

Original article

# Hallux valgus in a historical French population: Paleopathological study of 605 first metatarsal bones

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## Abstract

**Objectives:** To estimate the prevalence of hallux valgus in a historical population in France, to identify associated skeletal abnormalities, and to look for an influence of footwear changes through time.

**Methods:** We studied the 605 first metatarsals found in the necropolis of the Notre-Dame-du-Bourg cathedral in Digne in the Alpes-de-Hautes-Provence region of southern France. The necropolis contains remains from the 5th to the 17th century.

**Results:** Hallux valgus was identified only in individuals older than 30 years at death, and its prevalence increased significantly with age. Exostosis at the medial and dorsal aspects of the head of the first metatarsal were common in advanced forms. The prevalence was comparable in males and females in the Middle Ages but was significantly higher in males in the 16th and 17th centuries, whereas in contemporary populations females are selectively affected.

**Conclusions:** The increase in the prevalence of hallux valgus over time suggests an influence of changes in footwear. The heeled shoes and boots made of stiff leather that men wore in premodern times probably promoted the development of hallux valgus. However, the prevalence of hallux valgus in women in western industrialized countries today is even higher than that in our historical population of older premodern individuals, suggesting an extremely deleterious effect of contemporary female footwear.

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**Keywords:** Hallux valgus; Hallux rigidus; History; Footwear; Paleopathology

## Introduction

Hallux valgus selectively affects women in contemporary populations of western industrialized countries. It is a multifactorial disorder related both to constitutional anatomic factors [1], which may be inherited, and to biomechanical constraints such as those caused by western footwear [2–5]. The harmful effects of western footwear are illustrated by the low prevalence of hallux valgus in contemporary populations that live barefoot [6,7], the lower prevalence in individuals who live barefoot compared to those who wear western footwear in

various populations [8,9], and the prevalence increase associated with the widespread introduction of western footwear to New Guinea [10] and Japan [11]. Conversely, hallux valgus is less common in populations that continue to use broad-toed shoes, for instance in sub-Saharan Africa [12–14]. In contemporary western populations, the higher prevalence of hallux valgus in women than men may be related to the widespread use among women of pointed shoes that constrict the forefoot [15].

Our primary objective was to investigate changes in the prevalence of hallux valgus through time by examining skeletal remains in a burial site that was used from the Middle Ages to premodern times. Our secondary objectives were to identify skeletal abnormalities associated with hallux valgus and to look for evidence of a role for changes in footwear styles over time.

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## Methods

We studied the 605 first metatarsals recovered from the burial site of the Notre-Dame-du-Bourg cathedral in Digne in the Alpes-de-Hautes-Provence region of southern France, which was used from the 5th to the 17th century. Archeological evidence indicated five periods of a few centuries each (Table 1), with each grave being assigned to a period [16]. The distribution of the remains was uneven, with few individuals in the two earliest periods and late Middle Ages (Table 2). For our statistical evaluation of prevalence changes over time, we focused on the two periods with the largest numbers of individuals, namely, the 11th to 13th centuries and the 16th and 17th centuries. Bruzek's method was used to determine gender [17]. Age at death was estimated using Lovejoy's method as modified by Schmitt and Broqua [18], and the individuals were classified into three groups: death before 30 years of age, between 30 and 50 years of age, and after 50 years of age. When we considered the individuals in the 11th/13th and 16th/17th centuries in whom we were able to determine the gender and to estimate the age at death, we found no significant differences in sample size by age group across males or females or across males in the two periods. Females older than 50 years were significantly more numerous in the 11th/13th centuries than in the 16th/17th centuries.

