It runs in the family: kinship analysis using foot anomalies in the cemetery of Middenbeemster (Netherlands, 17th to 19th century)

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Received: 29 January 2022 | Revised: 5 March 2022 | Accepted: 7 March 2022
DOI: 10.1002/oa.3100

RESEARCH ARTICLE

It runs in the family: Kinship analysis using foot anomalies in the cemetery of Middenbeemster (Netherlands, 17th to 19th century)

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Abstract

In bioarchaeology, the universal concept of "kinship" can be explored through the study of archaeological remains and as such offers a way to connect modern-day life to the life of past people. This study examines the social structure of post-medieval Dutch communities and their level of genetic homogeneity and inter-relatedness. The research aims were to identify probable genetic relatives within the Middenbeemster skeletal collection through developmental foot anomalies and to analyze the spatial structure of the Middenbeemster cemetery in the context of intracemetery kinship relations. Three hundred eighty individuals from four different skeletal collections were examined for the presence of fourteen non-metric traits, selected on various criteria (e.g., heritability). The Middenbeemster trait frequencies were compared with those of a reference sample of the post-medieval Dutch population (consisting of individuals from the Dutch post-medieval collections of Arnhem, Eindhoven, and Zwolle). A hypothetical kinship group could be identified when the trait frequencies of the Middenbeemster sample were considerably higher than those in the reference sample. Other sources had only limited validation value in relation to the hypothesis. Visual examination and spatial statistics of the distribution of the hypothetical kinship group revealed a possible patrilineally structured cemetery, although this is based on a small sample. By putting the observed trait frequencies in a broader context, the data suggested a rather high inter-relatedness of the Middenbeemster community. It also exposed the need for a better understanding of the used traits and perhaps a different approach to kinship analysis (due to necessarily large time investment in contrast to limited results). In conclusion, this study gave an insight into the social structure of post-medieval Dutch communities. Future improvements to kinship analysis may not only be beneficial for bioarchaeology, but also for other fields such as forensic anthropology.

KEYWORDS
bioarchaeology, Dutch, foot anomalies, intracemetery relations, kinship analysis, post-medieval, spatial analysis

1 | INTRODUCTION

Kinship analysis greatly contributes to bioarchaeology as it can provide a unique window into our understanding of interrelatedness in the past (Johnson & Paul, 2016; Meyer et al., 2012; Stojanowski & Duncan, 2015). Insights gathered through this research can challenge the way people deal with kinship, family, and social structure in society, for example, same-sex marriage and adoption legislation. Biological kinship, as an inherent part of social kinship, can be approached from different levels (e.g., population and site) and from different angles (e.g., postmarital residence patterns). The reconstruction of biological kin groups seems to be one of the most challenging research fields within bioarchaeology (Alt & Vach, 1995; Stojanowski & Hubbard, 2017). Kinship analysis employs methods based on DNA, as well as on skeletal and dental morphology. Notwithstanding only DNA-analysis can discern the nature of the relationships between kin (together with historical sources), methods based on skeletal and dental morphology remain in use because they are non-destructive and less expensive than DNA-based methods (Meyer et al., 2012; Stojanowski & Hubbard, 2017; Stojanowski & Schillaci, 2006). Of the methods based on skeletal morphology, two main approaches can be distinguished. The first approach is based on similarities between phenotypic data of related individuals. This approach has been extensively explored since the 1960s, while the second approach, kinship analysis based on skeletal anomalies, has been examined less frequently despite its potential. Post-cranial non-metric traits, for example, *os acromiale* (Angel et al., 1987), seem to be the most useful to identify close genetic relatives, perhaps due to their dichotomous nature (present/absent). Recently, Case et al. (2017) developed a research method as a structured attempt at using these rare traits in kinship research. Further development was suggested to happen in small, rural contexts. Such research could improve our understanding of the social structure of communities, but also influence our perception of kinship in modern-day society and can play an important role in other fields such as forensic anthropology and legal medicine (Finnegan, 1978).

This study presents the next step in kinship research by following the recommendation made by Case et al. (2017). The small, rural context of Middenbeemster (the Netherlands) was selected to further investigate the method and to explore the community's social structures, genetic homogeneity, and inter-relatedness. To that end, two main aims were formulated: to identify probable genetic relatives within the Middenbeemster skeletal collection by using developmental anomalies of the foot and to analyze the spatial structure of the Middenbeemster cemetery in the context of intracemetery kinship relations.

2 | MATERIALS AND METHODS

2.1 | Materials

In this context, the Dutch skeletal collection of Middenbeemster was chosen after careful consideration of its characteristics and its historical context. The rural village of Middenbeemster (North-Holland, the Netherlands) (Figure 1) was founded at the beginning of the seventeenth century after the draining of the former lake present at this site, the "Beemstermeer" (Aten et al., 2012; de Jong, 1998). After the land reclamation, a rural population settled and stayed stable during the following centuries. The cemetery of Middenbeemster (1615–1866) was for the majority of its use the only cemetery available to the municipality (until 1847) (Hakvoort, 2013; Lemmers et al., 2013; van Spelde & Hoogland, 2018). More than 400 primary burials were excavated in 2011, which were mainly dated to the period between 1829 and 1866. Of all excavated individuals ($N = 452$) (Table 1), 219 were included in this study (48.5%) based on preservation of the feet and the age-at-death, as only adults were selected to be able to obtain an accurate sex estimation.

