2011, 2019; Põltsam-Jürjo, 2013, 2018, 2021). A smaller range of foods was available in rural areas, which mostly imported salt, herrings, and hops (Põltsam-Jürjo, 2013).

Unfortunately, few historical studies regarding childhood in medieval and early modern Livonia exist (Mänd et al., 2012; Põltsam-Jürjo, 2017). Therefore, no specific information concerning staple diet during childhood is available, and it is unknown whether and how much the diet of children differed from that of the adults, as well as their breastfeeding duration and weaning age. This undermines our knowledge of feeding customs and childcare in the area.

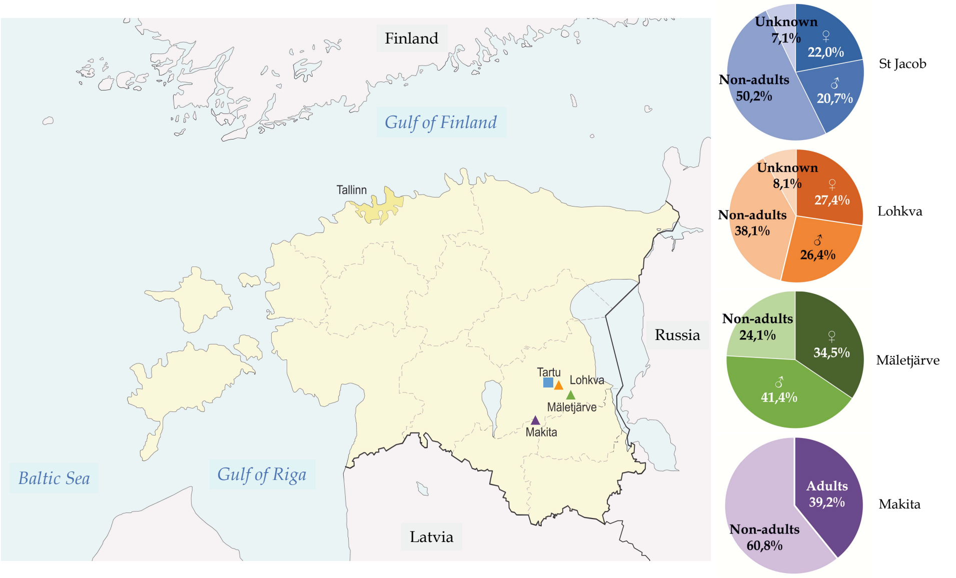


Figure 5. Location of the rural and urban cemeteries studied. Squares indicate urban contexts, while triangles represent rural areas. The demographic analysis for each site is reported in the pie charts (Valk, 1985, 1987; Heapost, 1993; Roog & Malve, 2012; Malve, original data). Map of Estonia by Marco Porcino, adapted for this thesis by Alessandra Morrone.

4.2. The urban site: St Jacob's cemetery in Tartu

St Jacob's cemetery is one of the medieval and early modern suburban cemeteries discovered in the city of Tartu, southern Estonia (Fig. 5). This was the third largest town in Livonia, with a population of 5,000–6,000 people in the mid-16th century (Palli, 1996). The churchyard was located outside the city walls, and it is assumed that inhabitants of Tartu's medieval suburbs, part of the lower-status urban population, and migrants from close rural areas were buried there (Freymuth, 1927; Helk, 2003). Archaeological excavations (2010–2017) revealed at least 614 individuals. Based on the associated artifacts, the cemetery was dated to the mid-13th – late 16th/early 17th centuries. The burials were mostly simple graves with no coffin or grave goods, and the dead were buried with their heads turned westward. The demographic analysis of the cemetery indicated that non-adults constituted the 50.2% of the population, adult females made up the 22%, adult males made up the 20.7%, and the remaining 7.1% were adults of unknown age and sex (Malve, original data). The percentage of non-adult burials in St. Jacob's cemetery (ca. 50%, including both the graves outside and within the cemetery borders) is in line with other coeval Estonian churchyards (Allmäe, 1998; Heapost, 1993; Kalling, 1995).

Paper IV was specifically focused on the analysis of one large mass grave (Mass Grave 1) of 21 fetuses and perinates buried together with a single adult female individual (Fig. 6), three smaller mass graves (Mass Graves 2, 3, and 4) containing six perinates each, and two double graves of perinates (Double Graves 1 and 2). The burials were discovered outside the cemetery walls, suggesting that they were socially separated from the rest of the community. There were also other single adult burials outside the cemetery walls. In all these cases, the body disposal did not follow the typical Christian depositional trends observed in the cemetery (supine position, head turned west) or any other organized fashion, suggesting that they had been either thrown or quickly placed in the cuts.

Figure 6. The female adult burial in Mass Grave 1. The cluttered disposal of the remains suggests that this individual was either thrown or quickly placed in the grave, without any shroud or coffin. The fetuses and perinates were placed over and under the female skeleton. The white arrows indicate the position of four babies still on site. Photo by Martin Malve.

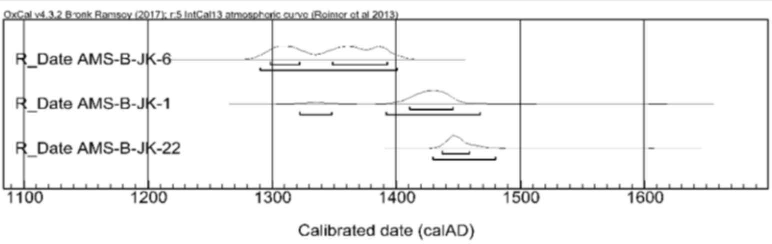
The female skeleton in Mass Grave 1 was supine, articulated, and was not moved since deposition, confirming the primary nature of the burial (Fig. 6). Furthermore, the individual showed several *ante-mortem* traumas, including blunt force trauma on the skull, several rib fractures, parry fracture on the ulna, and fractures of both fibulae. The non-adults were placed over and under the female adult. Whereas some of the burials were disturbed during the rescue excavations, others were consistent with the babies having been placed in the grave in a supine position, a fashion also observed in the other graves under examination (Figs. 7 and 8). The only artifacts recovered were two bronze rings associated with the adult female in Mass Grave 1, dated to the 13th–15th centuries. This timespan was confirmed by radiocarbon accelerator mass spectrometry (AMS) dating, performed on the adult female (late 14th to mid-15th centuries), on Individual 6 (Ind. 6) at the bottom of Mass Grave 1 (representing a *terminus post quem*: late 13th to late 14th centuries), and on Ind. 22 in Double Grave 1 (mid-15th to late 15th

century, Fig. 7b) (see Table 1)[3]. As the estimated dates partially overlap, it was assumed that these graves were populated in the same period or during mass fatality episodes occurring relatively close in time.

Figure 7. Excavation photos of the perinates in the double graves. **a)** Individual 21 from Double Grave 1. **b)** Individual 22 from Double Grave 1. **c)** Individual 23 from Double Grave 2. Photos by Martin Malve.

Table 1. Calibrated AMS dating of three individuals from St Jacob's samples. Performed at the 14CHRONO Centre, Queen's University Belfast. The AMS dates were calibrated with the OxCal v4.3.2 (Ramsey, 2009; 2017) and the IntCal13 atmospheric curve was used (Reimer et al., 2013). All the obtained dates were rounded to the nearest 10 years.

Sample ID UT/Belfast	No. Burial	Bone element	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	C:N ratio	Collagen Yield	Radiocarbon Age BP	Calibrated date AD (1 σ: 68.2%)	Calibrated date AD (2 σ: 95.4%)
AMS-B-JK-22 UBA-40315	22	Fragment left femur	-20.0	12.8	3.16	3.30	432 ± 22	1430–1460	1420–1480
AMS-B-JK-1 UBA-40313	1	Fragment 9th rib	-20.4	12.3	3.15	13.40	490 ± 41	1410–1450	1320–1350 (6.1%) 1390–1470 (89.3%)
AMS-B-JK-6 UBA-40314	6	Whole right femur	-20.0	14.4	3.16	10.90	623 ± 32	1290–1330 (25.7%) 1340–1400 (42.5%)	1290–1400



[3] The results after the recalibration with the updated version of IntCal20 did not change significantly: JK-6: 68.3 = 1300-1330 (28.8), 1340-1400 (39.5); 95.4 = 1290-1400; JK-1: 68.3 = 1410-1450; 95-4 1320-1350 (4.1), 1390-1470 (91.4); JK-22: 68.3 = 1430-1460, 95.4 = 1420-1480.

Figure 8. Excavation photos of the perinates in Mass Grave 2. **a)** Individual 15. **b)** Individual 17. **c)** Individual 20. The numbers indicate the ID codes of the individuals. Photos by Martin Malve.

Paper V expands further on material from this cemetery, since the 43 babies previously examined were also sampled for stable isotope analysis. To these individuals, another 39 non-adults between the fetal and the 7–15 age categories were added to the total number of individuals from St Jacob's cemetery (Table 2).

Table 2. Non-adult skeletal assemblage sampled for SIA and number of individuals with good collagen quality for each age category.

Site/Dates	**Fetus**	**Perinate I**	**Perinate II**	**Neonate**	**Infant 0–1**	**Child 1–7**	**Child 7–15**	**Selected samples for SIA**	**Samples meeting quality criteria**
St Jacob (13th–17th century)	5	25	28	2	3	12	7	82	68
Lohkva (14th–17th century)	0	1	2	1	1	10	5	20	19
Mäletjärve (14th–17th century)	0	0	0	0	0	3	4	7	2
Makita (13th–17th century)	1	2	1	3	7	37	16	67	51
Total	6	28	31	6	11	62	32	176	140

4.3. The rural cemeteries: Lohkva, Mäletjärve, and Makita

The medieval/early modern settlement of Lohkva (11^{th}–17^{th} century) is located southeast of Tartu (Fig. 5). Rescue excavations were carried out in 2011, unearthing the ancient settlement and the village cemetery (Roog & Malve, 2012). Ninety-nine burials were recovered, most of which were single inhumations in a supine stretched position, with the head facing westward; most burials included coffin wood and/or nails (Roog & Malve, 2012). The grave goods mainly consisted of coins, rings, brooches, and knives dated to the second half of the 16^{th} and to the 17^{th} century. However, one burial contained a14^{th}–16^{th} century needle-sheath, suggesting that the cemetery was already in use in the medieval period (Roog & Malve, 2012). The rather low proportion of non-adults (38.1%) was considered exceptional in the context of Estonian medieval/early modern cemeteries (Heapost, 1993; Allmäe, 1998; Kaldre et al., 2010). Of interest was also the high number (51%) of mature and elderly adults (35+ years), suggestive of a relative longevity among the community.

The village cemetery of Mäletjärve, excavated in 1984, is located southeast of Tartu (Fig. 5). It was in use between the 14^{th} and the 17^{th} centuries, based on the recovered artifacts (coins, rings, bronze jewelry), but most graves are from the 16^{th} century (Valk, 1985). Due to the rescue nature of the excavation, a limited number of skeletons (29, all supine with head turned westwards) was available for osteological investigation.

The rural cemetery of Makita is located in the Tartu district near Otepää, and was excavated in 1986–1987 (Fig. 5). The numerous artifacts (including coins, brooches, jewelry, and ornaments) date the cemetery between the 13^{th} and the 17^{th} centuries (Valk, 1987). The burials were mainly single inhumations in a supine stretched position with the head turned west, and the hands in variable positions. Many burials included coffin wood and/or nails and were often delimited by stones inside and on the grave margins (Valk, 1987). A hundred and twenty-five skeletons were recovered and divided in two chronological groups based on artifacts belonging to the 13^{th}–15^{th} and the 15^{th}–17^{th} centuries AD. The demographic composition is comparable to that of other coeval Estonian cemeteries (Valk, 1987; Heapost, 1993).

A total of 92 individuals between the fetal and the 7–15 age category were selected from these rural sites for stable isotope analysis sampling, meeting the criteria for developing Paper V (Table 2).

4.4. Osteological material for Reflectance Transformation Imaging (RTI) testing

A selection of specimens with signs of bone pathology and optimal preservation conditions was chosen for RTI testing. These samples consisted of human bones and teeth recovered from seven medieval and early modern Estonian urban cemeteries (Paper III, Supplementary Material, Tables 1 and 2). Both adult and non-adult specimens were included, and several elements were gathered from assemblages of commingled remains. Pathological bone changes of productive, destructive, and mixed nature were considered for this study to provide the widest range of common disease manifestations observable on archaeological bone (Chapter 5.1.).

Among the non-adults, the RTI images of some of the fetuses and perinates from St Jacob's cemetery were acquired and employed for study purposes and in Paper IV. The 45 total chosen specimens were grouped into four general categories according to the type of pathological process involved in the surface lesion formation (bone production, bone destruction, mixed lesions and dental pathology) (see Paper III, Table 1). Several pathological specimens were photographed for each category of skeletal lesions.

5. ANALYTICAL METHODS

5.1. Reconstruction of the Biological Profile

Basic osteological methods based on morphological examination and bone measurements were chosen. In the study of non-adult human remains, particular attention is given to the age at death estimation, since it allows inserting the individuals into specific age categories for paleodemographic reconstructions, as well as interpreting possible evidence of age-specific diseases.

To successfully report the employed methods and record the necessary diagnostic elements for analysis, specific bioarchaeological recording forms were crafted in Excel spreadsheets. To record the lesions and make the findings addressable standard photography was used to display the most informative lesions, with the images stored in online cloud-drives and institutional repositories at the UT.

5.1.1. Age at death estimation and age categories

Contrarily to adult individuals, for whom the degree of degeneration of specific joints is graded, age estimation in non-adults is somewhat simplified. This is because the skeletal changes linked to growth and development occur in very brief stages (weeks or months in neonates and infants, and a few years in older children), producing more reliable and precise results.

The morphological estimation of age at death mainly relies on developmental standards for dental and skeletal elements, taking into account different stages of development in relation to age (Hadley & Hemer, 2014; Lewis, 2007; Halcrow & Ward, 2020). However, it must be considered that most of the methods currently available were developed on modern populations, and therefore the intrinsic limits connected to the use of specific parameters ought to be considered. Among these, we can include individual variability, difficulties in sex estimation, and population changes, but also possible differences in secular trends and the impossibility of exactly linking the current growth phases with those that occurred in the past (Lewis, 2007; Canci & Minozzi, 2015).

