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Abstract

Objectives: Although rare, tooth transposition—an exchange in location of two teeth—is a frequent topic of study. Clinical and, to a much lesser extent, dental anthropological research have focused predominantly on prevalence (0.03-0.74% in several world populations) and case studies, albeit on a restricted spatiotemporal scale. Many regions have received little attention, including sub-Saharan Africa, while premodern data are few. Here, the aim is to supplement both fields of dental research by reviewing previous publications, and newly reporting transposition rates, types, and co-occurring abnormalities in time-successive samples across the sub-continent.

Methods: Dental data in 51 sub-Saharan samples (>2500 individuals) dating >10,000 BC-20th century were recorded. Of these, 36 are of modern and 15 pre-modern age, comprising males and females ≥12-years of age. Transposition presence, quadrant, and type were tabulated, cases described, and prevalence presented. In the latter case, Poisson 95% confidence intervals were calculated to better discern true population rates at various geographic levels.

Results: Overall, six of 1886 modern individuals (0.32%) and one of pre-modern age evidence Mx.C.P1, an exchange of the maxillary canine and first premolar. Various associated dental abnormalities are also evident, including retained deciduous teeth, reduced permanent crowns, and agenesis.

Conclusions: This study provides additional insight into the geographic distribution, features, and time depth of transposition, along with hints supporting a genetic etiology and, potentially, some indications of diachronic change from an initial Mx.C.P1 to several types more recently based on pre-modern evidence. It is of clinical concern today, but is not just a modern anomaly.

1) INTRODUCTION

Tooth transposition, a partial or complete exchange of location between teeth, is rare. Based on results of limited sampling, primarily in Europe and, by diminishing degrees, the U.S., Mideast, India, and Africa, its prevalence is 0.03%-0.74% (though see below) in modern populations (Van Reenen, 1964; Peck et al., 1993, Burnett, 1999; Hatzoudi & Papadopoulous, 2006; Onyeaso & Onyeaso, 2006; Watted et al., 2015; etc.). Excluding syndromic cases (e.g. Lewyllie et al., 2017), a meta-analysis by Papadopoulous et al. (2010) yielded a mean of 0.33%. Thus, it may follow that documentation is equally rare. Not so.

A search for alternative forms of the words "transposition" and "tooth" or "teeth" or "dental" or "incisor" or "canine" or "cuspid" or "premolar" or "bicuspid" or "molar" yielded >350 results on Scopus (scopus.com), Web of Science (http://apps.webofknowledge.com/), and PubMed (ncbi.nlm.nih.gov/pubmed). For example, PubMed returned 363 unique titles, with 243 referencing the positional anomaly. Of these, 238 (97.9%) are clinical in scope, including: 1) case studies and treatment (Newman, 1977; Shapira & Kuftinec, 1983; Maia & Maia, 2005; Onyeaso & Onyeaso, 2006; Hatzoudi & Papadopoulous, 2006; Babacan et al., 2008; Taguchi et al., 2009; Kuttapa et al., 2011, etc.), 2) literature reviews (Järvinen, 1982; Peck et al., 1993; Huber et al., 2008; Papadopoulos et al., 2010), 3) a combination of these two (Shapira et al., 1989; Peck & Peck, 1995; Mattos et al., 2005; Tripathi et al., 2014; Watted et al., 2015; Loil, 2017), 4) etiology (Feichtinger et al., 1977; Sandham & Harvie, 1985; Shah, 1994; Shapira et al., 2000; Ely et al., 2006; Lewyllie et al., 2017) and 5) in one case, forensic pathology (Nambiar et al., 2014). Tooth transposition is largely perceived to be a modern orthodontic issue (Shapira & Kuftinec, 1989, 2001; Peck et al., 1993; Peck & Peck, 1995; Plunket et al., 1998; Budai et al., 2003; Maia & Maia, 2005; Yilmaz et al., 2005; Mattos et al., 2005; Ely et al., 2006; Babacan et al., 2008; Tripathi et al., 2014; Watted et al., 2015; among others). However, as the remaining five of 238 articles (2.1%) reveal, the anomaly has long affected humans, based on dental anthropological research in mostly pre-modern (archaeological) samples from the New and Old Worlds (Nelson, 1992; Lukacs, 1998; Burnett, 1999; Burnett & Weets, 2001; Sholts et al., 2010).