Although the Middenbeemster collection is the focal point of this study, the applied approach requires the study of a reference sample to compare frequencies and to identify possible kinship relations in the Middenbeemster collection. The reference sample should contain relatively few related individuals and its temporal and spatial context should be like those of the principal study sample (Middenbeemster). Therefore, three separate, urban skeletal collections, contemporary to Middenbeemster, were chosen to be used as a reference sample ($N = 161$): the Eindhoven (Catharinakerk) collection ($N = 62$), the Zwolle (Broerenkerk) collection ($N = 41$), and the Arnhem (Eusebiuskerk) collection ($N = 58$). Given that these samples all originate from urban contexts, they are much more likely to be genetically heterogenous. Analogous to the Middenbeemster collection, preservation of the feet and the age-at-death (adult) were the selection criteria. This resulted in a selection of no more than 20% of the total number of excavated individuals from each collection, which limits the number of related individuals within the sample.

2.2 | Methods

The main approach of this study is that rare anomalies found in a high frequency within a population can indicate biological kinship. These rare anomalies should foremost have a high heritability with minimal influence from environmental conditions (Alt & Vach, 1995; Tyrrell, 2000). Other necessary characteristics are no sex bias, no age bias, a low intertrait-correlation, a low trait incidence, and a clear expression. Such a selection was already carefully made by Case et al. (2017) for anomalies regarding the feet by researching clinical evidence of these traits. The traits were deemed to be rare as their trait frequency was less than 10%. In the present study, this careful selection was adopted (Table 2). The selected traits are accessory navicular; *os intermetatarseum*; brachydactyly of the first metatarsal, of the fourth metatarsal, of the first proximal phalanx and the first distal phalanx; calcaneocuboid coalition; calcaneonavicular coalition; talocalcaneal coalition; the coalition between the second and third cuneiform and coalition between the third cuneiform and third metatarsal.

FIGURE 1 Map of the Netherlands, with the indication of the town of Middenbeemster and the collections in the reference sample. Figure produced by Elle Liagre, with data available from GADM (2018) and Kadaster (2020) [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Overview of (the portions of) the skeletal collections used in this study

Site name	Studied individuals (#)	Selected portion of collection (%)	Site type	Dating of the context	Reference
Study sample					
Middenbeemster	219	48.5% (219 out of 452)	Rural	1623–1866	Hakvoort (2013)
Reference					
Eindhoven	62	8.2% (62 out of 752)	Urban	1500–1850[a]	Arts (2013)
Zwolle	41	7.8% (41 out of 529)	Urban	1675–1828	Clevis and Constandse-Westermann (1992)
Arnhem	58	7.7% (58 out of 750)	Urban	1400–1829	Baetsen et al. (2018)
Total	161	7.9% (161 out of 2031)	-	-	-

[a]The skeletal collection of Eindhoven exists mainly out of individuals from the post-medieval period (1500–1850) but also contains some individuals from the medieval period (1200–1500) or with no specific period assigned (1200–1850).

The feet bones of 380 individuals of the principal and the reference samples were macroscopically observed by the first author and scored according to Case et al. (1998, 2017), Case and Burnett (2012), Offenbecker and Case (2012), and Temtamy and Aglan (2008). The scoring itself was performed without prior knowledge of skeletal data like sex and age-at-death to avoid observer bias. The trait could be

TABLE 2 Overview of the selected traits as according to Case et al. (2017)

Name	Abbreviation	Description
Accessory bones		
Accessory navicular	AccessNav	An accessory bone of the navicular, located near its tubercle (Offenbecker & Case, 2012). It can be free-standing (type I), articulating (type II), or fused (type III) to the navicular. Type II is easily recognizable and will be the type examined in this study.
Os intermetatarseum	InternetCF1 IntermetMT1 IntermetMT2	An accessory bone, located between the medial cuneiform (CF1), the first (MT1), and the second metatarsal (MT2) (Case et al., 1998). It can be free-standing, articulating, or fusing with any of these bones. The free-standing form is archaeologically not visible unless the ossicle is found. Only the articulating and fused forms will be examined in this study.
Brachydactyly		
Brachydactyly D	BrachyD	A shortening of the first distal foot phalanx (Temtamy & Aglan, 2008).
Brachydactyly PP1	BrachyPP1	A shortening of the first proximal foot phalanx (David et al., 2015).
Brachydactyly MT1	BrachyMT1	A shortening of the first metatarsal (Temtamy & Aglan, 2008).
Brachydactyly MT4	BrachyMT4	A shortening of the fourth metatarsal (Temtamy & Aglan, 2008).
Tarsal coalitions		
Calcaneocuboid coalition	CalcCubCoal	A (non-)osseous coalition between the calcaneus and the cuboid (Case & Burnett, 2012).
Calcaneonavicular coalition	CalcNavCoal	A (non-)osseous coalition between the calcaneus and the navicular (Case & Burnett, 2012).
Intermediate cuneiform – Lateral cuneiform coalition	CF2CF3Coal	A (non-)osseous coalition between the middle and lateral cuneiform (Case & Burnett, 2012).
Lateral cuneiform – Third metatarsal coalition	CF3MT3Coal	A (non-)osseous coalition between the lateral cuneiform and the third metatarsal (Regan et al., 1999).
Talocalcaneal coalition	TaloCalcCoal	A (non-)osseous coalition between the talus and the calcaneus (Case & Burnett, 2012).
Talonavicular coalition	TaloNavCoal	A (non-)osseous coalition between the talus and the navicular (Case & Burnett, 2012).