The age categories used in this thesis followed the guidelines by (Lewis, 2007), and are reported in Table 3. It must be borne in mind that these categories are exclusively based on skeletal biology, and not indicative of the social age of the individuals, which is generally created by the communities in specific social and historical contexts (Chapter 3.2.)

Assuming the average moment of birth at 40 gestation weeks, the age categories for the youngest individuals were crafted to minimize the overlapping caused by different aging techniques. This grouping also allows distinguishing newborns from individuals who died around the time of birth. Babies were therefore included in the following groups: *fetus* (under 28 gestation weeks), *perinate I* (preterm, from 28 to 37 gestation weeks), *perinate II* (full-term, from 37 to 42 gestation weeks), and *neonate* (from 42 weeks to around a month of age). The term "perinate" therefore defines the individuals who died around the time of birth, with the *perinates II* category including possible full-term and post-term births. On the other hand, it can be assumed that those aged younger than 37 weeks (*perinates I*) were either aborted (death in utero), stillborn (death after 28 weeks of gestation), or could have died immediately post-birth, in the case of preterms or babies that were small for gestational age (Lewis & Gowland, 2007).

Table 3. Age categories employed for non-adults in this study, adapted from Lewis (2007).

Age category	Estimated age
Fetus	< 28 gestation weeks
Perinate I	28–37 gestation weeks
Perinate II	37–42 gestation weeks
Neonate	42 weeks –1 month
Infant	From birth to 1 year of life
Child	Between 1 year and 15 years
Child I	1–7 years
Child II	7–15 years
Juvenile	15–20 years
Non adult	≤ 17 years

5.1.1.1. Dental development and eruption

The techniques based on the development of dental elements, beginning with calcification and finally reaching eruption through the maxillary/mandibular bone and gums, are among the most accurate methods for age estimation in children, since the dental growth process is less affected by extrinsic environmental factors and largely influenced by the genetic asset of the individual (Lewis, 2018).

In this study, internationally accepted standards based on tooth formation and eruption (Moorrees et al., 1963; Ubelaker, 1989; AlQahtani et al., 2010, 2014) were used. The former method, available in commonly used standards (Smith, 1991) and workbooks (White & Folkens, 2005), is based on cumulative distribution functions and provides thorough descriptions of developmental stages for each dental element; the latter two are comparative techniques based on graphic tables reporting the average developmental stages of the whole dentition for each age, plus the standard error. The use of comparative methods is undoubtedly straightforward and rapid, although it must be remembered that the criteria were developed by testing performed on modern American and British populations, lowering the level of accuracy for past populations. In summary, age estimation through dental eruption/formation is among the most reliable and precise techniques for non-adults, although the availability of dental elements is not always guaranteed in archaeological contexts.

5.1.1.2. Appearance and fusion of skeletal elements

In the absence of tooth crowns and dental elements, age was estimated by relying on bone fusion whenever possible. Here, the formation and fusion of cranial and postcranial elements is observed, indicating the growth stage of the child. In the cases of babies and infants, the most informative areas are the skull and the vertebral column. Most of the cranial bones appear separately and fuse in specific moments of life. Among these are the *pars basilaris* of the occipital bone (which slowly evolves from a nearly rectangular to a more squared shape during pregnancy), the sphenoid bone components, and the temporal ring and petrous portion of the temporal bone (Scheuer & Black, 2000, Nagaoka & Kawakubo, 2015). For the postcranium, the fusion of different vertebral elements is particularly useful for infants (Scheuer & Black, 2000).

In the case of children in the 1–7 age category, different postcranial areas become more informative. The evaluation of the degree of fusion of the long bone epiphyses, vertebral epiphyses, pelvic bones, and other skeletal elements, a process ending around 20–23 years of age, is performed; combining the results for each skeletal area in a wider final range permits a more accurate estimate (White & Folkens, 2005). Moving to juveniles, the degree of fusion of long bones, sacral elements, and clavicles is used to determine whether the individual can be classified as an adult or not (White & Folkens, 2005). The last skeletal area to complete ossification is the sternal end of the clavicle, starting around 21 years and ending around 28–30 years of age (Schmeling et al., 2008; Schulz et al., 2008).

The well-known and internationally used volumes by Scheuer & Black (2000), Schaefer et al. (2009), and Cunningham et al. (2016), reporting ages and degrees of fusion for each bone of the immature skeleton, were employed in this study.

It has to be remembered that individual, secular, and population differences strongly affect the degree of reliability of these estimates, and that the epiphyseal fusion generally occurs earlier in females compared to male individuals (White & Folkens, 2005). However, the availability of different cranial and postcranial elements allows determination of a reasonable age range for immature individuals, in the absence of dental elements or when the skeleton is incomplete.

5.1.1.3. Long bone measurements

In the absence of dental elements, bone fusion evaluations were integrated with methods based on bone measurements. The basis of these techniques is that the chronological age of individuals is correlated with their long bone diaphyseal length (or with the measurements of other skeletal elements). Specific tables reporting the age intervals for each bone measurement are mostly used for older children and adolescents (Fazekas & Kósa, 1978; Stloukal & Hanáková, 1978; Ubelaker, 1989). Linear regression formulas in which the length of the bone element has to be inserted are much more useful for babies (Scheuer et al., 1980; Sherwood et al., 2000).

The limitations of long bone length methods have been widely discussed in literature and are mainly concerned with the weak correlation between the diaphyseal length and the gestational age due to endogenous and exogenous factors affecting mother and child. Age, height, social and nutritional status of the mother (Adair, 2004), secular changes (Hauspie et al., 1996), season, environmental or even noise pollution (Schell, 1981) are among the factors that may delay growth; the physiological mechanisms involved are still not completely understood (Lewis, 2007). It is therefore impossible to determine whether the child was small, average, or large for gestational age by simply relying on these measurements. Furthermore, it is known that metabolic disorders in the mother and fetus may hinder the normal growth of individuals, possibly resulting in age underestimation (Fewtrell et al., 2000; Moreira et al., 2015; Wu et al., 2004). In addition, Gowland & Chamberlain (2002) argued that aging methods based on regression formulas may produce biased results because they mimic the age distribution of the reference datasets on which they are based. The authors therefore proposed a reassessment of perinatal skeletal remains from Romano-British sites using a Bayesian age estimation procedure (Gowland & Chamberlain, 2002).

However, those methods based on diaphyseal lengths remain the only methods available in the absence of dental crowns, and are still considered to provide reliable estimates of age for non-adults. Due to the rapid bone growth occurring in a very short time, large differences in bone length between age categories are observable and quantifiable (Jeanty & Romero 1984; Lewis & Gowland, 2007). The age estimation methods employed in this work are listed in Table 4.

Table 4. Methods employed for age at death estimation in the non-adults.

Method	Reference
Long bone diaphysis length	Fazekas & Kósa (1978); Stloukal & Hanáková (1978); Ubelaker (1989); Scheuer et al. (1980), Sherwood et al. (2000)
Bone Fusion	Scheuer & Black (2004); Schaefer et al. (2004); Cunningham et al. (2016)
Tooth Eruption and Formation	Moorrees et al. (1963); Ubelaker (1989); AlQahtani (2010)

5.1.2. Considerations on sex estimation in non-adults

Sex estimation represents the Holy Grail of non-adult bioarchaeology. The amount of information we could obtain would be priceless, not only for more accurate age estimations, but also for understanding of gender roles during childhood, identification of differential treatments reserved to males and females at different ages, as well as gender-linked differences in burial customs, dietary choices and resistance to diseases. Numerous factors affecting the *sex ratio* of the populations could be investigated further, resulting in interesting new lines of research. For instance, estimating the sex of perinates and neonates would allow exploring unknown aspects of childcare affecting survival in different historical periods.

However, the path towards an accurate sex estimation in children is still long and quite tortuous. In adults sex is estimated by comparing clearly recognizable dimorphic characteristics of skull and pelvis; these allowed development of methods exceeding 98% accuracy (Phenice, 1969; Buikstra & Ubelaker, 1994) This task becomes particularly tricky in non-adults where we are observing secondary sexual characteristics, since the dimorphic traits of skull and pelvis do not appear before puberty, greatly affecting the accuracy of our estimation. Hence, obtaining a reliable sex estimation by applying only morphological techniques is not possible. The methods for sex estimation in non-adults hardly reach 70–80% accuracy, with great overlap between male/female characteristics and problems in testing the techniques on populations different from the reference ones. The majority of these methods show an increased reliability for individuals older than 10 years of age (Lewis, 2007; Loth & Henneberg, 2001).

Biomolecular techniques based on aDNA are currently among the most reliable sex estimation methods available. These rely on sex-specific sequences in the amelogenin and SRY genes on the X and Y chromosomes (Stone et al., 1996). Research on the topic recently resulted in sex determination through DNA shotgun sequencing (Skoglund et al., 2013; Mittnik et al., 2016).

Since the majority of the individuals included in this study were babies and infants, it was decided to avoid the application of anthropological sex estimation methods in this work. However, 10 perinates from the rural and urban sites under study were selected for aDNA. In addition to detection of disease biomolecular markers, this analysis will also allow for genetic sex estimation. This will provide precious information on possible gender-related differential treatment of these babies.

5.1.3. Paleopathology

The pathological assessment of each individual took place in the laboratory through macroscopic examination. To systematically record the presence or absence of any relevant pathological change, the bioarchaeological recording forms were provided with a dedicated section (Sheet 3). A detailed protocol (Appendix 1), including each pathological change and its recording system, was developed with the aim of making this research easy to repeat and compare with other similar studies. The protocol was developed following internationally used standards and guidelines (Brickley & McKinley, 2004; Mitchell et al., 2017).

Each significant sample feature was photographed and labeled. The interpretation of lesions was conducted through differential diagnosis referenced to proper clinical and paleopathological literature (Aufderheide & Rodriguez-Martìn, 1998; Ortner, 2003; Waldron, 2009; Lewis, 2018).

Recording of the pathological lesions was designed to allow collection of essential information regarding specific aspects of physical health and diet, particularly focusing on the skeletal lesions indicative of infectious and systemic metabolic disease (vitamin C and D deficiencies, anemias and other carential diseases linked to diet and nutrition of the individuals). The standardized recording of these lesions allows comparison between individuals from different social groups, ages, and social status.

Identification of specific metabolic diseases can be extremely challenging with perinatal remains. This is due to the difficulty in distinguishing subtle bone production/porosity related to normal age-specific physiological growth from pathological lesions. In addition, various metabolic diseases often co-occur, resulting in the enhancement or obliteration of particular diagnostic lesions (Schattman et al., 2016). Given the complexity of the paleopathological investigation, the recording system was customized for fetal, perinatal and neonatal remains in this study. The type and distribution of the observed bone changes were examined macroscopically and grouped into four specifically crafted macro-categories of cranial and postcranial lesions (Table 5). These skeletal changes are those most frequently encountered in metabolic disease studies, but unfortunately, they are also those more subject to diagnostic mistakes. Hence, a more detailed description was needed to record them properly, and a present/absent recording criterion was adopted to avoid an excessively subjective evaluation. This was also performed in the light of the Papers III and IV, specifically dedicated to the pathological lesions of this section of the population.

The scoring system by Stuart-Macadam (1991) was used for cribra orbitalia and porotic hyperostosis. The differential diagnosis for Vitamin C deficiency was performed following the "Ortner criteria", while Vitamin D deficiency was differentially diagnosed following internationally accepted criteria (Table 6).

For each individual, each relevant lesion was first recorded with standard photography, after which Reflectance Transformation Imaging (RTI) was employed to provide detailed magnifications of the subtle surface lesions.

In infants and children, the pathological lesions were recorded with a presence/absence criterion to increase comparability with other coeval populations, to avoid intra-observer error (particularly problematic when subjective grading systems are used), and also to save as much time as possible during the process.

The conditions examined in this work, as well as their potential causes and guidelines for differential diagnosis, are listed in Table 6.

Table 5. Skeletal changes attributable to metabolic disease, recorded for fetal, perinatal and neonatal remains.

Pathological Changes	Description	Reference
Abnormal porosity	1. Localized condition in which fine holes, visible without/with low magnification and typically < 1 mm in diameter, penetrate a lamellar bone surface. 2. On long bones, abnormal porosity extends > 10 mm from the distal metaphyseal plate, differently from porosity due to normal endochondral growth.	Ortner (2003)
Bone deformation	1. Alterations in shape and dimensions in response to developmental abnormalities or trauma. 2. Torsion, bending, antero-posterior or lateral bowing are recorded for the long bones.	Ortner (2003); Waldron (2009); Lewis (2018)
Endocranial lesions	1. *Inflammatory pitted lesions*: porous bone formation of white or gray color, often surrounding the sagittal and transverse cranial sulci and the cruciform eminence. 2. *Fiber bone deposits*: of white or gray, fiber or immature new bone formation 3. *Capillary formations*: new bone organized with or around vascular structures. Appear as flat isolated layers of subperiosteal new bone on the original surface with smooth texture and vascular reaction. May also appear as vascular impressions extending into the inner lamina, with no new bone formation. 4. *'Hair-on-end' lesions*: expansion of the diploë. May become 'frosted' or thickened and remodeled.	Lewis (2004; 2018)
Subperiosteal bone production	1. Deposition of a new fine layer of bone under an inflamed periosteum, forming localized or diffused bone deposits. 2. Recorded as healed (compact bone) or active (woven bone).	Ortner (2003)

Table 6. Pathological conditions recorded in this thesis. Respiratory infections were not discovered in the material under examination but are included in the table for completeness. Similarly, although dental disease was not the main object of this dissertation, it was still recorded during the work, and included in the RTI capture testing. Future research will further explore this topic.