The present study complements both clinical and anthropological research by exploring further the geographic range of transposition and its antiquity. Firstly, prevalence is reported in samples across sub-Saharan Africa—a major yet underreported world region. Case studies are described to assess comparability with others worldwide. Specifically, prior study found that maxillary transposition is most common; the canine and first premolar are frequently affected; unilateral left quadrant expression dominates; occurrences seem biased toward females; other developmental abnormalities in tooth formation and position (though not stress, e.g., hypoplasia) often co-occur (below); and a genetic etiology is thought likely but not confirmed (e.g. Shapira & Kuftinec, 1989, 2001; Peck et al., 1993; Peck & Peck, 1995; Plunket et al., 1998; Budai et al., 2003; Maia & Maia, 2005; Yilmaz et al., 2005; Mattos et al., 2005; Ely et al., 2006; Babacan et al., 2008; Tripathi et al., 2014; Watted et al., 2015). Lastly, tooth transposition in pre-modern specimens, some dating to >9000 BC, is also discussed with one new-found example described. The overarching intent, then, is to help further place "clinical research . . . in historical perspective," and understand better the "evolutionary origins and significance of this dental anomaly" (Lukacs, 1998:479).

2) METHODS

Tooth transposition data were collected during the course of research into sub-Saharan African population affinities (Irish, 1993, 1997, 1998, 2010, 2013, 2016a,b; Irish & Guatelli-Steinberg, 2003; Irish et al., 2014, 2018), using highly hereditary nonmetric traits from the Arizona State University Dental Anthropology System (ASUDAS) (Turner et al., 1991; Scott & Irish, 2017). In a few cases, transposition recorded by the author was either previously or subsequently reported by other authors, and is so noted. All told, 52 samples defined securely by ethnicity and/or site provenience across 19 countries were analyzed. Sampling was purposefully broad to represent a maximum number of populations at the sub-continental level. These samples comprise 2742 skeletal dentitions and casts of living individuals dating 10,880 BC-20th century.

For the present study, only those aged ≥12-years with at least one extant quadrant were included. This left 51 samples with 2527 maxillae and 2116 mandibles for which transposition, e.g. Mx.C.I2, Mx.C.P1, Mx.C to M1, Mx.I2.I1 and Mx.C to I1 (after Peck & Peck, 1995), and abnormalities are reported (Peck et al., 1993, 1996; Yilmaz et al., 2005). Based on the curation records or as determined from diagnostic skeletal indicators (Buikstra & Ubelaker, 1994), 246 maxillae were categorized as 'male' or 'male?', 892 'female' or 'female?', and 389 unknown. Mandible counts are 1043, 745, and 328. Samples were then subdivided into: 1) 36 modern, considered 19th-20th centuries, with 1886 maxillary and 1597 mandibular dentitions, and 2) 15 pre-modern samples, 10,880 BC-AD 1780, totaling 641 and 519, respectively. These dates are from curation data, or sources referenced in Irish (1993, 1997, 2013, 2016b, et al., 2014). Due to the rarity of transposition, all modern samples were then pooled to obtain prevalence by sub-Saharan region—western, central, eastern, southern—rather than 36 rates of mostly 0.00%. The total sample is large relative to the aforementioned prevalence studies, but the infrequency and vast geographic scale encouraged use of a Poisson model to calculate 95% confidence intervals (CI), within which true population rates are likely contained (e.g. Rothman et al., 2008). For the smaller total pre-modern sample, derived from the same geographic range plus markedly greater time depth, only counts and a description are provided.

3) RESULTS

Six of the 1886 modern maxillae, 0.32%, evidence transposition (Table 1) with a 95% CI of 0.12-0.69%. Three are from the central region (0.96% of 314; CI 0.20-2.79%) and three from southern sub-Saharan Africa (0.37% of 806; CI 0.08-1.09%).

The central individuals, all ethnic Hutu, derive from one cemetery (3/93 individuals; 3.2%) in Nyirankuba Cave, near Ruhengeri, Rwanda (Ribot, 2003; Giblin, 2008). Each has Mx.C.P1 (Peck & Peck, 1995), i.e. maxillary canine-first premolar exchange. Brabant (1963) also noted the anomalies; unfortunately, sexes of the affected individuals were not reported in this French-language publication, which is generally unavailable today. For the present study, the sexes were determined as two females and one male. The first female has unilateral partial left transposition (Figure 1A). Many teeth are missing post-mortem, but associated abnormalities include left first and second premolar rotation, a reduced right second premolar, reduced right and left lateral incisors, and a retained deciduous left canine. The second female exhibits bilateral Mx.C.P1, with partial right- and complete left transposition (Figure 1B). Beyond the premolar rotation, abnormalities include a reduced right lateral incisor, a congenitally absent left lateral incisor, and bilateral third molar agenesis—which is otherwise very rare (<4.5%) in sub-Saharan populations (Irish, 2016b). The male has partial left side transposition. Only the left second premolar and first molar are retained postmortem. The root of the latter tooth is taurodont, but no other abnormalities are evident.