marked absent (0), present (1), indiscernible (6), or missing (9) for each separate foot. The distinction between "indiscernible" and "missing" was made to evaluate the usefulness of traits concerning the preservation of the bones. Tarsal coalitions were scored if at least one of the two bones could be marked "absent/present". The scores for each individual were determined by following the order of priority of "present," "indiscernible," "missing", and "absent". Individuals marked as "indiscernible/missing" were excluded from the frequency calculation for that specific trait. Another important element in these frequency calculations is the clustering of traits. The *os intermetatarseum* can appear under different forms, articulating with or fused to the first cuneiform, the first and/or the second metatarsal. Although these different forms were marked separately, they were clustered as one trait due to their common etiology (Case et al., 1998). The traits calcaneonavicular and talocalcaneal coalition were clustered based on the study by Leonard (1974) under the name of "ankle coalition" as proposed by Case et al. (2017). The calculations and comparisons of the trait frequencies were performed in the open-source tool R (version 4.0.3). This allows for a transparent and reproducible data processing procedure. For this reason, both the .csv file (Table S1) and the R script (Appendix S1) will be made available to the reader.

Although the grouping of burials by sex in postmedieval Dutch cemeteries (i.e., the period after the Middle Ages up until now) does not seem prevalent, it may be prudent to separate the individuals according to sex. The sex estimations of the individuals were based on pelvic and cranial morphology (Bainbridge & Genoves

Tarazaga, 1956; Bass, 1987; Buikstra & Ubelaker, 1997; Maat & Mastwijk, 2009; McCormick et al., 1991; Phenice, 1969; Stewart, 1979; Steyn & Işcan, 1999; Workshop for European Anthropologists [WEA], 1980) and were supported by archival data. For the Eindhoven collection, the DNA-determined sex estimations took precedence over the estimations by traditional bioarchaeological techniques (Baetsen & Weterings-Korthorst, 2013). Age-at-death estimations were only considered for the Middenbeemster collection as they may give an insight into the hypothetical group structure. Estimations were made according to traditional bioarchaeological techniques (Brooks & Suchey, 1990; Buckberry & Chamberlain, 2002; İşcan et al., 1984, 1985; Lovejoy et al., 1985; Maat, 2001; Meindle & Lovejoy, 1985; Todd, 1920).

The statistical significance of the difference between trait frequencies was assessed using the non-parametric Fisher's exact test because of the small sample sizes. The test was applied in this study under the Null hypothesis that both samples were equal with a significance level of 95% (alpha-value of 0.05, hereafter referred to as alpha-value). The Null hypothesis can be rejected; that is, the samples are statistically significantly different, if the calculated p value is lower than the alpha-value. Further, the traits and the inferred kinship relations should be considered carefully as not all of these traits could be tested on bias by Case et al. (2017) due to their rarity. The distribution of sex and age-at-death within the proposed hypothetical kinship group was also considered as the archaeological context and other kinship studies carried out on the Middenbeemster collection in the validation process. A visual exploration of the distribution was done by analyzing the excavation plans and the collected data about the presence of foot anomalies in the open-source tool QGIS (Version 3.10.9-A Coruña). The spatial statistics were chosen after Keron (2015) and are tailored to intracemetery kinship analyses for individual trait analyses in a uniformly distributed cemetery: Hodder and Okell's (1978) A-statistic, proximity count, and nearest neighbor-random labelling. In this context, the Null hypothesis is a random distribution of graves. The distance-based methods are complementary to get a better insight into their results (Keron, 2015). The radii for the proximity count statistic were determined to be 3, 5, and 7 m based on the dimensions of the cemetery (30 m × 18 m). To perform these statistics, a single pair of (x, y) coordinates was determined from the grave polygons in QGIS by calculating the centroids of these polygons. These data were added to the .csv file to perform these statistics in R with the R script provided by Keron (2015). If the hypothetical kinship group was large enough (more than five for each sex), the statistical analyses of cross nearest neighbor by sex and the cross proximity count by sex were performed.

3 | RESULTS

The majority of the traits were not present in both the Middenbeemster and the reference samples (Table 3). Only accessory navicular, the coalition between the lateral cuneiform and the third metatarsal, the *os intermetatarseum*, and ankle coalition were observed in these samples. All observed coalitions were non-osseous; that is, coalitions formed by cartilaginous bridges. Overall, the observed frequencies are quite similar between the sexes.

The comparison of trait frequencies between the reference samples and the study sample demonstrates that the trait frequencies of the accessory navicular and the ankle coalition are higher in the Middenbeemster sample for males as well as females. The accessory navicular trait is not statistically significantly different between the two samples in both the male and the female groups ($p = 0.496$). The frequency difference for the ankle coalition trait, on the other hand, is statistically significant for the males ($p = 0.045$) and is near to being so for the females ($p = 0.083$). As there were no significant differences between the sexes, it seemed justifiable to combine both groups and to compare the frequencies for the full study and reference samples. When the sexes were combined, the difference between Middenbeemster and the comparative sample for the ankle coalition trait became even more statistically significant ($p = 0.03$). This may suggest that its high frequency in the Middenbeemster collection might indicate a kinship-associated trait. Therefore, the individuals from the Middenbeemster collection exhibiting the ankle coalition trait ($n = 10$) may be a hypothetical kinship group (Table 4). This group was further examined to validate the hypothesis. Within the hypothetical kinship group itself, the distribution of sex and age-at-death is well spread. The group consists of four female and six male individuals. All age categories are represented: one early young adult, four late young adults, three middle adults, one old adult, and one "adult" individual.