Pathology	Potential cause	Reference
Metabolic disease		
Cribra orbitalia and porotic hyperostosis	Dietary deficiency or malabsorption (iron, vitamin B_{12})	Ortner (2003); Stuart-Macadam (1987a, 1987b, 1991); Walker et al. (2009)
Scurvy	Dietary vitamin C deficiency or malabsorption	"Ortner criteria": Ortner & Ericksen (1997); Ortner et al. (1999, 2001); Ortner (2003); Brown & Ortner (2011). Further guidelines: Brickley & Ives (2006); Geber & Murphy (2012); Armelagos et al. (2014); Buckley et al. (2014); Crandall & Klaus (2014a, 2014b); Stark (2014); Moore & Koon (2017); Snoddy et al. (2017)
Rickets/ osteomalacia	Vitamin D deficiency due to insufficient exposure to sunlight or dietary deficiency	Ortner & Mays (1998); Ortner (2003); Brickley & Ives (2006); Mays et al. (2006); Mays (2008)
Infectious disease		
Respiratory infection: Tuberculosis, Brucellosis	High population density, poor living conditions, air pollution, close relations with domestic animals	Roberts & Buikstra (2003); Roberts & Cox (2003); Roberts et al. (1998)
Non-specific infection: Subperiosteal Bone Production (SBP), osteitis, osteomyelitis	Chronic or recent/ongoing pathological condition: systemic infectious disease (syphilis, leprosy, TB etc.), soft tissue or skeletal trauma, metabolic disease (scurvy)	Resnick & Niwayama (1995); Ortner (2003); Roberts & Manchester (2005); Weston (2008); Larsen (2015)
Dental disease		
Enamel hypoplasia	Early life physiological stress, metabolic disease, Infectious disease, psychological stress	Lukacs (1991); Lukacs et al. (2001); Hillson (1996)
Periodontal disease, caries, periapical lesions, AMTL, dental calculus, dental attrition	Dietary factors, oral hygiene, metabolic disease, pregnancy, access to dental treatments	Smith (1984); Buikstra & Ubelaker (1994); Roberts & Connell (2004); Ogden (2008)

5.2. Carbon and Nitrogen Stable Isotope Analysis

Human bone collagen provides information on individual dietary intake at different life stages. For cross-sectional analysis, rib fragments are generally used, showing a short-term dietary average of 2–5 years prior to death in adults (Sealy et al., 1995; Fahy et al., 2017). Bone turnover rates vary in respect to the individual's age, being faster in babies and infants, and slowing down with age (Fahy et al., 2017; Szulc et al., 2000). Providing a universal turnover value is unreasonable since a plethora of factors affect the process. Among these, the age of the individuals (turnover is accelerated in early infancy), and their relation to birth (for instance, turnover after birth is higher in premature babies compared to full-term babies) strongly influence remodeling (Lapillonne et al., 2000; Szulc et al., 2000; Shiff et al., 2001). Other factors that play a significant role in determining the time of bone remodeling include metabolic diseases such as rickets or any pathology that leads to osteopenia (Lapillonne et al., 2000), the lifestyle and malnutrition of the mothers (Högler et al., 2003; Wu et al., 2004), and of course the specific skeletal element and bone area sampled.

The sampling strategy was specifically crafted according to the research questions of Paper V, which investigates the staple diet and feeding practices of Estonian children:

- The adult individuals (N=60) were sampled to constitute a comparative sample, answering the question regarding whether children accessed food sources differently from the adult population.
- Non-adult individuals (N=176) were selected to obtain a sample virtually representing all age categories from both rural and urban sites, to investigate possible disparities in diet and feeding practices among children of different ages and contexts.
- Particular attention was given to the age ranges between birth and 3–4 years, since I was interested in determining for how long Estonian children were breastfed, and at which age the weaning process began and ended. The adult female individuals were selected to have a baseline representing the possible mothers.

Well-preserved ribs or rib fragments were preferred for sampling. However, when these were unavailable or pathological, long bones (mainly upper limbs for consistency) or other skeletal elements were chosen. From these, 60–100 mg of bone pieces and powder were collected with a Saeyang Marathon-N7 drill using new precleaned drill bits for each sample at the University of Tartu (UT) Department of Archaeology laboratory. The samples were photographed before and after drilling, and then processed at the Archemy Lab, UT.

5.2.1. Collagen extraction and EA-IRMS analysis

Collagen extraction was performed using the modified Longin method (Brown et al., 1988). Bone samples were demineralized in 0.25M hydrochloric acid solution (HCl) at room temperature for 48 hours. The demineralized samples were then rinsed with deionized water, and collagen was gelatinized in the oven at 58 °C for 16 hours in tubes with 0.01M HCl (Figs. 9a, b). The resulting solution was filtered with Whatman® nitrocellulose membrane filters (pore size 5 µm) to remove any insoluble residue, and freeze-dried (Figs. 9c, d).

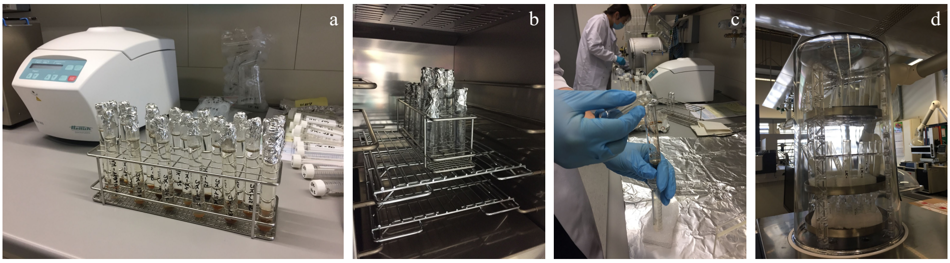


Figure 9. Some steps of the collagen extraction process. **a)** Demineralization in 0.25M HCl. **b)** Gelatinization in the oven with 0.01 M HCl. **c)** Filtration of the resulting solution with glass syringes and nitrocellulose membrane filters. **d)** Freeze-drying of the samples. Photos by Alessandra Morrone.

The analysis was performed on duplicated samples and was subject to material availability. Stable carbon (δ^{13}C) and nitrogen (δ^{15}N) isotopic compositions were measured using EA-IRMS (Glossary) at the Department of Geology, UT. Bone collagen samples (~1.0–1.2 mg) were weighed into tin capsules and combusted in a Thermo Flash HT EA with the introduction of separated N2 and CO2 to a Delta V Plus™ via a ConFlo IV™ interface. The analysis was run in duplicates (i.e., two samples of collagen from the same individual), and the final values averaged. The data were calibrated against international standards from IAEA (for nitrogen IAEA N-1, δ^{15}NAIR= +0.4‰, IAEA N-2, δ^{15}NAIR= +20.3‰, USGS25, δ^{15}NAIR = −30.4‰, and for carbon IAEA CH3, δ^{13}CVPDB = −24.72‰, and IAEA CH6, δ^{13}CVPDB = −10.449‰). The results are expressed using the delta notation in parts per thousand (per mil or ‰, see (McKinney et al., 1950)) relative to the international marine limestone VPDB standard for carbon and AIR for nitrogen. The long-term stability error for the isotope value measurements, estimated from repeated measurements of international and laboratory standards, was better than ±0.2 ‰ (1sd) for nitrogen, and ±0.1 ‰ (1sd) for carbon.

Collagen preservation was established according to standard quality control methods: C:N atomic ratio between 3.07 and 3.59; weight percent collagen yield ≥1%; weight percent carbon (%C) >13%; weight percent nitrogen (%N) >4% (De Niro, 1985; Ambrose, 1990, 1993; van Klinken, 1999; Guiry & Szpak, 2020). Similar results indicate good collagen preservation in the samples under examination, and minimal alteration due to taphonomic factors.

As major food group baseline references, the mean values of the adult population from the sampled cemeteries were used. The adult individuals (n=25) were sampled and analyzed by me, while the local and temporally coeval faunal stable isotope results were provided by Aguraiuja-Lätti (original data), and Malve (original data).

5.2.2. Statistical analysis

Statistical analysis employed in Paper V was performed using PAST 4.09 free software (Hammer et al., 2001). In the case of a SIA dataset, we are dealing with numerical continuous values. These are connected to groups based on qualitative data, such as age and sex categories. The first essential step when dealing with archaeological samples and isotopic results is to understand whether the population data under study are normally distributed. The successive appropriate statistical tests are then chosen according to the statistical distribution of the sample. The most commonly used statistical test for this purpose is the **Shapiro-Wilk test of normality**. This was used in this study before selecting the appropriate comparative tests.

The urban portion of the data from this study has shown a normal distribution, while the rural part was not normally distributed. Although the whole rural sample did not follow a normal distribution, the single rural subgroups varied due to limited sample size, some showing a normal distribution and others not. When the samples to be statistically compared are not all normally distributed, it is necessary to apply non-parametric statistical tests to obtain a reliable comparison between them. Generally, the **Mann–Whitney *U* test** (the non-parametric equivalent of a two-sample t-test) is used to understand whether significant differences exist between the individuals from two different samples. Here, this test was used to compare rural and urban samples. The **Kruskall–Wallis test** (the non-parametric equivalent of the ANOVA test) is generally used to detect whether significant statistical differences exist among more than two samples. In this study, I have used this test to compare the SIA values among the four different cemeteries, as well as between different age ranges. Possible statistical outliers were identified using the **IQR (Tukey's Interquartile Range) criterion**, in which individuals exceeding the interquartile range of the sample are considered anomalous.

5.3. Reflectance Transformation Imaging (RTI)

The recording of subtle surface lesions is a challenging task in paleopathology, especially when dealing with fetal and perinatal remains. For this reason, it was decided to test the applicability of Reflectance Transformation Imaging (RTI) on several paleopathological specimens to understand whether it could provide suitable documentation options for identifying and recording subtle pathological lesions. RTI is a photographic method that combines a set of photographs of an object obtained under different illumination conditions, enhancing subtle surface details and creating an interactive digital image (Earl et al., 2011; Mudge et al., 2006, 2008; Mytum & Peterson, 2018). RTI has been frequently used in archaeological artifact studies (Mudge et al., 2005; Dellepiane et al., 2006; Malzbender & Gelb, 2009; Earl et al., 2010; Karsten & Earl, 2010; Montani et al., 2012), paleontology (Hammer et al., 2002), forensic sciences (Hamiel & Yoshida, 2007), art history (Padfield et al., 2005; Purdy et al., 2011; Diaz-Guardamino et al., 2015) and cultural heritage management (Malzbender et al., 2000; Malzbender & Gelb, 2001; Malzbender et al., 2001; Mudge et al., 2008; Malzbender & Gelb, 2009; Schroer & Mudge, 2012; Duffy, 2013; Pagi et al., 2017). However, its use for studying human remains has been limited to the examination of surface details such as striations, taphonomical alterations, or tool marks in archaeological contexts (Newman, 2015), and to cut-mark analyses in forensic contexts (Clark & Christensen, 2016; Martlin & Rando, 2020). Paper III is the first study in which the technique was applied to pathological bone.

In the RTI process, for each analysis a set of photographs is acquired with a camera in a fixed position, using the same camera settings at each acquisition (exposure, white balance, focal point, etc.). An external light source (continuous light or flash) is employed to illuminate the sample at a series of different angles, thus creating a series of different shadows on the surface of the item. Normally, 40–70 images are acquired during each data capture, with each image recording a different illumination angle. In this way, a number of different shadow patterns are recorded, and each pattern enhances different aspects of the object's surface (Pagi et al., 2017). The technique employed in this work uses a fixed set of illumination sources known as a "dome setup", in which each light is energized separately, and its position is known from the design of the dome. In this case, the known light location information can be used later during the RTI processing. This method allows for fast capture and processing speeds, but the objects need to be transportable and compatible with the dome, and are therefore of limited size (Pagi et al., 2017).

Image processing is performed using the free software RTIBuilder that combines the multiple images into a single file, accessible through a dedicated viewer (RTIViewer), which allows virtual re-illumination of the object and observation from any angle. The official website provides downloadable copies of the RTI-Builder and RTIViewer software.

The visual data for this study were captured at the ArchaeoVision laboratories (Tallinn, Estonia) using a Nikon DSLR camera in manual settings, with a fixed-focal-length macro lens. A dome with a fixed set of lights ("dome setup") was used, since the dimensions of the bone specimens were relatively small, allowing them to be transported to the laboratory and placed under the instrument (Fig. 10a). The camera was fixed on the dome, positioned directly above each bone specimen, with the camera aligned to the object at a 90° angle. 50 photographs were taken during each RTI sequence.

After performing the white balance correction and converting them to JPEG format (Fig. 10b), the photographs must be processed using specific software, in my case the RTIBuilder with HTH Fitter (Hemispherical Harmonics fitting algorithm, available by default in the RTIBuilder bundle), which employs the known dome light directions and directly generates a single RTI file as output. At this point, the file can be easily viewed using the RTIViewer software (Fig. 10c) and manipulated according to need with dedicated rendering modalities.

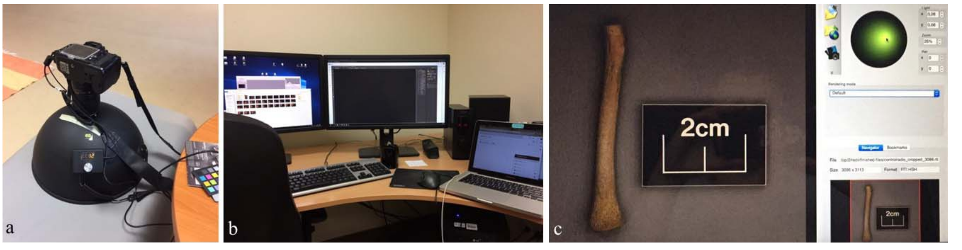


Figure 10. RTI capture working flow. **a)** The dome setup with camera. **b)** Working area with Camera Control Pro software. **c)** RTIViewer software interface. The light position panel is visible in the upper-right side of the interface, and the illuminating angle can be modified by manipulating the light controller circle or by changing the numeric values in the light position x/y coordinate scale. Photos by Alessandra Morrone.

The pathological changes of bones and teeth were first examined macroscopically, and then each standard photograph was compared with RTI images to determine the relative level of detail revealed in the RTI captures. Paper III stands as a pioneering study for the use of RTI on pathological specimens, resulting in a large dataset of unmodified and rendered photos of different pathological conditions, which can be used for future reference. Specific details and information on the application of the RTI technique can be found in the Materials and Methods section of Paper III.

Pathological bone changes of productive, destructive, and mixed nature were considered for the RTI testing. The lesions of paramount interest chosen for the study of non-adult disease are SBP, endocranial lesions, abnormal porosity, cribra orbitalia, and enamel developmental defects. As mentioned in Chapter 3.4, the recording of similar bone changes is informative in the study of the health of past children, since the former three lesions can be suggestive of systemic metabolic disease, and the latter two are non-specific physiological stress indicators.