Of the three affected modern southern Africans two, both females, are from a collection of 143 casts of San, from the !Kung, Naron, Tshakwe, Mkaukau, and Gwikwe ethnic groups

(Irish, 1993). The prevalence, 1.4% (2/143), was also reported by Burnett (1999). The casts are copies of originals from the Nuffield Foundation-Witwatersrand Kalahari Research Committee Expedition to Ghanzi, Botswana (Irish, 1993). The first individual has right complete Mx.C.P1, with an impacted maxillary left first premolar, and mandibular second premolar agenesis. The second individual also has right complete Mx.C.P1. Further maxillary abnormalities include a retained right deciduous canine, right lateral incisor agenesis, and peg-shaped left lateral incisor. The third southern African case, unilateral partial right Mx.C.P1 (Figure 1C), occurred in one 32-year old male out of 57 Swazi (1.7%); this sample was chosen randomly from a larger Swazi collection for the nonmetric study (Irish, 2016b). No other abnormalities are evident.

Lastly, transposition occurred in one of 641 pre-modern maxillae (Table 2), and none of the 519 mandibles. This southern region male displays unilateral right partial Mx.C.P1 (Figure 1D). Accompanying abnormalities include reduced third molars and a retained right deciduous canine. It is one of 41 complete crania recorded in the Matjes River Rockshelter sample from South Africa (Irish et al., 2014). Unfortunately, this particular cranium is undated, though Matjes River and nearby rock shelters were used by local peoples during 9186-250 BC.[45]

4) DISCUSSION

Numerous transposition articles are available yet the rates, 0.03%- 0.64% [excluding 0.74% in Van Reenen's (1964) small Africa sample], are based on few studies from fewer locations. They are limited further spatially, i.e. patients visiting a local clinic, and/or sample sizes (Peck et al., 1993, Hatzoudi & Papadopoulous, 2006; Papadopoulous et al., 2010; Watted et al., 2015; etc.). Less is known about other regions including sub-Saharan Africa, where only five studies have been published and are subject to the above limitations. One reports 11 cases in 8125 (0.14%) dental patients, but from just one location in Nigeria (Umweni & Ojo, 1997). Of interest, only four Mx.C.P1 examples were observed. A second clinical study reports a higher prevalence, 0.60%, but again in one location and a smaller sample of 361 Nigerian students; the types are unspecified (Onyeaso & Onyeaso, 2006). The other studies are anthropological, including the Rwandan cases (Brabant, 1963). As well, two of 385 casts from two southern region groups, many of which are included in prior research (Irish, 1993, 1997) and the present study, were noted with Mx.C.P1 at 0.52% (Burnett, 1999). Lastly, Van Reenen (1964) recorded a rate of 0.74% Mx.C.P1 in 406 casts of San from Botswana, some of which may duplicate those in Burnett (1999) and here.

The present results, 0.32% (6/1866) and CI 0.12-0.69%, lie within the range for other world groups (above)—perhaps suggesting uniform occurrence of transposition independent of population origin. While not completely 'modern' (19^{th}-20^{th} centuries), the total sample size from 36 well-defined ethnic groups in many locations is large (Table 1). Further, transposition was not the focus of study during nonmetric trait recording, so sampling was basically random. Thus, the results are, arguably, representative estimates for the collective native inhabitants of sub-Saharan Africa. With regard to regional prevalence (Table 1), although some insight may be obtained, the anomaly's infrequency, again, compromises reliability— until larger samples are available at these specific levels.

Of the six modern individuals with transposition, many features are also comparable with those noted in the introduction for other populations. The maxilla is involved (100%), all are the Mx.C.P1 type (100%), and five of six (83.3%) have unilateral expression. That said, three of the five occurrences, 60%, are in the right maxilla—contra reported left quadrant dominance. Back in agreement, four individuals (66.7%) were females, and five (83.3%) evidence abnormalities known to co-occur. The latter include: 1) 33% (2/6) with a retained maxillary deciduous canine, compared to 50% for other world areas, 2) 50% (3/6) reduced or peg-shaped permanent teeth—mostly lateral incisors, relative to 25%, and 3) 50% (3/6) agenesis, often lateral incisors, which otherwise occurs in 37-40% of cases (Shapira & Kuftinec, 1989; Peck et al., 1993, 1996; Peck & Peck, 1995; Plunket et al., 1998; Budai et al., 2003; Mattos et al., 2005; Tripathi et al., 2014; Watted et al., 2015). Moreover, though not the focus here, a genetic etiology may be supported in that these sub-Saharan characteristics emulate those of other populations, while transposition occurs multiple times within two samples, perhaps suggesting familial affinity (see Nelson, 1992 for an overview of this and other potential causes of transposition); these factors are reminiscent of more common positional anomalies commonly recorded as ASUDAS traits, including incisor winging, midline diastema, and torsomolar angle (Turner et al., 1991; Scott & Irish, 2017). Of course, specific genetic-focused research and increasing sample numbers are requisite for confirmation.