The spatial analysis of the distribution of the hypothetical kinship group in the cemetery included nine out of the ten individuals as no spatial information was available for individual MB-129. The distribution of the individuals within this study indicates no clear segregation between the sexes, although it appears that females are more predominant in the north-eastern part of the cemetery (Figure 2). In the western part of the cemetery, four male individuals (MB-30, MB-166, MB-210, and MB-51) were found close to each other. Furthermore, individuals MB-198 (female) and MB-98 (male) in the eastern part of the cemetery were buried next to each other. The other female individuals (MB-32, MB-164, and MB-6) appear to have a more widespread distribution. Hodder and Okell's A-statistic indicated that segregation could be present (A-statistic = 0.968), although it is not statistically significant ($p = 0.242$). The p values of the proximity count analysis were also not significant, but they were all on the lower side and thus tend towards clustering (p value for distance 3 m = 0.307; p value for distance 5 m = 0.178; p value for distance 7 m = 0.318). In the nearest neighbor–random labelling analysis, the spatial distribution of the hypothetical kinship group tends clearly towards clustering (actual average NN = 2.215; random average NN = 2.905; NN ratio = 0.763) with an almost statistical significance (p value of 0.120).

These results correspond to the observations made for the visual representation. While there is a tendency towards clustering in the west (the four male individuals) and in the east (the male and female individuals), the general overview indicates a more scattered

TABLE 3 Overview table of the frequency of the selected traits in the Middenbeemster and the reference sample

Sample		Anomaly	AccessNav	BrachyD	BrachyMT1	BrachyMT4	BrachyPP1	CalcCubCoal	TaloNavCoal	CF2CF3Coal	CF3MT3Coal	OsIntermet	AnkleCoal
Males	Reference sample	Aff. /Stud. Individuals (*N*)	3/42	0/19	0/51	0/50	0/35	0/59	0/62	0/38	5/53	4/30	0/63
		Frequency (%)	7.14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.43	13.33	0.0
	Middenbeemster	Aff. /Stud. Individuals (*N*)	5/58	0/28	0/81	0/69	0/56	0/84	0/79	0/57	1/75	2/59	6/93
		Frequency (%)	8.62	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.33	3.39	6.45
	p value		0.496	-	-	-	-	-	-	-	0.08	0.439	0.045
Females	Reference sample	Aff. /Stud. Individuals (*N*)	1/36	0/20	0/47	0/46	0/34	0/48	0/54	0/32	2/43	1/30	1/58
		Frequency (%)	2.78	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.65	3.33	1.72
	Middenbeemster	Aff. /Stud. Individuals (*N*)	5/58	0/18	0/83	0/78	0/53	0/77	0/80	0/42	4/84	0/48	4/80
		Frequency (%)	8.62	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.76	0.0	5.00
	p value		0.496	-	-	-	-	-	-	-	0.546	0.064	0.083
Overall	Reference sample	Aff. /Stud. Individuals (*N*)	4/78	0/39	0/98	0/96	0/69	0/107	0/116	0/70	7/96	5/60	1/121
		Frequency (%)	5.13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.29	8.33	0.83
	Middenbeemster	Aff. /Stud. Individuals (*N*)	10/116	0/46	0/164	0/147	0/109	0/161	0/159	0/99	5/159	2/107	10/173
		Frequency (%)	8.62	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.14	1.87	5.78
	p value		0.411	-	-	-	-	-	-	-	0.14	0.099	0.03*

Note: The ratio between the number of affected individuals and the number of studied individuals is indicated with "Aff. /Stud. Individuals (*N*)". The *p* value for the males and females is the result of comparing the respective Middenbeemster sample (male or female) to the overall reference sample.

TABLE 4 Overview of the individuals in the Middenbeemster sample with the ankle coalition trait

Individual no.	Estimated sex	Estimated age-at-death	Related findings	Trait	Unilateral or bilateral
MB-6	Probable female	Middle adult	Textile fragments, bronze fragments, secondary findings	CalcNavCoal	Bilateral
MB-30	Male	Middle adult	Copper button, bone button, nails	CalcNavCoal	Bilateral
MB-32	Female	Late young adult	Bronze/copper clothing hooks, clothing hooks, secondary findings	CalcNavCoal	Unilateral (R)
MB-51	Probable male	Old adult	Bone button	TaloCalcCoal	Bilateral
MB-98	Male	Late young adult	Secondary findings, nails	CalcNavCoal	Bilateral
MB-129	Male	Middle adult		CalcNavCoal	Bilateral
MB-164	Female	Late young adult	-	CalcNavCoal	Unilateral (L)
MB-166	Male	Late young adult	Fragment rummer glass, baby bones	TaloCalcCoal	Unilateral (R)
MB-198	Female	Early young adult	Secondary findings	CalcNavCoal	Bilateral
MB-210	Probable male	Adult	Secondary findings, bone button	CalcNavCoal	-[a]

Note: The age categories described are early young adult (18 to 25 years old), late young adult (26 to 35 years old), middle adult (36 to 50 years old), and old adult (older than 50 years).
[a]The trait was present on one side, while the other side was indiscernible.