SBP is produced by the inner strata of the periosteum in response to inflammation caused by local or systemic infections, metabolic disorders, or traumatic events (Ortner, 2003; Waldron, 2009). **Endocranial lesions** are generally associated with low-grade inflammations of the meninges caused by meningitis, birth traumas, infections or metabolic conditions such as scurvy. Since their etiology is often obscure, they are considered evidence for non-specific physiological stress (Lewis, 2007, 2004). The **anomalous porosity** of cranial and postcranial elements is one of the main features recorded in case of systemic metabolic diseases such as scurvy and/or rickets. These lesions are among the most challenging in the paleopathology of children, as it is quite difficult to relate this subtle porosity to effective pathological processes rather than to normal physiological patterns

(Lewis, 2018). **Cribra orbitalia** is indicated when consistent pitting of the orbital roofs is identified. These lesions are generally related to iron deficiency anemia, thalassemia, parasite infections, malnutrition in mother and child, and malnourishment due to nutritionally poor or contaminated weaning foods (Lewis, 2007; Waldron, 2009). **Hypoplastic enamel defects** may appear as pits, furrows or large areas of missing enamel, and are normally regarded in bioarchaeology as non-specific indicators of stress caused by starvation, disease, or even psychological stress (Waldron, 2009). Blunt force trauma and Schmorl's nodes impressions can also be added to the list, since it is not infrequent to detect episodes of child abuse in archaeological material, as well as signs of heavy load lifting in very young individuals.

6. RESULTS AND DISCUSSION

The development of this dissertation allowed me to explore several aspects of childhood in the past from unexpected angles, turning my research into a kaleidoscope of different approaches.

From a theoretical point of view, Paper I presents an overview of the available child skeletal remains in the Baltic countries over prehistoric and historic periods. This was performed to trigger a reflection regarding child bioarchaeology in this area of Europe. These remains have significant potential for enabling wider and multifaceted bioarchaeological analysis of non-adult remains in the region. An essential aspect I would like to stress here concerns the availability of the materials, since a large number of well-preserved child burials is available for analysis. Although some papers report a problem of child underrepresentation in prehistoric and historic cemeteries (Gerhards, 2002; Zariņa, 2009; Malve et al., 2012; Roog & Malve, 2012; Ērkšķe, 2020), in many other contexts non-adults are more proportionally represented, constituting a large and nearly unstudied part of prehistoric and historic cemeteries in the Baltic states. Several examples can be listed for medieval/early modern Estonian contexts. For instance, the percentage of non-adult burials calculated for the urban cemetery of St Jakob in Tartu represented ca. 50% of the whole cemetery population, which is consistent with several other coeval churchyards. Similar (and sometimes larger) percentages were calculated for the urban cemetery of St John in Tartu (Kalling, 1995), the village cemetery of Tääksi in Viljandimaa (Allmäe, 1998), the Valjala cemetery in Saaremaa (Mägi et al., 2019), the rural cemetery of Makita in Tartumaa (with an impressive percentage of 60.8% non-adults (Heapost, 1993)), and the village cemetery of Mustla (Kaldre et al., 2011). These are just a few examples of the large number of immature skeletal remains available for study, which provide the quantity, quality, and potential to support large new research projects. Non-adult burials represent an essential and conspicuous part of archaeological reports, but they have been frequently ignored from a bioarchaeological point of view. With this dissertation, an attempt was made to fill this gap from the perspectives of paleopathology and SIA. The remarkable preservation conditions of the materials did not only allow me to perform my investigation in near-ideal conditions, but also constituted a promising starting point for new paleopathological, biochemical, and biomolecular analyses. These analyses should be undertaken by the next generations of Baltic osteologists, whose combined work may contribute step by step to acknowledge and minimize the issues of the Osteological Paradox with regard to these materials and topics.

As explored in Paper II, to overcome and partially downplay the effects of the Paradox, Wood et al. (1992) strongly recommended a multidisciplinary approach to the study of past lives, always keeping in mind the importance of historical records and contextual information. Wood et al. (1992) indeed stressed that, with regard to these topics, "*(...) the osteologists are unlikely to make fundamental contributions, and must remain consumers rather than producers of the relevant* *theory and observations*". Later on, they suggested a final paramount task in which the bioarchaeologist does have an active role, such as the investigation and better understanding of the historical and cultural contexts from which the material is driven (Wood et al., 1992). It is generally agreed that the historical scientist should greatly benefit from this collaborative and "omnivorous" approach (Siek, 2013; Reitsema & McIlvaine, 2014; Temple & Goodman, 2014; Milner & Boldsen, 2017; DeWitte & Yaussy, 2020).

During the unfolding of this doctoral project, the opportunity to take up this challenge became automatically appealing. Here, multiple techniques were used to explore past Estonian children from several perspectives, fulfilling the request for an "omnivorous" bioarchaeological approach, and a sincere search for a historical *truth*. RTI, a technique previously used for other kinds of cultural heritage materials, was chosen to support the paleopathological investigation of non-adult remains (Paper III). Subtle and pathological lesions in children constitute a typical example of *Heterogeneity in frailty* and *Selective mortality*: each individual in a cemetery sample shows the effects of disease in a personal way, and the difficulty in distinguishing pathological and physiological bone changes greatly complicates the differential diagnosis and the consequent pathological profile of the population. A better display of bone surface features helps minimize these issues, providing the means for a better understanding of the nature of the lesions. A more careful detection of disease patterns in babies offered further explanations for their anomalous burial conditions in Paper IV, in which the integration of paleopathological, historical, and archaeological data have been fundamental for developing the discussion regarding metabolic disease, marginalized members of society, and premature death in medieval Estonia. Here we have not only been consumers, but also producers of multifaceted historical data, again dealing with the concepts of *Heterogeneity in frailty* and *Selective mortality*. The detection of metabolic disease greatly contributed to the understanding of the general and anomalous isotopic data presented in Paper V. Here, the staple diet and feeding practices of Estonian children were explored, providing further data in support of the historical sources and pathological reconstruction. All the points of the Paradox were addressed in this study, since SIA values were discussed for individuals with and without signs of disease, who came from different populations that were either stationary or not. Although there is no way to solve this theoretical problem, this multidisciplinary approach did provide new reliable data to at least downplay its effects.

In the next three paragraphs, I will present how much has been learned about past Estonian children from multiple proxies, and how these means were able to compensate for each other's flaws in the reconstruction of the final picture.

6.1. RTI as a propaedeutic means for studying pathological bone

In paleopathological studies, it occurs very often that particular surface changes, which are clearly visible to the naked eye and under laboratory illumination, turn out to be almost invisible when attempting to record them photographically. This hinders the documentation process and the amount of information obtainable from the specimens, as well as the creation of a reliable reference base for different pathologies. The paleopathologist fully experiences only the lesions encountered in the samples analyzed personally, and often must deal with absent or problematic descriptions/imaging from the experiences of others.

The trial application of RTI to different samples of non-adult bones has been quite successful here, as it allowed highlighting of subtle features by exploiting the shadows from different illumination angles (Figs. 11 and 12).

Figure 11. a) SBP on tibia, magnified detail of the midshaft. RTI image of the midshaft with illumination angle from below. This means that the light source that resulted in the best visualization came from below the lesion. **b)** Schmorl's node impression. RTI image with illumination angle from below. **c)** Endocranial lesions in the form of capillary formations on occipital bone. RTI image with illumination from the right. **d)** Abnormal porosity of a perinatal right maxilla. RTI image with Specular Enhancement rendering modality. **e)** Oval-shaped remodeled blunt force trauma on a frontal bone. This individual (JK-1) was the lady buried with the babies in Mass Grave 1, St Jacob's cemetery (Paper IV). RTI images with illumination angle from the lower left. Photos by Alessandra Morrone.

The best results for RTI improvement of the visibility of lesions were obtained when the bone changes were extremely shallow, both for the productive (SBP, endocranial lesions), and for the destructive mechanisms (impressions of Schmorl's nodes, abnormal porosity, enamel hypoplastic defects) (Figs. 11a–d and 12). Remodeled blunt force traumas were also well shown (Fig. 11e). In these cases, RTI enables the display of the whole perimeter and depth of the lesions in one single image, and with one single capture session. Unfortunately, RTI did not produce significant improvement for recording cribra orbitalia, since the pitted lesions are too shallow to benefit from the enhancement of shadows on the bone surface.

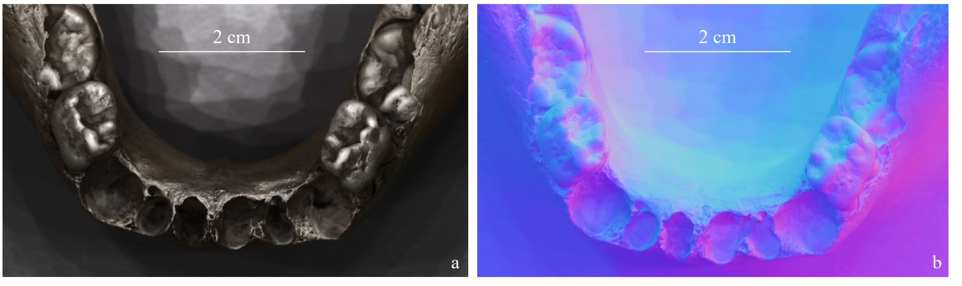


Figure 12. Pitted hypoplastic defects in an individual around 2 years of age. **a)** RTI image with Specular Enhancement rendering mode. **b)** RTI image with Normals Visualization rendering mode. Photos by Alessandra Morrone.

Particularly in babies, the distribution pattern of subtle lesions is sometimes as important as their individual appearance. RTI allows representing an object in its entirety, especially when dealing with tiny bones. The ability to manipulate the light conditions across a whole specimen is sometimes more important than the evaluation of the size or shape of specific lesions. Reporting subtle lesions in perinates and infants is crucial, as these non-extreme patterns are regularly encountered in paleopathological studies, and in some instances, other means of investigation such as microscopy and radiology are not as readily available in the field as RTI can be.

More importantly, this technique allows recording skeletal lesions in a rapid, inexpensive, and representable format. The resulting digital RTI file can be shared and interactively used by different scholars, allowing for complete, simultaneous and synergistic analyses of the material by several researchers, thereby increasing the probability of reaching a successful differential diagnosis. The remote visualization and manipulation of the files enable different researchers to provide expert consultations and specimen comparisons without physically moving the object. These capabilities provide the broadest benefits if the data are available in open access repositories (see repository for Paper III).

After testing this technique, it became clear that it could have been highly useful for displaying the skeletal changes in the sample of perinates from St Jacob's cemetery, which are the main interest and object of the paleopathology-focused Paper IV. The detection, interpretation, and especially imaging of those shallow lesions have been constant issues in the development of this case study, since even micro CT-scanning had been unsuccessful in capturing them. RTI turned out to be a propaedeutic tool in the study of systemic metabolic disease in these samples and allowed production of images for the dedicated publication. The successful testing of RTI in this case study proves that this method is a promising and useful tool to tackle these kinds of osteological lesions and has the potential to be used in further studies beyond the scope of this work. Continuing on this line, we can now move deeper into what these paleopathological lesions tell us about Baltic children in the past.

6.2. Perinatal disease in medieval Tartu: paleopathology of St Jacob's cemetery mass graves

Paper V of this dissertation presents the paleopathological study of the four mass graves and two double burials of babies located outside the cemetery walls of St Jacob's cemetery in Tartu, which were dated between the 13^{th}–15^{th} centuries AD. In ten of these 43 individuals, a recurrent pathological pattern including SBP (Glossary), abnormal porosity, endocranial lesions, and bone deformation was observed, and successfully displayed with RTI (Fig. 13). The differential diagnoses, performed in light of the bioarchaeological profile of the samples, were compatible with systemic metabolic disease, most likely connected to the nutritional status of the mothers.

The bioarchaeological profiles of the 43 individuals were reflected in their atypical burial treatment and discussed in the light of the available historical sources, especially with regard to baptism customs. Their estimated age-at-death covered the fetal and perinatal range (all babies in the samples were between 20 and 42 weeks of gestation), meaning they were either aborted or died around the time of birth.

Despite the scarcity of historical data concerning births and deaths in the Livonian Middle Ages, some written sources report that about half of a woman's offspring died from birth trauma, disease, negligence, or other reasons within the first year of life (Põltsam-Jürjo, 2017). Another unfortunately common occurrences in medieval and early modern Livonia were episodes of violence against unwanted newborns, sometimes reaching extreme scenarios such as murder. Illegitimate children who could not be fed and raised by a mother living in poverty often fell victim to similar crimes, which were perceived to be even worse in the case of an unbaptized child, deprived of the opportunity to enter the kingdom of heaven (Põltsam-Jürjo, 2017).

As anticipated in Chapter 3.4, in the Christian tradition the most important event after birth was baptism, which had to be performed within a month after birth and was mandatory for joining the Christian community (Põltsam-Jürjo, 2017). For this purpose, the child was usually taken to church, but occasionally baptized at home. An exceptional case was domestic emergency baptism, usually performed by a midwife. According to the 1428 Riga Provincial Council, the baptismal formula was required to be uttered in a clear and loud voice, since it contained the power of the sacrament ("*...in quibus virtus consistit sacramenti*").

Priests were also required to teach baptism to both men and women, and this was also allowed in the mother tongue (Põltsam-Jürjo, 2017). A scenario such as the one presented in the first quote of this dissertation, in which Tess of the D'Urbervilles is forced to baptize her own baby on its deathbed, must have been a sadly common event in medieval Livonia.