Full reconstitution of the foot skeleton is usually not possible with ancient remains. We studied degenerative changes in the distal part of the first metatarsal. When available, the proximal joint surface of the proximal phalanx was examined. Hallux valgus was diagnosed based on the presence of degenerative changes related to deviation of the first metatarsal, namely, osteoarthritis of the sesamoid articular facets lateral to their normal position at the base of the head of the first metatarsal. When examining the medial sesamoid, we looked for three lesions reflecting increasingly severe dislocation: a flat imprint on the medial edge of the intersesamoid crest, with or without minimal exostosis; osteoarthritis of the intersesamoid crest ranging in severity from a simple erosion to burnishing of the joint (Fig. S1; see the supplementary material associated with this article online); and a medial articular groove completely filled with newly formed bone as a result of permanent dislocation of the medial sesamoid (Fig. S2). For the lateral sesamoid, we looked for lateral protrusion of the articular facet or a neo-facet denoting complete dislocation of the sesamoid. Based on the sesamoid facet lesions, we defined three severity stages: stage 1, imprint on the medial edge of the medial sesamoid, with or without protrusion of the lateral facet; stage 2, osteoarthritis of the intersesamoid crest with at least protrusion of the lateral facet; and stage 3, filling of the groove for the medial sesamoid and neofacet developed on a lateral spur. These stages are not interchangeable with those used in clinical practice, which denote increasing dislocation of the sesamoids, a key abnormality in hallux valgus.

Exostosis and remodeling of the medial tuberosity were classified into three categories: evenly contoured protrusion with preservation of the normal cortical structure (Fig. S3); spur with or without bony geodes; and combination of

Table 1

Numbers of normal first metatarsals and of hallux valgus cases by period, gender, and side

| Period<br>(centuries) | Males |    | Females |    |    |    | Gender unknown |    |    |    | Total |     |     |
|-----------------------|-------|----|---------|----|----|----|----------------|----|----|----|-------|-----|-----|
|                       | HV    |    | N       |    | HV |    | N              |    | HV |    |       | N   |     |
|                       | R     | L  | R       | L  | R  | L  | R              | L  | R  | L  |       | R   | L   |
| 5th–7th               | 1     | 2  | 1       | 1  | 2  | 1  | 1              | 1  | 1  | 0  | 1     | 0   | 12  |
| 8th–11th              | 0     | 2  | 1       | 3  | 0  | 0  | 3              | 1  | 0  | 0  | 2     | 5   | 17  |
| 11th–13th             | 4     | 3  | 30      | 29 | 2  | 3  | 21             | 15 | 7  | 5  | 43    | 46  | 208 |
| Late 13th–15th        | 0     | 1  | 11      | 10 | 2  | 2  | 5              | 4  | 6  | 5  | 15    | 15  | 78  |
| 16th–17th             | 12    | 13 | 28      | 29 | 8  | 5  | 25             | 25 | 22 | 26 | 41    | 46  | 280 |
| Total                 | 17    | 21 | 71      | 72 | 14 | 11 | 55             | 46 | 36 | 36 | 103   | 112 | 593 |

unevenly contoured prominences and of a perforation with or without extension to the medial edge of the proximal articular surface (Fig. S4). These abnormalities were not considered specific of hallux valgus. We distinguished three types of dorsal exostosis: degenerative rim along the posterior and lateral edge of the proximal articular surface, spur measuring less than 2 mm in length, and spur measuring more than 2 mm in length. A supernumerary articular facet at the lateral aspect of the first metatarsal was looked for (Fig. S3). This facet articulates either with an os intermetatarsaleum or directly with the medial aspect of the second metatarsal and may promote the development of hallux valgus [19].

When examining dry bones, the main differential diagnoses of hallux valgus are hallux rigidus and osteoarthritis without deviation of the metatarsal-phalangeal joint. We diagnosed hallux rigidus based on presence of osteoarthritis of the dorsal aspect of the articular facet and of dorsal exostosis [20]. Non-specific osteoarthritis was defined as at least a degenerative cortical erosion confined to the distal articular surface, without the above-described criteria for hallux rigidus or hallux valgus.

The statistical evaluation involved comparisons using the chi-square test. All tests were done using Epi-info 6 (CDC, Atlanta, GA). *P* values equal to or smaller than 0.05 were considered statistically significant.

## Results

Hallux rigidus was uncommon and usually bilateral. Most cases of hallux rigidus occurred in older males. Osteoarthritis without deviation of the metatarsal was exceedingly rare. Hallux valgus affected about one-fifth of the metatarsals. Thus, hallux valgus was common in this historical population (Table 2).