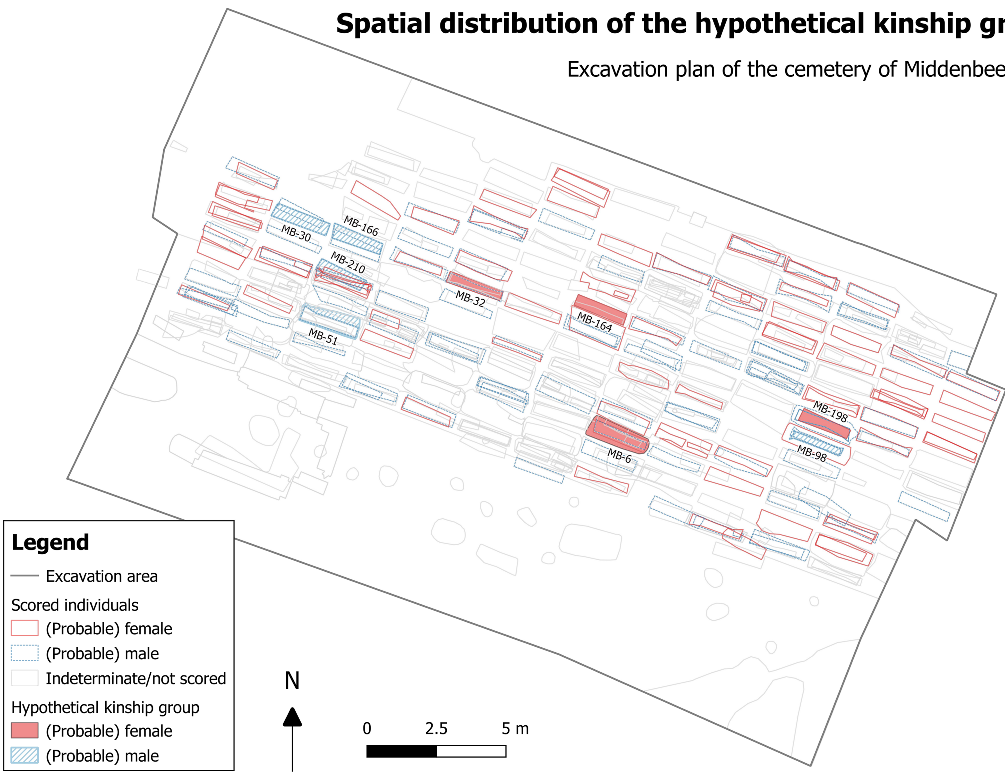

FIGURE 2 Visual representation of the spatial distribution of the hypothetical kinship group in the excavated cemetery of Middenbeemster. Figure produced by Elle Liagre, with data made available by Hollandia Archeologen [Colour figure can be viewed at wileyonlinelibrary.com]

distribution pattern (Figure 2). In this regard, more statistical analyses on sex patterning would be interesting to examine if the cluster of males in the west is statistically significant. However, the number of individuals within the hypothetical kinship group was too small (four female individuals and six male individuals, of which MB-129 was not recorded) to divide the group further according to sex for the statistical analyses.

4 | DISCUSSION

The results indicated that the difference between trait frequencies of the study and the reference samples for the ankle coalition trait (coalition between the calcaneus and navicular and between the calcaneus and talus) was significant. This indicates that the ten individuals in the Middenbeemster sample affected by the ankle coalition trait form a hypothetical kinship group. The background of the trait and the archaeological context may provide some validation for this proposed kinship group. The coalition between the calcaneus and navicular was examined by Case et al. (2017), and it was concluded that there was no sex or age bias for this trait (Case et al., 2017). The results of this study confirm these observations. Furthermore, in the same study, the limited presence of coalition between the talus and calcaneus made testing on sex and age bias not possible, although a sex bias was unlikely. In this study, a similar situation occurs and no further testing on these biases was done. An age bias seems unconvincing, as both individuals affected by the coalition between talus and calcaneus were part of different age categories. Coalition between the calcaneus and navicular co-occurred with a coalition between the lateral cuneiform and the third metatarsal in a single case, but previous studies indicated that the co-occurrence of these two traits was not statistically significant (Case et al., 2017). One individual in this study demonstrated the co-occurrence of the coalition between the talus and calcaneus and the coalition between the lateral cuneiform and the third metatarsal, but due to its rareness, no intertrait-correlation analyses could be done now or in previous studies.

A closer look at the archaeological context of the Middenbeemster collection reveals that eight out of ten individuals of the hypothetical kinship group can be placed within the same period (1829–1866) (Hakvoort, 2013; van Spelde & Hoogland, 2018). Of the two remaining individuals, individual MB-210 was placed in the eighteenth century, while the excavation form of the other individual (MB-129) was missing. Most of the grave goods within the hypothetical kinship group were clothing or coffin materials (Hakvoort, 2013). Such findings are relatively common in the context of the Middenbeemster cemetery. Only in the grave of individual MB-166, a rummer fragment was found, (i.e., a large drinking glass).

The results of this study were also compared to another kinship study, based on dental non-metric traits, carried out on the Middenbeemster collection (Leroux, 2012). There is a single individual (MB-32) that occurs in both our hypothetical kinship group as in the group presented in Leroux's study. This limited correspondence between the studies is not very telling and may suggest differing modes of inheritance between post-cranial anomaly traits and dental non-metric traits.