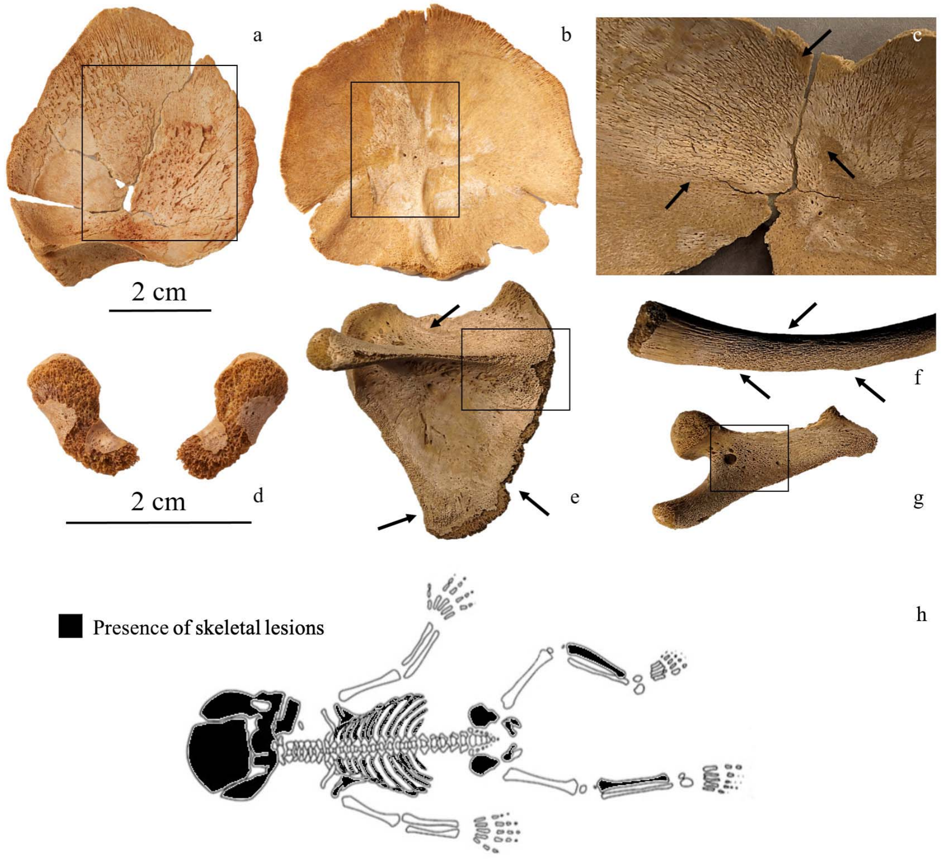


Figure 13. Patterns of skeletal lesions observed in the sample of 10 pathological babies. The individual in the collage is Ind. 14d from Mass Grave 3. **a)** Capillary endocranial lesions on the left frontal bone. Standard photograph. **b)** Inflammatory pitting on the occipital bone squama. Standard photograph. **c)** The arrows outline the capillary endocranial lesions on the left parietal bone. RTI image with illumination angle from below. **d)** Pubic bones showing bone loss and porosity. Standard photograph. **e)** Left scapula showing abnormal porosity on the supraspinous/infraspinous areas (arrows). RTI image with illumination angle from the upper right. **f)** Abnormal porosity and SBP on a central rib, indicated by the arrows. RTI image with illumination angle from below. **g)** Left scapula showing abnormal porosity on the supraspinous area. RTI image with illumination angle from the upper right. **h)** Graphic scheme showing the distribution of the skeletal lesions in this sample. Photos by Alessandra Morrone.

As commonly occurred in other medieval European contexts, in Livonia death before baptism resulted in exclusion of the newborn from proper burial in consecrated ground (Crawford, 1991; Ērkšķe, 2020; Gardeła & Duma, 2013; Murphy, 2011; Perez, 2014). Given the age of the babies in the St. Jacob's deviant burials, their premature death may have been too rapid to allow for even an emergency baptism, leading to their marginalization in multiple graves outside the cemetery walls. The inclusion of the mature woman in Mass Grave 1 strengthens the assumption of a burial area for outcasts, including beggars, slaves, and of course unbaptized babies. Unfortunately, we will never know what led this woman to marginalization in death.

The pattern of skeletal lesions observed in these ten babies was indicative of some type of systemic metabolic disease that could be rationally connected to the nutritional status of their mothers. Pathologies such as scurvy, rickets, or a co-occurrence of multiple deficiencies are likely to occur when low dietary diversity, quality, and/or quantity persist for extended periods of time, such as during famines and epidemics (Buckley et al., 2014; Geber & Murphy, 2012; Snoddy et al., 2016, 2017, 2018). Therefore, observing similar disorders in this sample fits well within the overall historical context of the period (Chapter 4.1.1.), since local sources report several subsequent episodes of famine and epidemic in medieval Estonia (Lang, 2006; Valk, 2006). The onset of acute and chronic infections such as TB, measles, syphilis, and the plague in pregnant women could easily have resulted in the premature loss of their offspring, especially if their health was already severely compromised by malnutrition. This may well have been the case back then, since the 1315–1317 Great European Famine was followed by several years of crisis during the whole 14th and 15th centuries, most likely affecting the population of Tartu as was reported for the whole of Livonia (Palli, 1996, 1997; Raudkivi, 2010).

My findings are consistent with more recent early modern Latvian material. In their 2013 study, Pētersone-Gordina et al. investigated metabolic disease in a wealthy, urban 17th–18th century population from Jelgava. The study identified rickets in 2 out of 28 observable non-adults (aged 3–6 months and 2–2.5 years), and scurvy was reported in 6 cases (aged from 3 months to 19 years), with a prevalence of 21% (Pētersone-Gordina et al., 2013). This is intriguingly similar to the prevalence of cranial and postcranial lesions in the babies from St Jacob’s cemetery (23.25%). However, the number of perinates (11) was lower than in my study, and the rest of the sample included older children. The authors argued that vitamin C deficiency in the non-adult diet was a significant problem even in this wealthy urban group, and historical sources reveal that the period over which the site had been used spanned times of devastating famine and warfare, which may have altered the normal subsistence strategies (Pētersone-Gordina et al., 2013).

Considering the overall date and context of my sample of babies, there are compelling reasons to believe these multiple graves resulted from one or more related mass fatalities. Although the problem exposed in Chapter 3.5.4. partially persists here since we cannot pinpoint any single specific fatality event due to the large AMS time frame, these babies lives overlap with several military, famine, and epidemic events described in written sources (Chronicle of Henry of Livonia 1180–1227, Book IV; Palli, 1996, 1997; Raudkivi, 2010; Selart, 2015. These protracted circumstances may have led to a co-occurrence of multiple deficiencies affecting mothers and fetuses. Combined with the unfortunate historical obstetric hazards, possible infections, and/or unhealthy cultural practices, these conditions may have easily resulted in abortion or stillbirth. For those who were born, a short breastfeeding period may not have been enough for them to recover properly, especially since a depletion of nutrient sources in the mothers could possibly result in vitamin-deficient breastmilk (Bourbou, 2018; Bourbou et al., 2013, 2019).

A natural outcome of this reasoning has been the issue of whether and how these questions could ever be answered, and whether we could get one step closer to the true stories of these marginalized individuals. A potential way to confirm or reject these assumptions is to apply SIA to reconstruct the diets of the mothers, to identify physiological stress in babies, and perhaps also to pinpoint the breastfeeding habits of the populations under study. The last paper of this dissertation was crafted to tackle these questions.

6.3. Diet, stress, and feeding practices in medieval and early modern Estonia through stable isotope analysis

Paper V explored one more aspect of non-adult life in medieval Estonia: child dietary staples and feeding practices. Although some information regarding infant diet in Livonia might be inferred from Lithuanian and Latvian studies, this knowledge was missing for medieval and early modern Estonia. Therefore, cross-sectional SIA in this study allowed comparison of infant and adult diets, and also identification of the timing when children were breastfed and weaned in medieval and early modern Estonia (Morrone, 2022). These analyses were performed on the marginalized babies from St Jacob's urban cemetery and on rural material from the Lohkva, Mäletjärve, and Makita cemeteries, covering all non-adult age categories.

Fig. 14 shows the results of SIA on the whole sample of 140 non-adults that met the collagen quality criteria, compared to the temporally and spatially relevant animal reference data (see Paper V). The mean $\delta^{13}C$ values of the whole sample (mean ± sd = –21.10 ± 0.50‰) suggest that the staple non-adult diet in medieval and early modern southern Estonia was based on a terrestrial C_3 ecosystem, dominated by C_3 plants or C_3 plant consumers and their secondary products. These results are compatible with $\delta^{13}C$ data from other coeval Baltic sites, reflecting the common subsistence in that period, with cultivations of barley, oats, rye, legumes, vegetables, fruits and berries constituting the main staple (Põltsam-Jürjo, 2013; Malve & Aguraiuja, 2014; Aguraiuja-Lätti & Lõugas, 2019; Lahtinen & Salmi, 2019; Lightfoot et al., 2016) (Fig. 15).

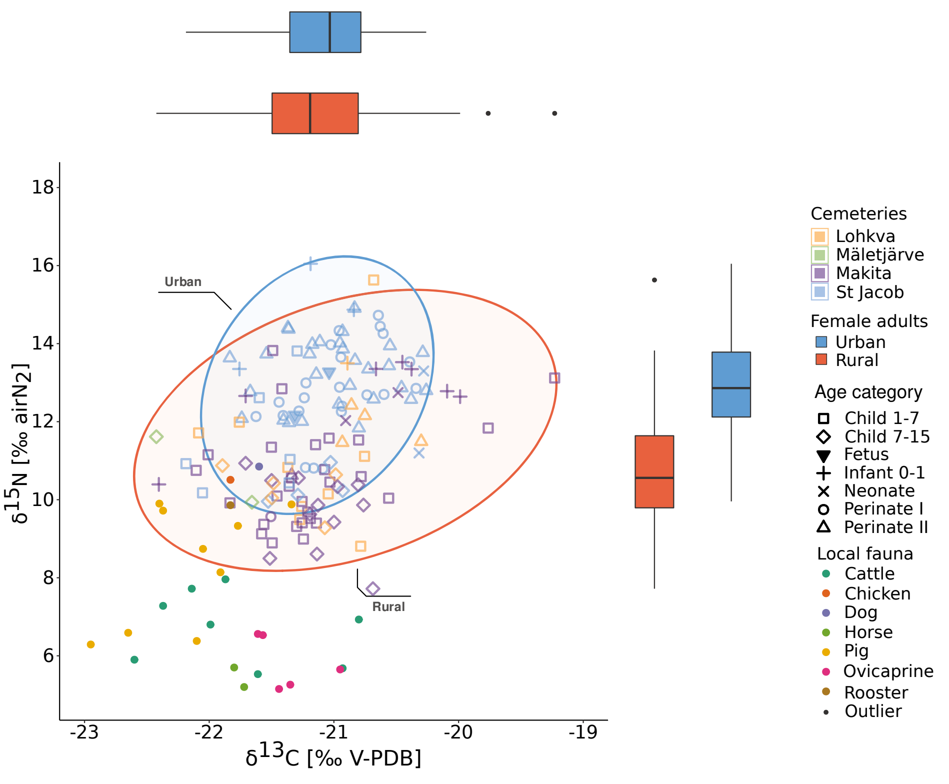


Figure 14. Carbon and nitrogen stable isotope values of the samples, color-coded to indicate the cemeteries used in this study. The urban and rural distributions are separated in the boxplots. The values of local fauna are added as references (Aguraiuja-Lätti, original data; Malve, original data). The ellipses indicate the 95% confidence interval. Here, the outliers (·) are outside of the interquartile ranges. Scatter plot and boxplots by Tina Saupe.

The analysis did not show any statistically significant difference in non-adult carbon values between urban and rural areas, with the former being only slightly higher than the latter (0.09‰). This suggests a similar diet for children living in different contexts, at least in these sites. The small difference in $\delta^{13}C$ could be attributable to slight variations in food habits and subsistence due to either ethnic differences and/or individual choices. Also, minimal differences were observed between rural sites, with the children from Mäletjärve showing lower $\delta^{13}C$ values compared to those from Lohkva and Makita, as well as compared to other Baltic sites (Fig. 15). This may be due to fewer animal products consumed by these children, and/or to lower amounts of available C4 plants. According to historical sources, the latter were included in the Livonian diet (Mänd, 2004; Sillasoo & Hiie, 2007. See Chapter 4.1.2.). This trend is also shown by adults, so it likely reflects a general population trend rather than a specific choice for children.

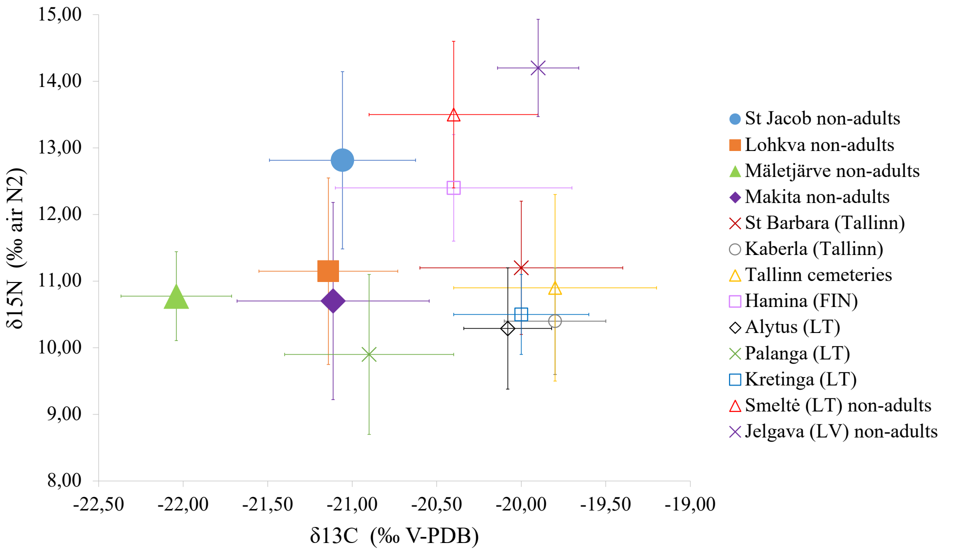


Figure 15. $\delta^{13}C$ and $\delta^{15}N$ mean values and standard deviations of the non-adult samples used in this study, compared to published data from medieval and early modern sites in Estonia and the Baltic area. From Tallinn, isotopic values from St Barbara, Kaberla, Holy Spirit, St Catherine, and Sulevimägi cemeteries were used (Lightfoot et al., 2016; Aguraiuja-Lätti & Lõugas, 2019). SIA values from Hamina cemetery in Finland were published in Lahtinen & Salmi (2019). The Lithuanian data from the town of Alytus come from Whitmore et al. (2018), and those from the coastal area (Palanga, Kretinga, and Smeltė) are published in Skipitytė et al. (2020). SIA data for the cemetery of Jelgava (Latvia) can be found in Pētersone-Gordina et al. (2018). Non-adult data was chosen when available. Plot by Alessandra Morrone.