With exceptions, little is known about pre-modern transposition. From the New World, nine of 106 (8.5%) Native American crania dating 3800-2500 BC, from Santa Cruz Island have Mx.C.P1 (Nelson, 1992). A study of other Santa Barbara Channel Island samples found seven of 966 (0.73%), 5500-600 BC, with Mx.C.P1 (Sholts et al., 2010). Eleven of 510 crania (2.2%) from New Mexico, AD 1300-1846, display this transposition (Burnett & Weets, 2001). In the Old World, one of 20 (5.0%) from Sarai Khola (1000-270 BC), and one of ca. 90 (>1.0%) from Harappa—both in Pakistan (2500 BC), exhibit Mx.C.P1 (Lukacs, 1998). From northeast Africa, one of 205 (0.49%) from Semna South in far-north Sudan has Mx.C.P1 (Burnett, 1999); the date is 100 BC-AD 350 (Irish, 1993). In addition, transposition of unnamed type(s) was reported in some Egyptian specimens of unspecified date (perhaps 3400-1077 BC?) (Satinoff, 1972). As above, these studies have sampling issues, i.e. few in number and restricted to one region. As well, it is the existence of transposition in these mostly small samples (though see Sholts et al., 2010) that likely prompted the publications and contributed to several extreme rates (1.1-8.5%).

The total of 641 pre-modern individuals is relatively large, and the sampling was random, as above (Table 2). That said, the geographic and temporal scales are significantly greater than in the abovementioned studies, so the overall and regional samples are likely not representative, at least relative to the modern analyses. Further, the regions are not equally represented. Thus, the result (1/641) is primarily useful in assessing further the type(s) and antiquity of transposition alongside those described earlier.

Characteristics of the affected sub-Saharan individual parallel many from modern cases, with unilateral Mx.C.P1 and associated abnormalities; yet, contrarily, this was a male with right quadrant transposition. The Santa Barbara Channel Island (Nelson, 1992; Sholts et al., 2010) and Pakistan features (Lukacs, 1998) correspond with modern tendencies, though the rest vary to some extent. In the New Mexico study, males (55.6%) and the right quadrant (66.7%) were more affected (Burnett & Weets, 2001), while the Sudanese individual was also male (Burnett, 1999). Accompanying crown rotation, reduced size, retained deciduous teeth, and agenesis occur as well, although less than modern cases (i.e. personal observation, 1989; Nelson, 1992; Lukacs, 1998; Burnett & Weets, 2001; Sholts et al., 2010). Of interest, not only is Mx.C.P1 the most common today but, based on this overview, it is the only type recorded in pre-modern samples. The oldest confirmed examples date 5500 BC (Sholts et al., 2010) in the New World and 2500 BC in the Old World (Lukacs, 1998). As mentioned, the present southern African individual *could* predate both (≤9186 BC), to help establish further the antiquity of transposition; of course, the date is unknown, and could be younger. In any event, though samples and examples are few, it seems Mx.C.P1 may be the earliest, with other maxillary, i.e. Mx.C.I2, Mx.C to M1, Mx.I2.I1, Mx.C to I1 (Peck & Peck, 1995), and mandibular types not evident until recently. In sum, this overview not only provides additional historical context, but new insight into the distribution, origins and, perhaps, evolution of tooth transposition. It is patently not just a modern anomaly.

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CONFLICT OF INTEREST STATEMENT

The author declares no potential conflicts of interest with respect to the authorship and/or publication of this article.

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FIGURE LEGEND

FIGURE 1 (**A**) Female Hutu from Rwanda with left Mx.C.P1 (arrow); numbers indicate 1) reduced second premolar, 2) reduced lateral incisors, and 3) retained deciduous canine. (**B**) Second female Hutu, showing bilateral Mx.C.P1 and 1) third molar agenesis, 2) reduced lateral incisor, and 3) congenitally absent lateral incisor. (**C**) Right Mx.C.P1 in South African Swazi male. (**D**) Mx.C.P1 in pre-modern South African male, with 1) bilaterally-reduced third molars and 2) retained deciduous canine.

TABLE 1 Tooth Transposition Frequency (k) and Percent Present (%) out of Total Number of Dentitions Observed (n) in Modern Population Samples from Four Geographic Regions of Sub-Saharan Africa (see text for details).