Of the hypothetical kinship group, the sex and age-at-death estimations seemed to be evenly distributed in the group. It does not indicate a post-marital residence preference, for example, patrilocal household structures, in which the group would be predominantly male. However, the absence of this indication could suggest that the small, rural context of Middenbeemster was rather a closed community where marriage happened between individuals of the same community. This inference is based on a small number of individuals and must be treated with caution. Even though the archaeological context added limited validation to the hypothetical kinship group, it is not unimaginable that in various other contexts grave goods could be useful as validation of the hypothetical kinship groups. The spatial analysis revealed a cluster of four male individuals, but this clustering could not be statistically confirmed due to the small number of individuals. During the spatial analysis, however, various issues arose, which could have influenced this interpretation: the cemetery's (re-)use, the depth of the burial locations and the selection of individuals. Additionally, a spatial analysis of the burial locations in relation to hypothetical kinship groups has been carried out before by Leroux (2012). She concluded that the cemetery of Middenbeemster was likely not kin structured, but with the observed clusters as the result of randomness. However, her spatial analysis lacked the statistical component that was applied in this study as well as the division between the sexes.

The preservation of the foot bones limited the number of individuals who could be examined (Figure 3). This issue is even more evident in the reference samples as the sample size could not match that of the study sample. This could be addressed in the future with the addition of other skeletal collections. A larger sample size would aid in detecting statistical differences and would perhaps produce hypothetical relatives. Small bones like the first proximal and distal phalanges were largely absent, while tarsals were predominantly present. However, this did not mean that the latter were always complete enough to collect data (e.g., accessory navicular and coalition between the intermediate and the lateral cuneiform). Clustered traits could also visibly lower the number of scored individuals as these required more bones to be present and complete enough to score. In general, traits that included the calcaneus and/or talus had the highest numbers of scored individuals. This could be due to better preservation and their larger size.

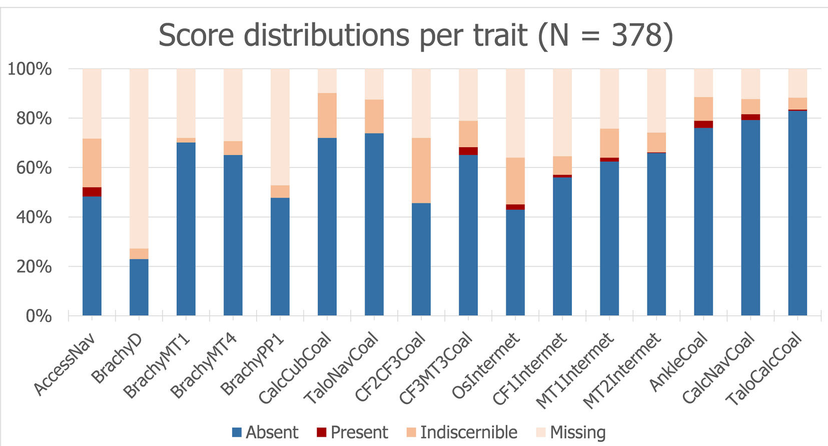

FIGURE 3 Graphical presentation of the score distributions (absent, present, indiscernible, and missing) viewed for every trait [Colour figure can be viewed at wileyonlinelibrary.com]

Out of all the traits studied, it turned out that the majority were not observed in both the study and the reference samples. The absence of the brachydactyly traits in the studied post-medieval Dutch sample is not surprising as they are quite rare (Table 5). Even less so, when the small sample size for some of these traits is considered (e.g., brachydactyly D). Only the Native American sample of Cybulski (1988) shows a substantially higher frequency, but it is suggested that this high frequency is due to close genetic relationships among the individuals within the sample. Among the traits considered, coalition between the talus and navicular and coalition between the intermediate and lateral cuneiform, there are only a few anatomical or archaeological cases found (Case & Burnett, 2012).

Both accessory ossicle traits were found in the post-medieval Dutch population. The accessory navicular trait frequency found for the present study (7.22%) is considerably higher than in other archaeological samples (1–4.2%) (Case et al., 2017; Offenbecker & Case, 2012), a difference that may be explained by population variation between the post-medieval Dutch population and other populations. There is also a difference notable between the Middenbeemster sample (8.6%) and the reference samples (5.1%). Although the difference is not statistically significant, the higher trait frequency in the Middenbeemster sample may point to a rather close genetic relationship among the Middenbeemster individuals. Contrary to the results of Offenbecker and Case (2012), there were more cases of bilaterality observed (55%; six out of eleven) than unilaterality (45%, five out of eleven, with two left and three right). The reason for this discrepancy between these results is unclear and seems to call for more research into laterality, the type of accessory navicular, and the inheritance.

Although other studies on the *os intermetatarseum* trait are available, a comparison is difficult because of the different forms and bones that are part of this trait. The trait frequencies found for the post-medieval Dutch sample fit within the reported frequency ranges, except for the presence of the fused form of the first metatarsal (Case et al., 1998, 2017). The two affected individuals are present in different samples (Middenbeemster and Eindhoven), which could suggest that the trait's presence is rather related to population variation instead of intracemetery genetic relations. Nevertheless, these extremely small numbers prevent any profound conclusions. No comparable studies were done on the laterality of this trait, but it seems to be predominantly unilateral (R) (83%, five out of six) with only one out of six (17%) bilateral.

The trait frequency for the coalition between the calcaneus and cuboid trait in the post-medieval Dutch population (0.0%) lies in line with the range of frequencies found in archaeological and anatomical collections (0.0% to 0.55%) (Albee, 2020; Case et al., 2017; Case & Burnett, 2012). The extensively studied coalition between the lateral cuneiform and the third metatarsal (mainly in Regan et al., 1999, and Tenney, 1991) has a great frequency variability between different populations in which the post-medieval Dutch population fits. The predominant unilateral expression of the trait (75%, six out eight) in individuals in the postmedieval Dutch sample contradicts the literature results (Regan et al., 1999; Tenney, 1991; Wilbur, 1997). The exclusive presence of unilateral trait expression in the Middenbeemster sample is noteworthy and raises the question of the relation between laterality and inheritability for this trait.