The **$\delta^{13}C$ values** in non-adults (mean ± sd = –21.10 ± 0.50‰) are comparable with the adult values (mean ± sd = –21.31 ± 0.47‰), so it can be assumed that they received proportions of C3 foods like those of adults once they were completely weaned. This interpretation is compatible with historical sources from which it can be inferred that children were put to work quite early, already at 5–6 years of age (Põltsam-Jürjo, 2017). The principle was that hard workers could not be undernourished and required larger amounts of food, so it is reasonable to assume similar diets for children and adult workers. However, it was also stated that children were usually given less meat (Põltsam-Jürjo, 2017), and this may explain the lower $\delta^{15}N$ values recorded for older children and adolescents (Fig. 16).

The **$\delta^{15}N$ values** range from 7.72‰ to 16.05‰, showing the greatest variability and spread in both urban and rural contexts (Fig. 16). The $\delta^{15}N$ values in non-adults (mean ± sd = 11.79 ± 1.72‰) are similar to the adult values (mean ± sd = 11.26 ± 0.69‰), although they show great variability possibly due to the wide age range selection. These results imply that adults and children in southern Estonia likely had wide access to animal products, possibly relying on small amounts of higher trophic level proteins, such as fish.

A significant difference between urban and rural areas was observed for $\delta^{15}N$ values (1.99‰ higher in the urban sample), a general trend detectable in both babies and older children (Fig. 16).

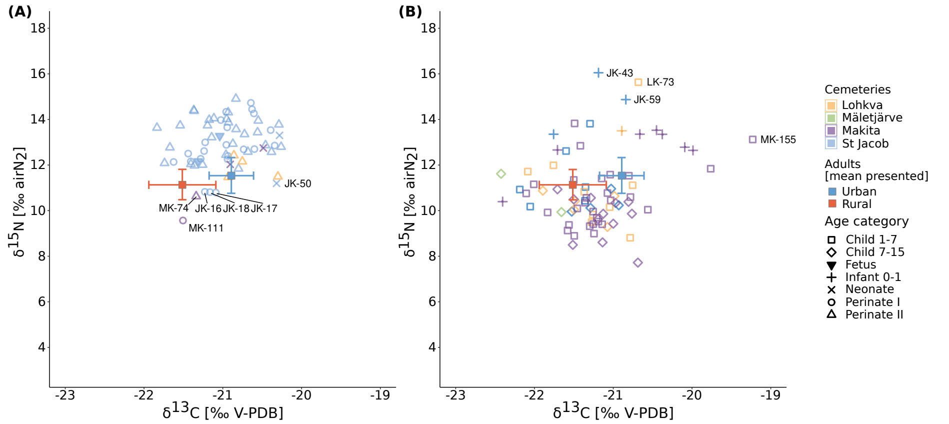


Figure 16. Carbon and nitrogen stable isotope values of the samples color coded to indicate the cemeteries used in this study, plotted with the urban and rural mean adult values. **a)** Scatter plot of the fetuses, perinates I, perinates II, and neonates. **b)** Scatter plot of the infants and older children. The ID codes of the outliers and individuals with anomalous values discussed in the text are included. Scatter plots by Tina Saupe.

Besides standard dietary variations, it must also be considered that this sample is constituted exclusively of non-adults, for which we must take into account additional factors that might influence nitrogen values. First, the sample from St Jacob displays the highest number of perinates, which normally have higher mean $\delta^{15}N$ values compared to adult means. Different $\delta^{15}N$ values in perinatal bone collagen are likely to reflect in-utero values, since the positive nitrogen balance caused by pregnancy and rapid fetal development can result in a $\delta^{15}N$ increase. However, it is unclear how physiological variations in protein metabolism between mother and fetus influence $\delta^{15}N$ values in fetal bone collagen (see Chapter 3.5.4). On the other hand, high nitrogen values have also been correlated to physiological stress and disease (White & Armelagos, 1997; Beaumont et al., 2013; Katzenberg & Lovell, 1999; Olsen et al., 2014, Chapter 3.5.3). The perinates from St Jacob displayed paleopathological signs of systemic metabolic disease in the form of bone production and deformation, abnormal porosity, and endocranial lesions. These lesions were clearly displayed through RTI imaging. The effects of disorders such as congenital scurvy and/or rickets transmitted by undernourished mothers are among the possible reasons for their $\delta^{15}N$ values, especially for those babies showing $\delta^{15}N$ values >13‰. However, although the number of rural perinates is much fewer than those from Tartu, their values tend to reflect the general urban/rural trend of the whole non-adult sample, with lower $\delta^{15}N$ compared to the urban babies. Therefore, in addition to mother/fetus physiological variations and perinatal stress, possible dietary differences among pregnant and lactating mothers are still a possible explanation.

Second, if we temporarily leave the perinatal samples aside, the non-adult $\delta^{15}N$ values in St Jacob's are still significantly higher than those of the rural sites, strengthening the assumption that dietary variations between town and countryside dwellers occurred at an early age. The former possibly had access to a wider range of foodstuffs, including imported marine products, given the importance of Tartu in the Livonian trading system (Põltsam-Jürjo, 2013).

As introduced in Chapter 3.5.2, another aspect that can be addressed from SIA when working with children is the timing of **weaning**, which is another threshold of physiological stress occurring in a child's life. In order to estimate the ages of breastfeeding and weaning, the $\delta^{15}N$ values of children are evaluated in relation to their high-resolution age categories and compared with the adult female means (Fig. 17). The reason for using the female values is that in cross-sectional studies it is assumed that the women of the population roughly represent the possible mothers of the children. This is of course speculative, since we will never know whether the mothers of these specific children are among the individuals sampled for SIA in the absence of confirmation from aDNA. Furthermore, if some of them had a particular diet that was reflected in their nitrogen values and might have resulted in outlier values of their offspring, this cannot be fully detected through bulk SIA. This is one of the limitations of cross-sectional studies, thoroughly discussed in Chapter 3.5.4. However, it can be reasonably assumed that at least some of these adult females were mothers who may have had diets similar to the real mothers of these children.

Most non-adult individuals show elevated $\delta^{15}N$ values compared with the adult women. The fetal and preterm individuals fall around 1–2‰ above the adult females, while the term babies exceed the mean by 2‰.

Even though no statistical outlier for stable nitrogen emerged from this dataset, the $\delta^{15}N$ values of several individuals are worth discussing, since they are anomalously lower or higher in respect to the rest of the sample. MK-111 (preterm around 32 weeks, $\delta^{15}N$=9.57‰) and MK-74 (term baby around 39 weeks, $\delta^{15}N$=10.36‰) showed the lowest $\delta^{15}N$ values of the whole sample, comparable to the rural female means (Fig. 17). According to their estimated age, it appears unlikely that they lived long enough to be breastfed, and even in the case of age underestimation due to physiological stress, that MK-74 had enough time to develop a breastfeeding signal. We can hypothesize that these babies were reflecting in-utero values of their pregnant mothers, who may have had lower $\delta^{15}N$ values than the rural female means. Both perinates also displayed endocranial lesions and abnormal cranial porosity compatible with possible infectious or metabolic disease, similarly to the ten perinates in St Jacob's cemetery. In this case, it can be argued that low in-utero maternal values may have shadowed the expected $\delta^{15}N$ increase caused by a pathological condition, leading to the observed isotopic results. It is also possible that the effects of disease were simply not recorded in the nitrogen values of these particular babies, who may have died before their bone tissue had time to incorporate the isotopic signal.

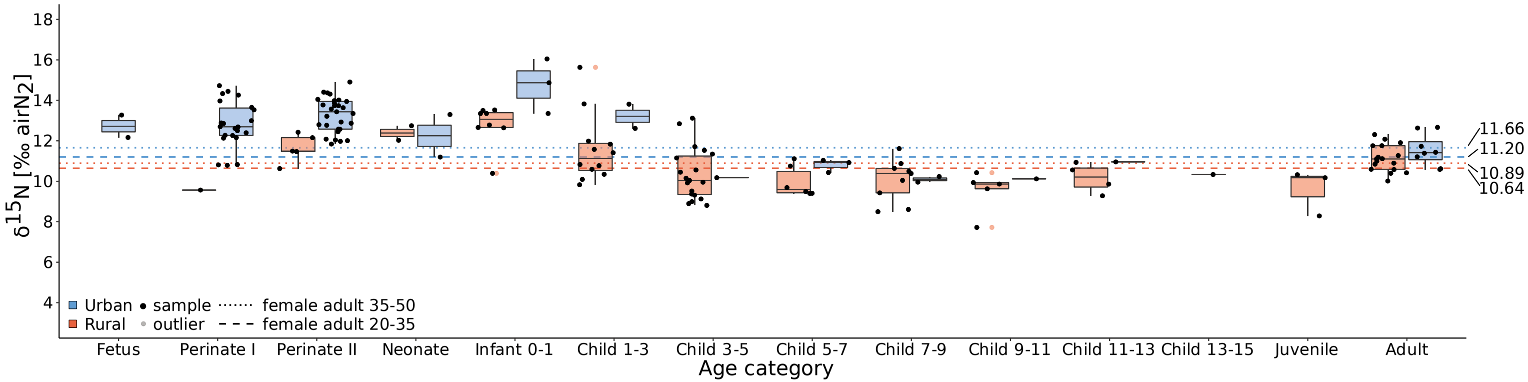


Figure 17. Boxplot of the $\delta^{15}N$ values of rural and urban children, plotted against the mean $\delta^{15}N$ values of the urban and rural female individuals at the age of 20–35 and 35–50 years. The children in the 1–7 and 7–15 categories were further divided into smaller 2-years groups to provide higher resolution to the data. Boxplot by Tina Saupe.

Among the urban counterparts, three babies clearly stood out. Individuals JK-16, JK-17 and JK-18 (all perinates I about 31 weeks old) exhibited $\delta^{15}N$ values around 10.80‰, much lower than the other urban perinates. These babies were buried together in Mass Grave II, one of the mass graves of 6 individuals from St Jacob's cemetery (Paper IV). These babies may also be reflecting in-utero values of their mothers, who could have been rural migrants (we have recorded overall lower nitrogen values in the rural samples compared to the urban ones, see Figs. 16 and 17), or lower-class urban dwellers with lower $\delta^{15}N$ values. The fact that they were of similar age and buried in the same grave is quite intriguing, indicating a spatial-temporal or perhaps even social relationship between them, or a similar pathological condition occurring before death (perhaps an epidemic?). This may indeed support the assumption of a cluster of mass graves linked to a mass fatality episode or period carried out in Paper IV. To further address this intriguing dataset, these individuals have been sampled for aDNA to perform kinship analysis, genetic sex determination, and search for evidence of infectious neonatal diseases within the project "*Population structure, health and disease in Medieval Estonia through aDNA perspective*" (ETAg grant PRG1027, PI Kristiina Tambets, Institute of Genomics, UT).

A somewhat unexpected result concerns neonates, where the mean values are closer to the perinate I category (ca. 1–2‰) than to what is expected in a nursing context. However, since the number of neonates in this sample is only four, their mean values are particularly affected by outliers. For instance, individual JK-50 (around 42 weeks) shows quite low $\delta^{15}N$ (11.20‰), while the other three cluster around the female means. Since the estimated age seems to indicate death after birth, a reasonable explanation for their $\delta^{15}N$ values could be that they were either not breastfed or did not live long enough to develop a breastfeeding signal. Alternatively, they could have been shortly nursed by a mother/wet-nurse with very low $\delta^{15}N$ values (Bourbou et al., 2019; Fuller et al., 2006; Siebke et al., 2019). If the mother was unavailable or died shortly after delivery, we can hypothesize that the babies could have been fed with foods other than breastmilk (ruminant dairy, paps, porridges), which failed to meet their nutritional needs resulting in lower nitrogen values. In a historical period in which famines and epidemics were an exhausting constant, similar scenarios may have been quite frequent.

Considering older individuals, the infants between birth and 1 year of age show an expected ca. 2–3‰ increase in $\delta^{15}N$ values. These results seem to reflect an effective breastfeeding signal, with a successive drop between 1 and 3 years of age. The children in this category show $\delta^{15}N$ values ranging from 12.61‰ to 13.81‰ in the urban cemetery and from 9.83‰ to 15.63‰ in the rural areas, possibly reflecting different individual choices or local customs in the weaning practice.

In particular, individuals JK-43 (around 6 months), JK-59 (ca. 9 months) and LK-73 (about 1 year), show the highest $\delta^{15}N$ values in the whole dataset (respectively 16.05‰, 14.86‰, and 15.63‰). This may be linked to the effects of metabolic disease: outlier JK-43 displayed endocranial lesions, abnormal porosity of cranial and postcranial elements, and SBP of the skull (particularly on the orbital roofs), a pattern compatible with scurvy (Ortner & Ericksen, 1997; Ortner, 2003). For infants JK-59 and LK-73 we can also consider the effects of a systemic metabolic disease, since endocranial lesions and abnormal porosity of the skull/postcranium were recorded in the former, and SBP and abnormal porosity of the skull/postcranium were observed in the latter. For these infants we can hypothesize that the $\delta^{15}N$ value reflected the effects of either severe malnutrition, or a combination of breastfeeding/weaning and metabolic disease. A striking outlier is MK-155 (ca. 4 years), showing high $\delta^{13}C$ and $\delta^{15}N$ values ($\delta^{13}C = -19.23‰$, $\delta^{15}N = 13.12‰$) (Fig 4b). This child is a statistical outlier for stable carbon according to the IQR criterion. The individual displays bone deformation of the inferior long bones and ribs (rachitic rosary), endocranial lesions in the form inflammatory pitting on the occipital bone squama and fiber bone deposits on the frontal and parietal bones. In addition, the child shows subperiosteal reactions on the ectocranial surface of the skull and on the tibiae, and abnormal porosity of skull and postcranium. Such a lesion pattern is consistent with a differential diagnosis of rickets (Brickley & Ives, 2006; Mays et al., 2006). Another similar case is represented by individual MK-104 (around 1 year of age), another statistical outlier for stable carbon showing lower nitrogen levels ($\delta^{13}C = -19.76‰$, $\delta^{15}N = 11{,}84‰$). These values may be reflecting the dietary choices of the caregivers and, given the estimated age, perhaps the supplementary foods selected for weaning. However, the individual displayed porotic bone production on the orbits as well as abnormal porosity on the palate and around the infraorbital foramen. Bone production was also observed on the superior surface of the sphenoid lesser wings, on the pterygoid processes and mostly around the rotundus and ovale foramina. Furthermore, the individual showed signs of endocranial lesions in the form of patchy capillary lesions on the frontal bones above the orbital floor and on the greater wings of the sphenoid, as well as hair-on-end lesions on the temporal bone squama and inflammatory pitting on the occipital squama. Abnormal porosity of the postcranium was also detected. This pattern of lesions is compatible with a case of scurvy (Ortner & Ericksen, 1997; Ortner, 2003). It is worth reporting how two cases of systemic metabolic disease show very high $\delta^{13}C$, which in MK-155 is also associated with high $\delta^{15}N$. These recorded values therefore likely reflect physiological stress. Given the estimated age, the chosen weaning strategy may have played a role in the development or worsening of a systemic metabolic disease.