Region	Countries of Origin	Date	k	%	n
Western	Benin, Cameroon, Ghana, Nigeria, Senegal, Togo	19th-20th centuries	0	0.00	317
Central	Chad, Congo, Democratic Republic of the Congo, Gabon, Rwanda	19th-20th centuries	3†	0.96	314
Eastern	Ethiopia, Kenya, Somalia, Tanzania	19th-20th centuries	0	0.00	449
Southern	Botswana, South Africa	19th-20th centuries	3‡§	0.37	806
Total			6	0.318	1886

†Royal Belgian Institute of Natural Sciences (Cat No. AF13 #659, AF12 #651, AF6 #605).

‡Arizona State University (Cat No. BU 82, BU 99).

§Dart Collection, University of the Witwatersrand, (Cat No. A 1570).

TABLE 2 Tooth Transposition Frequency (k) and Number of Dentitions Observed (n) in Premodern Population Samples from Four Geographic Regions of Sub-Saharan Africa (see text for details).

Region	Countries of Origin	Date	k	n
Western	Burkina Faso, Cameroon	5879 BC-AD 1390	0	15
Central	Democratic Republic of the Congo, Niger	7700 BC-AD 1400	0	103
Eastern	Kenya	8100 BC-AD 1350	0	121
Southern	South Africa	10,880 BC-AD 1780	1[†]	402
Total			1	641

[†]National Museum Bloemfontein (Cat No. P1447).

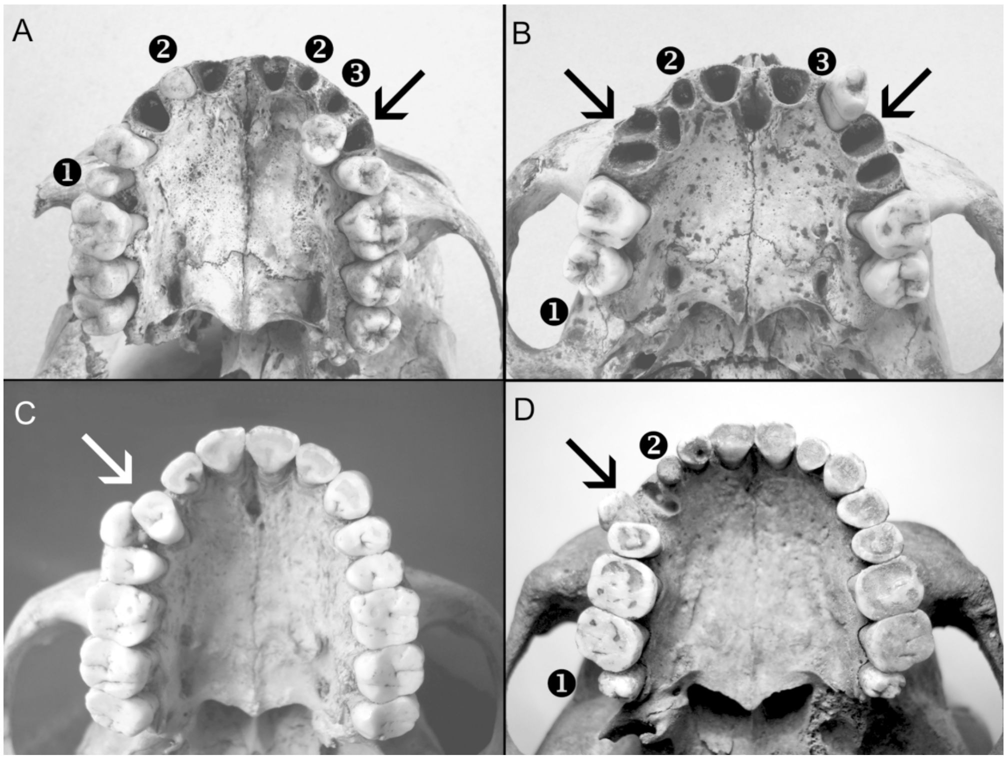

FIGURE 1 (A) Female Hutu from Rwanda with left Mx.C.P1 (arrow); numbers indicate 1) reduced second premolar, 2) reduced lateral incisors, and 3) retained deciduous canine. (B) Second female Hutu, showing bilateral Mx.C.P1 and 1) third molar agenesis, 2) reduced lateral incisor, and 3) congenitally absent lateral incisor. (C) Right Mx.C.P1 in South African Swazi male. (D) Mx.C.P1 in pre-modern South African male, with 1) bilaterally-reduced third molars and 2) retained deciduous canine.