The coalition between calcaneus and navicular and between the talus and calcaneus are the most common types of tarsal coalition found in clinical studies (Fopma & Macnicol, 2002) and archaeological literature (Case & Burnett, 2012). Although the coalition between the calcaneus and navicular trait frequencies for the post-medieval Dutch agree with the observed frequencies in other populations, there is a considerable difference between the study (4.7%) and the reference samples (0.8%) which is likely due to intracemetery kinship relations in the small, rural archaeological Middenbeemster context. The coalition between the calcaneus and navicular trait was observed to be predominantly bilaterally present (62.5%; five out of eight), contrary to other studies (Albee, 2020; Case & Burnett, 2012). The coalition between talus and calcaneus trait frequency for the post-medieval Dutch sample (0.7%) can be placed in the reported frequency range, that is, 0.0% to 1.3%, even when focusing solely on the Middenbeemster frequency (1.1%). The laterality of this notably small sample, that is, one bilateral and one unilateral (R) is in accord with other studies (Case & Burnett, 2012).

4.1 | Limitations

As with all research, there are some limitations to this study. It has to be taken into account that this research has been conducted with limited experience with foot anomalies. Knowledge about these rare traits and how to recognize them in dry bone was solely derived from literature. This could have influenced the consistency of the data collection during its gathering, as the familiarity with the foot bones and their variations increased. Furthermore, the rarity of the foot anomalies requires a large enough sample size of a few hundred individuals. For most of the traits, this number was reached, although not for all of them (e.g., Brachydactyly D) due to preservation issues and excavation techniques. Non-adults were not included in this sample as the traits are not formed yet for these individuals, but this means that a segment of the community is not considered in the kinship analysis. Lastly, this study offers hypotheses on biological relationships between individuals, but these could not be evaluated. It would be interesting to assess the hypotheses by applying for example aDNA analysis.

When reflecting on the method by Case et al. (2017), the results presented here are rather limited as only one hypothetical kinship group was found. This is not surprising as the number of hypothetical kinship groups is restricted to the number of traits included in the kinship analysis. Going forward, a large sample (of a few hundred individuals) is recommended, otherwise, the traits are too rare to be observed. Although a reference sample allows contextualization of the results in a broader framework of population variation, the limited results of this time-consuming method culminate in a rather unfruitful approach. This does not necessarily imply that the traits are useless in kinship analysis as they may be included as non-metric traits in a

TABLE 5 General overview of the trait frequencies examined in this study and the frequencies reported in archaeological and clinical literature

		OsIntermet						
Study/anomaly	**AccessNav**	**CF1Intermet**	**MT1Intermet**	**MT2Intermet**	**OsIntermet**	**BrachyD**	**BrachyPP1**	**BrachyMT1**
Present study								
Aff. /Stud. Ind. (N)	14/194	2/214	2/240	0/248	7/168	0/85	0/178	0/262
Frequency (%)	7.22	0.93	0.83	0.0	4.17	0.0	0.0	0.0
Other studies (%)								
Albee (2020)	-	-	-	-	-	-	-	-
Burnett and Wilczak (2012)	-	-	-	-	-	-	-	-
Case et al. (1998)	-	0–2	0	0–8	0–14	-	-	-
Case et al. (2017)	~3	~1	0	<5	-	0–3	0.5–1	0.5
Case and Burnett (2012)	-	-	-	-	-	-	-	-
Cybulski (1988)	-	-	-	-	-	-	-	1.3
David et al. (2015)	-	-	-	-	-	-	<2	-
Offenbecker and Case (2012)	1–4.2	-	-	-	-	-	-	-
Ray (1968)	-	-	-	-	-	-	-	-
Regan et al. (1999)	-	-	-	-	-	-	-	-
Temtamy and Aglan (2008)	-	-	-	-	-	0.41–4	-	<2

Note: "Aff. /Stud. Ind. (*N*)" refers to the ratio of affected individuals (*N*)/studied individuals (*N*). The full name and description of the traits can be found in the trait summary (Table 2).

TABLE 5 (Continued)

Study/anomaly	BrahcyMT4	CalcCubCoal	TaloNavCoal	CF2CF3Coal	CF3MT3Coal	AnkleCoal		
						CalcNavCoal	TaloCalcCoal	AnkleCoal
Present study								
Aff. /Stud. Ind. (N)	0/243	0/268	0/275	0/169	12/255	9/297	2/311	11/294
Frequency (%)	0.0	0.0	0.0	0.0	4.71	3.03	0.64	3.74
Other studies (%)								
Albee (2020)	-	0.55	-	-	0.55	2.73	0.55	-
Burnett and Wilczak (2012)	-	-	-	-	3.2–8.4	-	-	-
Case et al. (1998)	-	-	-	-	-	-	-	-
Case et al. (2017)	0–1	<0.1	0	0	~5	1–2	<5	-
Case and Burnett (2012)	-	0–0.4	-	-	-	0.2–3.5	0–0.8	-
Cybulski (1988)	3.3	-	-	-	-	-	-	-
David et al. (2015)	-	-	-	-	-	-	-	-
Offenbecker and Case (2012)	-	-	-	-	-	-	-	-
Ray (1968)	<1	-	-	-	-	-	-	-
Regan et al. (1999)	-	-	-	-	3.2–26	-	-	-
Temtamy and Aglan (2008)	-	-	-	-	-	-	-	-

Note: "Aff. /Stud. Ind. (*N*)" refers to the ratio of affected individuals (*N*)/studied individuals (*N*). The full name and description of the traits can be found in the trait summary (Table 2).

similarity approach to kinship analysis. It would avoid the need for a reference sample in the analysis and the rarity of the traits could be an added value in the interpretation of the resulting hypothetical kinship groups.