The high variability of the isotopic values encountered in this study may be explained by the social composition of this sample, which included townspeople from different social statuses, foreign elites, and countryside migrants. This also means that people involved in childcare, including mothers and perhaps wet-nurses, likely came from different backgrounds. Hence, in addition to rural and urban food availability, childcare practices at the local or family level also ought to be considered as possible factors of diversity. For instance, according to the few available 16^{th}–17^{th} century written sources, the families of German elites and manor owners often hired Estonian wet-nurses and nannies. The 18^{th} century publicist Peter Ernst Wilde interestingly wrote that a good wet-nurse must not be a drinker, or a wanton or angry woman (Wilde, 1766). Hiring a wet-nurse was not only a status symbol, but also added a multicultural dimension to childcare, preserving local traditions and connecting the gaps between ethnicity and social class (Põltsam-Jürjo, 2017). This trend progressively decreased during the 19th century, when more German women began to breastfeed their own children (Gortfelder & Puur, 2020). It is unknown whether the babies analyzed could have accessed wet nursing, given that the sample mainly included lower status dwellers and rural communities. However, the different food habits of these people with multi-ethnic origins and personal traditions are likely to be reflected in this dataset since they were most likely buried in the same cemeteries.

This cross-sectional analysis seems to place the duration of breastfeeding between 1 and 2 years. The introduction of supplementary foods apparently started around 1 year and weaning was completed around or after 3 years of age. This is in line with isotopic data from other medieval and early modern contexts in Lithuania and Latvia. Whitmore et al. (2018) reported the SIA of adult individuals from the non-urban town cemetery of Alytus (southern Lithuania, 14th to early 18th centuries). Although children were not included in the study, bone and dentine sampling of the adults revealed that individuals had higher $\delta^{15}N$ values during the first years of life compared to their last years of life. The authors interpreted this to be a result of an incorporated breastfeeding signature, and/or of access to terrestrial or aquatic protein sources even in the very young individuals buried at Alytus. Skipitytė et al. (2020) performed cross-sectional SIA on adult and non-adult remains from three coastal communities (Palanga, Kretinga, and Smeltė), dated from the medieval to the early modern periods (14th–early 20th centuries), located near the Curonian Lagoon and the Baltic Sea in Lithuania. Their results are comparable to those of this study, and the paper reported that $\delta^{15}N$ values were slightly elevated in non-adults compared to adults, probably indicating nursing. The authors argue that breastfeeding was practiced until the age of 3–4 years, suggesting that early weaning was not the cause of death in these populations (Skipitytė et al., 2020). In the children from St Gertrude church urban cemetery in Riga (Latvia, 15th–17th centuries), Pētersone-Gordina et al. (2020) also reported nitrogen values comparable to this study. The results of incremental dentine SIA supported folklore and ethnographic studies reporting that Latvian children were not completely weaned until one or two years of age, and the authors attributed high $\delta^{15}N$ values at younger ages to physiological stress *in utero* (Pētersone-Gordina et al., 2020).

Observing the Infant 0–1 and Child 1–3 categories, a striking difference between weaning children in St Jacob's and in the rural areas can be seen (Fig. 17). Urban infants and children show $\delta^{15}N$ values respectively 1.98‰ and 1.65‰ higher compared to rural individuals. This is likely reflecting the general dietary variations between town and countryside dwellers discussed above, also considering that the female baseline follows a similar trend (Fig. 17). The women in Tartu may have had access to a wider range of foodstuffs, including imported terrestrial and marine products. This would have reasonably resulted in higher

$\delta^{15}N$ values in their breastmilk, reflected in the overall values of their nursing and weaning children.

Although no historical data regarding the length of breastfeeding and the age of weaning in Estonia have been retrieved, indirect inferences can be attempted on the basis of written sources: for instance, the 18th century publicist August Wilhelm Hupel wrote that Estonian mothers let their babies crawl on the ground as soon as possible, implying that they were wrapped for a short time compared to babies of elite German mothers (Hupel, 1777). This may have meant that lower class mothers needed their hands to perform housework and had to leave their babies free to crawl, and also that caregivers let them be quite independent very early. The older siblings (5–6 years old) used to look after the younger ones (Hupel, 1777). Hence, we may assume that 5–6-year-old children should have been fully weaned, since they were able to care for their younger siblings and go to work (Põltsam-Jürjo, 2017). It cannot be excluded that breastfeeding could have continued also when children were performing these tasks. However, it is reasonable to think that a working child could have reached a more mature status, especially considering that they were often sent far from home for apprenticeship (Põltsam-Jürjo, 2017). Becoming part of the family workforce could have represented a sign of maturity for the individual, who may have been considered closer to the adult world, also from a dietary point of view.

The introduction of supplementary foods may have therefore already started before one year of age, as reported for more recent contexts (Gortfelder & Puur, 2020). Although no information about what kinds of foodstuffs were used to start the weaning process in medieval/early modern contexts, 19th–20th centuries sources mention that barley-water, breadcrumbs in milk, and probably gruel were used as supplementary foods for infants (Põltsam-Jürjo, 2017; Gortfelder & Puur, 2020). Thus, there is no reason to doubt that similar porridges and paps could have also been used in the medieval and early modern periods. The drop in SIA values of the children between birth and 3 years observed in this study are therefore compatible with similar mixed patterns of maternal and supplementary foods.

These results represent an interesting new tile in the mosaic of non-adult social age in Livonia, for which we need to open a brief historical footnote. According to Põltsam-Jürjo (2017), children did not experience a long and carefree childhood in the medieval and early modern periods. Both in the town and in the countryside, they were commonly working from an early age and given simple tasks in the household. For instance, one of the most common child labors was herding.

A series of gender-linked behavioral differences also occurred. Compared to boys, girls grew up in more spatially limited areas, especially domestic households in which they were under constant supervision of family members and neighbors until marriage. Boys, on the other hand, had more freedom of movement and were sent to start apprenticeships far from home and quite soon, already at 5–6 years of age. Parents were responsible for the security and care of their offspring, although during the upheavals of the time, abandoned or orphaned children were numerous. Such children could find shelter with relatives, live in orphanages, or had to make a living from begging and theft (Põltsam-Jürjo, 2017).

An important milestone in the life of a child was at the age of 12, with the Christian sacrament of confirmation (Glossary). This was the threshold for adolescence and signified assuming a new social status. At that age, an individual could finally become a godparent. In Livonia, some taxes were already pending on those over 12 years of age (an example is the 16^{th} century warfare tax, and the so-called "*oat tax*", collected by ecclesiastic authorities from each "*spirit*", indicating a family member over 12 years of age) (Põltsam-Jürjo, 2017).

Under the Riga city law, young men became adults (*mundig*) at the age of 18 and girls at the age of 14; under the Lübeck law, young men became adults at the age of 18 and girls at the age of 12, the latter being subject to the clause that "*...she is not otherwise fully adult, if only through a guardian*" (Põltsam-Jürjo, 2017). Under the Livonian knighthood, an adult was considered to be a man who had reached the age of 20, and boys were thought to reach the age of maturity even later. This of course did not mean that they stayed at their parents' home until that age, as discussed above. It was the duty of the parents to ensure that their descendants properly survived, but at the same time, under parental custody, children were often forced to choose a profession and later a spouse, or to opt for a monastic or clerical life (Põltsam-Jürjo, 2017).

This cross-sectional isotopic study greatly benefited from the integration of paleopathological methods and results. The paleopathological examination, enhanced by integrating RTI capture, provided a context for improved understanding of common physiological stressors in babies/infants, and helped contextualizing the anomalous isotopic values of the outliers. This approach allowed interpretation of the SIA values not only in light of everyday diet, but also – and especially – of physiological stress in the early years of life. Furthermore, SIA allowed crafting a much more informed discussion regarding the case studies of babies from St Jacob's cemetery, as well as pioneering understanding of when children were weaned in this area of Livonia. This study provided a new multifaceted picture of these populations, one in which rural and urban communities had different diets but similar weaning times. In these communities, some individuals suffered from disease and malnutrition as effects of historical events (epidemics, famines), but likely also due to unfortunate choices in feeding practices and supplementary food introduction. These results are a promising starting point for new high-resolution analyses such as incremental SIA methods, which have the potential to improve the time resolution in understanding the past lives of Estonian children.

7. CONCLUSIONS

"So, you children of the world
Listen to what I say
If you want a better place to live in
Spread the word today
Show the world that love is still alive, you must be brave
Or you children of today are children of the grave, yeah!"

– *Children of the grave*
Black Sabbath, Master of Reality (1971)

At the beginning of this thesis, a series of questions was displayed. Starting from the particular and moving to the general picture, it became clear that these questions were all intertwined with one another, sometimes through unexpected connections.

Paper I answered the first question regarding the state of art of childhood bioarchaeology in the Baltic states, highlighting what is missing in the field and proposing a starting point for a new line of research in the area, perhaps beginning with this thesis.

Paper II answered the question regarding the philosophical implications of the paleopathological study of non-adult remains in the light of the Osteological Paradox, creating a solid theoretical framework for the analytical and laboratory work reported here, and that is planned for the future.

Paper III began the hands-on experience, answering the third question regarding which new imaging methods could be used to study non-adult bone pathology. By proposing RTI for the study of pathological specimens, this paper dealt with the Paradox by providing a more detailed display of pathological lesions; using this technique, the specimens can be better described during differential diagnoses and identical data can be shared among fellow researchers. In addition, RTI capture was demonstrated to be particularly useful for studying subtle bone changes in perinatal individuals and was therefore successfully employed also in the fourth paper of this thesis.

Paper IV addressed the question regarding the impact of the intense upheavals occurring in medieval and early modern Estonia on the weakest and marginalized members of society. Through the paleopathological study of perinatal remains conducted macroscopically and through RTI capture, systemic metabolic disease was detected in the samples. The physiological health of pregnant women and their offspring was then discussed, as well as the treatment of the prematurely deceased in the light of cultural practices such as baptism.

The health status of these individuals directly connects to Paper V, which answers the research question concerning the staple non-adult diet and feeding practices in medieval and early modern Estonia. Here, bones from children of different ages, including the babies from St Jacob's cemetery, were sampled for SIA to permit dietary reconstruction. The results of this study suggest that children accessed food sources similarly to the adult population and also confirmed that there were disparities in diet and feeding practices between children in rural versus urban contexts. Furthermore, this paper provides the first data on how long Estonian children were breastfed, and at which age the weaning process took place.

Relative to the overall aim of this work, it proved possible to obtain a large-scale overview of childhood in medieval and early modern Estonia (13th–17th centuries), covering health, social role and age, staple diet, and feeding practices. RTI aided in the paleopathological investigation of non-adult remains, permitting more sensitive and accurate detection of disease patterns in these individuals, as well as providing new means for their display and communication. Furthermore, it enabled consistent explanations for their general and anomalous SIA data. The integration of these results with the available historical data provided an example of how a multidisciplinary study can address philosophical issues such as the Osteological Paradox and the problem of equifinality, at the same time filling the gap in the bioarchaeological understanding of children in the Eastern Baltics. In a metaphor for the RTI technique itself, the final picture was crafted by merging together every single angle of light and shadow. In some instances, the merging of several results coming from different sciences helped reducing the theoretical limitations of each of these disciplines (Fig. 18).

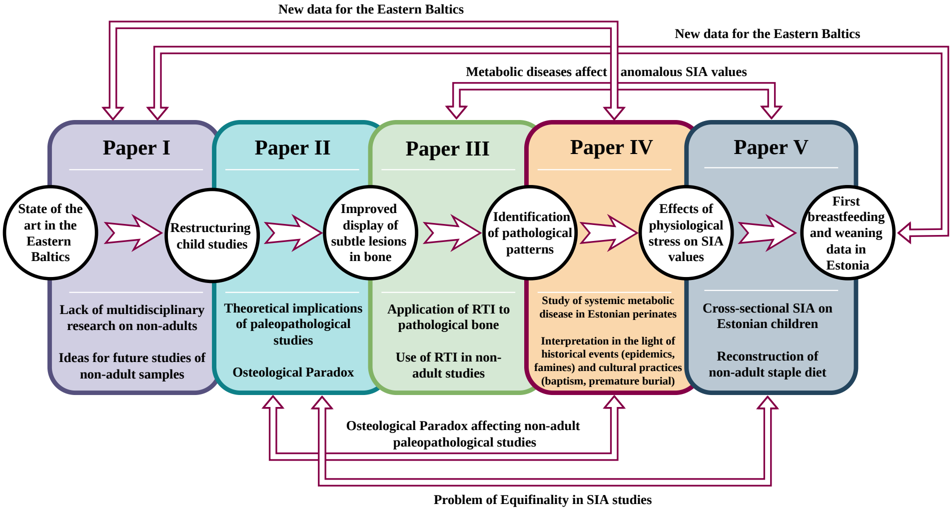


Figure 18. Graphic scheme showing the interactions and overlapping of the five papers constituting this dissertation. Graphic scheme by Alessandra Morrone.

Estonian children were dynamic actors in the life of their communities from the moment of birth through their passage to adolescence and adulthood. The youngest represent the most vulnerable population groups, fully dependent on their mothers' health and diet. In this study, babies vividly reflected the devastating effects of famines and epidemics affecting this area of Europe in their premature deaths and subtle skeletal lesions, unfolding stories of disease and malnutrition. Some were marginalized not only in life but even in death, since those who were unbaptized faced the unfortunate destiny of a burial outside consecrated ground together with the outsiders, other people considered unworthy of the approval of society (Paper IV).

At the same time, the special care for those who did survive a bit longer became evident through the study of the feeding practices of older infants and children. The stories emerging from their isotopic values reveal a diet similar to that of adults in towns and countryside, able to sustain them through apprenticeship and work. Because working started early for Estonian children, they definitely cannot be considered as those passive and silent members of medieval society described by Ariés (1962). They were not only taking care of their younger siblings and of the household, but also contributing economically to their community, in the fields or in towns. Estonian early childhood was brief but not careless, as our first isotopic values tell us about breastfeeding lasting 1 to 2 years, with the weaning process starting around 1 and ending close or after 3 years of age. Our outliers show that sometimes they did not survive breastfeeding, despite perhaps being fed by local wet-nurses, who may have been inadequately nourished themselves. Furthermore, the weaning strategy may have sometimes led to metabolic disease and premature death due to the unsuitability, or simply unavailability, of the chosen supplements. This matter is worth future investigation.

Now that we have a preliminary picture of childhood in medieval and early modern Estonia, further research to discover new aspects of the lives of children ought to be proposed. This research, built on the foundation of the present study, will sprout a new branch of tomorrow's bioarcheological understanding. Recent lines of investigation on non-adults have tackled the adolescent age category, with interesting insights into sex estimation and gender issues (Lewis, 2018). As an example, incremental SIA has recently been successfully applied to adolescents, shedding light on gender differences in food consumption in Late Roman Gaul (Creighton Avery et al., 2021). Since the study of non-adults in the Baltics is only now taking its first steps, a focus on adolescent individuals with regard to their social age and gender may be of great interest due to the current attention towards social rights and gender-related issues. We may tackle questions regarding dietary differences between male and female workers, as well as whether their diet changed between childhood and adolescence. As discussed in Chapter 6.3, boys were sent out for apprenticeship quite early, while girls were mainly kept in their family house. This may have resulted in differences in diet and metabolic disease patterns. Furthermore, exploring the ages of marriage and first pregnancies, and possible choices of particular foods for young mothers, also represent a new and intriguing research avenue. New questions may include whether we can identify mothers in the archaeological record, and whether pregnant women were treated differently with respect to the rest of the community.

Regarding incremental isotopic studies, a life history approach to this material through incremental dentine and bone sampling is already among future plans.

This will allow integrating the cross-sectional data, confirming or rejecting the estimated timing of breastfeeding and weaning, and obtaining a high-resolution picture of diet and feeding practices in single individuals. For instance, dentine analyses on adult individuals may highlight differences in nursing/weaning patterns between male and female children. In addition, one could further investigate the lives of the outliers that showed anomalous nitrogen values and metabolic disease lesions (Chapter 6.3). Higher resolution analyses of their tissues may explain whether their isotopic values were related to a long-term disease or to inadequate weaning strategies. A successive comparison with the survivors of the population may unfold possible strategies adopted by mothers to maximize survivorship. The application of these techniques to different temporal-geographical and social contexts may provide further comparative data to reconstruct the larger picture of Livonian children.

Another current theme in child studies is trauma analysis. Performed within a life-course theory framework combining paleopathology and incremental SIA, it has the potential to reveal information on child abuse, caregiving, child labor, and personhood in childhood (Kozakaitė et al., 2018; Lewis, 2007). With the increased interest in the bioarchaeology of care, including minorities and disabled individuals, there are several avenues of future research available (Oxenham & Willis, 2017).

The future development of new paleopathological and bioarchaeological studies on children in this part of Europe may lead to the creation of a specific database of Baltic collections, including individuals of all ages and from different sites and periods. This would allow future researchers to add more data and information about the life and death of children in the Baltics, and to compare various childhood analyses on a wider temporal and spatial scale.

This dissertation begun with the aim of constituting a first step for the development of the bioarchaeology of children in the Eastern Baltics. The combination of methodological and theoretical approaches adopted here has opened new avenues for understanding children and social minorities in this area of Europe, confirming the need for a multifaceted and flexible approach to the osteological data. The children of the grave reflect their times from historical, theoretical, biological, and social points of view, and thus integrating each of these aspects provides the best means to unfold their individual stories.

GLOSSARY AND ABBREVIATIONS

Confirmation: Christian rite by which admission to the church, established previously by the infant baptism, is said to be confirmed (or strengthened and established in faith). It is considered a sacrament in Roman Catholic and Anglican churches, and it is equivalent to the Eastern Orthodox sacrament of chrismation. The sacrament confers the gifts of the Holy Spirit (wisdom, understanding, knowledge, counsel, fortitude, piety, and fear of the Lord) upon the recipient, who must be a baptized person at least seven years old. A bishop normally performs the rite, including the laying on of hands and anointing the forehead with holy oil.

Differential diagnosis: the process of identification and determination of a pathological condition with the aid of existing literature. It starts with a thorough description of the lesions using specific terminology, and successively follows a series of diagnostic steps with the aid of medical and paleopathological literature, considering all possible etiologies for the observed skeletal changes. The less probable causes are eliminated one by one, finally reaching a brief list of possible causative agents, or a single result in case of pathognomonic lesions (i.e., diagnostic for a specific disease).

Fractionation: this is the basis for stable isotope variation in biochemical systems. This variation is due to the fact that isotopes vary in mass and therefore have slightly different chemical and physical properties. Isotopes with higher mass such as 13C usually react more slowly than lighter isotopes such as 12C. For this reason, in biochemical and metabolic reactions the lighter isotope is generally preferred compared to the heaviest, resulting in a clear difference in the isotopic ratios in different body tissues or in successive steps of the food chain.

EA-IRMS: Automated Elemental Analyzer Isotope Ratio Mass Spectrometer

Non-parametric statistical test: also known as “distribution-free test”, this is a statistical test that does not assume anything about the underlying distribution (for example, that the data comes from a normal distribution). This is in comparison to parametric tests, which make assumptions about the parameters of a population (for example, the mean or standard deviation); When the word “non-parametric” is used in statistics, it usually means that the population data does not have a normal distribution.

Normal distribution: also known as the Gaussian distribution, this is a probability distribution that is symmetric about the mean, showing that data near the mean are more frequent in occurrence than data far from the mean. In graph form, normal distribution will appear as a bell curve.

LEH: Linear Enamel Hypoplasia

RTI: Reflectance Transformation Imaging

SBP: Subperiosteal Bone Production

sd: Standard Deviation

SIA: Stable Isotope Analysis

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SUMMARY IN ESTONIAN

Vaikuse lapsed: Lõuna-Eesti kesk- ja varauusaegsete laste toitumise ja tervise multidistsiplinaarsed uuringud arheoloogilise ainese põhjal

Laste roll mineviku ühiskondades pakub bioarheoloogidele järjest enam huvi iseäranis seetõttu, et lapsed on sageli ajalooallikates ja narratiivides tähelepanuta jäänud. Laste ja noorukite luustikud sisaldavad palju teavet nende isiklikust ja sotsiaalsest elust alates sünnist kuni täiskasvanuikka jõudmiseni. Viimasel kümnendil on avaldatud mitmeid bioarheoloogia-alaseid uuringuid, mis täiendavad meie teadmisi lapsepõlvest üldisemalt (Halcrow & Tayles, 2008; Inglis & Halcrow, 2018; Gowland & Halcrow, 2020; Halcrow & Ward, 2020; Halcrow et al., 2020; Hodson, 2021), tervisest (Lewis, 2007, 2017), toitumisest ja sellega seotud praktikatest (Dupras & Tocheri, 2007; Wheeler, 2012; Bourbou, 2018).

Baltikumis on laste bioarheoloogiale seni vähe tähelepanu pööratud: puudub süsteemne laste elu ja surma aspekte käsitlev uurimissuund. Käesolev väitekiri püüab seda lünka täita, hõlmates ajaloolisi, arheoloogilisi, teadusteoreetilisi ja filosoofilisi vaatenurki. Minu väitekiri on esimene valdkondadeülene Eesti ja Baltikumi laste ja noorukite luustike uurimisele keskenduv uurimistöö. Doktoritöö eesmärk on anda ülevaade lapsepõlve-aegsest tervisest, laste sotsiaalsest rollist, põhitoidusest ja toidukultuurist kesk- ja varauusaegses Eestis (13.–17. sajandil pKr). Esmalt lähenetakse lastele teoreetiliselt, seejärel paleopatoloogiliste, uuenduslike kuvamistehnikate ja biomolekulaarsete analüüside rakendamise kaudu.

Käesolev väitekiri koosneb viiest artiklis, millest igaüks vastab ühele kesk- ja varauusaja varast lapsepõlve puudutavale uurimisküsimusele.

Artikkel I andis ülevaate lapsepõlve bioarheoloogia uurimise olukorrast Baltimaades, tuues esile valdkonna peamised puudused ja pakkudes välja lähtekoha uuele laste bioarheoloogilisele uurimissuunale.

Artikkel II uuris osteoloogilise paradoksi (Wood et al., 1992) filosoofilisi implikatsioone laste ja noorukite luustike paleoarheoloogilisele analüüsile. Artikkel lõi selge teoreetilise raamistiku edasise analüütilise ja laboratoorse töö jaoks.

Artikkel III vastas küsimusele, milliseid uusi kuvamistehnikaid saaks rakendada (laste ja noorukite) luustike patoloogiate uurimisel. Artiklis demonstreeriti RTI (ingl *Reflectance Transformation Imaging*) sobivust patoloogiliste luude uurimisel: erinevalt tavapärasest fotost võimaldab RTI-tehnoloogia detailsemalt kuvada skeleti kahjustusi. Lisaks olid RTI pildid iseäranis kasulikud väikeste luumuutuste uurimiseks perinataalses eas surnute puhul. RTI meetodit rakendati edukalt ka väitekirja IV artiklis.

Artikkel IV keskendus kesk- ja varauusajal Liivimaal teadaolevate näljahädade, epideemiate ja sõdade mõju uurimisele ühiskonna kõige nõrgematele liikmetele. Paleopatoloogiliseks juhtumiuuringuks valiti Tartus Püha Jakobi kalmistult (13.–18. saj pKr) välja tulnud vastsündinute ja imikute ühishauad.

Makroskoopilise paleopatoloogilise analüüsi tulemusel (mh RTI-kuvad) tuvastati mitmetel väikelastel süsteemsete metaboolsete haigusete tunnused. See võimaldas arutelu kesk- ja varauusaegsete rasedate ning nende laste tervise, aga ka enneaegselt lahkunud laste matmiskombestiku (mh ristimine) üle.

Artikkel V jätkab Püha Jakobi kalmistule maetud väikelaste käsitlemist, vaagides koos Tartu lähiümbruse külade laste ja noorukite toidueelistusi ja -praktikaid. Artiklis rekonstrueeriti stabiilsete isotoopide analüüsidega linna ja maa kalmistutele maetud laste toitumine. Näidati, et laste toit sarnanes täiskasvanute omale, olles siiski linna ja maapiirkonnas erinevad. Esmakordselt demonstreeriti kesk- ja varauusaja imetamise aega ning lisatoidu andmise algust väikelastele.

Käesolev väitekiri on esimene samm Baltikumi laste bioarheoloogia arenguteel. Rakendatud teoreetiliste ja metodoloogiliste lähenemiste kombinatsioon avab uusi võimalusi laste ja teiste sotsiaalsete vähemusgruppide mõistmiseks selles Euroopa piirkonnas. Töö demonstreerib, et osteoloogiliste allikate tulemuslik analüüs eeldab multidistsiplinaarset ja paindlikku lähenemist. Lapsed on oma ajastu peegliks ajaloolises, teoreetilises, bioloogilises ja sotsiaalses mõttes. Distsipliinideülene lähenemine annab meile parimad vahendid lugematute lugude avastamiseks ja avamiseks.

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2017: Magistrikraad, Kohtuarheoloogia ja -antropoloogia, Cranfieldi Ülikool, Suurbritannia (lõpphinne: A).

2015: Magistrikraad, Bioarheoloogia, Paleopatoloogia ja Kohtuantropoloogia, Bologna Ülikool, Itaalia.

2013: Loodusteaduste bakalaureus, Milano Ülikool, Itaalia (lõpphinne: 110/110 *cum laude*)

Töökogemus:

2021–2022: Nooremteadur, Tartu Ülikool, Eesti.

2020: Rühmaliige, Archemy, Tartu Ülikool, Eesti.

2020: Bioarheoloog, Projekt Tervis ja Haigused Sitsiilia territooriumil, Itaalia.

2018: Külalisteadur, Mummy Study Field School, Kultuuripärandi ja Sitsiilia Identiteedi osakond, Itaalia & Nebraska-Lincolni Ülikool, Ameerika Ühendriigid

2018: Ekspeditsiooni liige, Ferentillo Muumia Projekt, Vilniuse Ülikool, Leedu

2018: Rühmaliige, Cranfield Recovery and Identification of Conflict Casualties, Cranfieldi Ülikool, Suurbritannia

2017: Bioarheoloog, Bone Matters, NOVA Ülikool Lissabonis, Portugal

2017: Rühmaliige, Kenyon International Emergency Services, Ameerika Ühendriigid

Teised publikatsioonid:

Morrone, A., Piombino-Mascali, D., Randazzo, M., Raimondi, G., & Maniscalco, L. 2021. Children in roof tiles: A case study from medieval Paternò (Sicily). *Medicina Historica*, 5(1): e2021006.

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Alves Cardoso, F., Casimiro, S., Morrone, A., Braga Rosa, C. 2018. *O que de nós perdura – What of us endures*. Avatud juurdepääsuga e-raamat. Saadaval aadressil https://youtu.be/-oGiZjAV-vo.

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1. **Heidi Luik.** Luu- ja sarvesemed Eesti arheoloogilises leiumaterjalis viikingiajast keskajani. Bone and antler artefacts among Estonian archaeological finds from the viking age until the middle ages. Tartu, 2005.
2. **Tõnno Jonuks.** Eesti muinasusund. Tartu, 2009.
3. **Gurly Vedru.** Põhja-Eesti arheoloogilised maastikud. Archaeological landscapes of North-Estonia. Tartu, 2011.
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