5 | CONCLUSIONS

The research goals of this study were aimed at obtaining an insight into the genetic homogeneity and interrelatedness of the post-medieval Dutch community of Middenbeemster by identifying probable genetic relatives within the Middenbeemster skeletal collection using developmental foot anomalies (a method by Case et al., 2017) and by analyzing the spatial structure of the cemetery of Middenbeemster in the context of intracemetery kinship relations.

Through comparison of trait frequencies in a study sample (Middenbeemster) and reference samples (Arnhem, Eindhoven, and Zwolle), hypothetical groups of genetic relatives could be established if the frequency for a certain trait was considerably higher in the study sample than in the reference samples, which should reflect the trait frequency in the population. Most of the frequencies found for the traits, even the absence of more than half of them, fell within the range of frequencies reported in the literature. The presence of the *os intermetarseum* of the first metatarsal is remarkable as it is mostly absent in other populations. However, the trait is present in the study and reference samples, which would suggest that this is due to population variation. Secondly, the frequencies for the traits accessory navicular and the coalition between the calcaneus and navicular were unusually high when solely the Middenbeemster sample was considered. These high frequencies are likely due to close genetic relationships among the individuals of the cemetery as they are also larger than the frequencies found in the reference samples. Although the accessory navicular trait frequency was not statistically higher than the reference sample, the high frequencies seen in the Middenbeemster skeletal collection for both traits indicate close genetic relationships among the individuals of this small, rural context. It suggests that the post-medieval Middenbeemster community was far more inter-related than the other (urban) populations examined in this study (Arnhem, Eindhoven, and Zwolle).

The argument that post-medieval Middenbeemster was a rather closed community returns in the validation of the ankle coalition-based hypothetical kinship group. The even distribution of sex and age-at-death could be seen as suggestive of marriage within the community rather than post-marital relocation. The validation value from the archaeological context and the other sources (historical sources, other research) was limited, but this does not alter the fact that these validation methods could be useful in other contexts. A spatial analysis of the trait distribution in the cemetery formed the last step in the validation of the hypothetical kinship group and gave an insight into the spatial structure of the cemetery. No statistical clustering was found for the whole group, but the visual representation suggested a cluster of four male individuals. However, this indication could not be tested due to the small sample size. It would be interesting to test these hypotheses in the future through aDNA-analysis. Other issues with the spatial analysis were the re-use of the Middenbeemster cemetery, the limitation to cartesian coordinates, and the restricted sampling because of preservation. Despite these issues, the clustering of four male individuals of the hypothetical kinship group could reflect a bought family burial ground. It suggests that the Middenbeemster cemetery had, to a certain extent, a patrilineal organization. However, the results of a similar study by Leroux, although with a partially different methodology, contradict this suggestion. The observed clustering is thus more likely to be random than the result of the limited kin organization of the cemetery.

After a reflection on the method developed by Case et al. (2017), certain disadvantages of the method could be determined. The large sample needed for the method (due to the rarity of the traits) is time-consuming and yields only limited results (restricted by the number of traits). Additionally, the general preservation of the feet bones is problematic because they cannot always be scored even if they are present. The traits themselves, however, can certainly be useful in future kinship analysis, and due to their rarity, they would be even more convincing when part of a hypothetical kinship group. In this context, future research on the heritability of the traits (e.g., *os intermetatarseum*, the laterality of traits like the accessory navicular, the coalition between the calcaneus and navicular, and between the lateral cuneiform and third metatarsal) will be valuable. These recommendations will allow further development of the methodology used in kinship research and demonstrate the significance of methodology assessment in (bio)archaeological research. Improvement of methodology also benefits other fields such as forensic anthropology and legal medicine. Future research may include a follow-up study on the Middenbeemster context with attention to the accessory navicular-based hypothetical kinship group and on validation of the hypothetical kinship groups and the spatial structure of the cemetery with archival records.

In conclusion, even if the method developed by Case et al. (2017) is applied to a small, rural context as Middenbeemster with good general preservation, the results are limited due to issues inherent to the context (e.g., small sample size) and to the method (e.g., limiting the number of traits, the rarity of traits, and preservation of foot bones). Notwithstanding that the foot anomalies may be used in other approaches.

ACKNOWLEDGMENTS

The authors are grateful to the Historische Genootschap Beemster (Historic Society Beemster) for their support and to the people of Arnhem, Eindhoven, Zwolle, and Middenbeemster for allowing the study of their ancestors. The help provided by S. Baetsen for providing the much-needed final sex determinations for the Eindhoven collection was greatly appreciated. The authors would also like to thank the anonymous reviewers, who gave important remarks and aided in increasing the quality of the manuscript.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest. This research was completed without any funding or research grants.

DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the supplementary material of this article and are openly available in Zenodo at https://doi.org/10.5281/zenodo.5879487.

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How to cite this article: Liagre, E. B. K., Hoogland, M. L. P., & Schrader, S. A. (2022). It runs in the family: Kinship analysis using foot anomalies in the cemetery of Middenbeemster (Netherlands, 17th to 19th century). *International Journal of Osteoarchaeology*, *32*(4), 769–782. https://doi.org/10.1002/oa.3100