### *Paleoepidemiology of hallux valgus in our historical population*

Exclusion of the 12 first metatarsals with hallux rigidus or non-specific osteoarthritis left 593 metatarsals for comparing bones with hallux valgus to normal bones (Table 2). In none of the severity groups did we find statistically significant differences in hallux valgus prevalence between the right and left sides, either in the entire sample or in the feet that had both the first and the second metatarsals.

Table 2  
Prevalence of lesions of the 605 first metatarsals from the Notre-Dame-du-Bourg burial site in Digne, France

| Hallux rigidus |     | Osteoarthritis |     | Hallux valgus |      | Normal |      | Total |
|----------------|-----|----------------|-----|---------------|------|--------|------|-------|
| N              | %   | N              | %   | N             | %    | N      | %    |       |
| 9              | 1.5 | 3              | 0.5 | 132           | 21.8 | 461    | 76.2 | 605   |

In the population of individuals whose age at death could be estimated, the prevalence of hallux valgus increased significantly with age. None of the 100 metatarsals from individuals who died before 30 years of age showed evidence of hallux valgus. Therefore, prevalence changes through time were evaluated only in the two older age groups (Table 3).

In the overall sample of 593 first metatarsals, no significant difference in the prevalence of hallux valgus was found between males and females. However, comparing the 11th/13th centuries to the 16th/17th centuries showed that the prevalence increased over time and that the increase was larger in males than in females (Fig. 1). Irrespective of severity, no significant difference in hallux valgus prevalence was found between males and females in the 11th/13th centuries, whereas in the 16th/17th centuries the prevalence was significantly higher in males than in females ( $\text{Chi}^2 = 4.74$ ;  $P = 0.03$ ). In the females, the prevalence of hallux valgus showed no significant change between the two periods. In the males, the prevalence was significantly higher in the later period than in the earlier period ( $\text{Chi}^2 = 5.79$ ;  $P = 0.016$ ). Finally, when we compared the group aged 30 to 50 years to the group older than 50 years of age, we found a significant prevalence increase in the oldest males from the earlier to the later period ( $\text{Chi}^2 = 2.74$ ;  $P = 0.046$ ) and a trend in the same direction in the males aged 30 to 50 years.

We compared the prevalence of hallux valgus in the individuals who died in the 16th/17th centuries, when the prevalence was highest, to the prevalence in a contemporary population in the absence of surgical correction [15]. The prevalence of hallux valgus was significantly lower in the historical sample (males,  $\text{Chi}^2 = 7.87$ ,  $P < 10^{-3}$ ; females,  $\text{Chi}^2 = 33.4$ ,  $P < 10^{-6}$ ).

#### Bony lesions associated with hallux valgus

Medial exostosis is usually associated with hallux valgus. The severity of medial exostosis increases with the severity of the sesamoid lesions related to hallux valgus (Table 4). Major medial exostosis (types 2 and 3) was significantly more common in metatarsals with hallux valgus than in normal metatarsals ( $\text{Chi}^2 = 200$ ,  $P < 10^{-6}$ ). The prevalences of both hallux valgus and medial exostosis increased with age (Table 5).

Dorsal exostosis is caused by migration of the first phalanx to a dorsal and medial position in extension. Dorsal exostosis was significantly more prevalent in metatarsals with hallux valgus than in normal metatarsals ( $\text{Chi}^2 = 21.2$ ;  $P < 10^{-5}$ ) (Table 6).

The prevalence of a supernumerary articular facet was similar in the group of normal metatarsals and in the group with hallux valgus (Table 7). This finding indicates that the

Table 3  
Distribution of normal first metatarsals and of first metatarsals with hallux valgus in individuals older than 30 years buried during the 11th–13th centuries or 16th–17th centuries

| Period              | Gender | Age (y) | Normal | HV, Stage 1 | HV, Stages 2 and 3 | Total |
|---------------------|--------|---------|--------|-------------|--------------------|-------|
| 11th–13th centuries | M      | 30–50   | 32     | 1           | 4                  | 37    |
|                     |        | >50     | 8      | 1           | 1                  | 10    |
|                     | F      | 30–50   | 26     | 1           | 2                  | 29    |
|                     |        | >50     | 5      | 1           | 2                  | 8     |
| 16th–17th centuries | M      | 30–50   | 25     | 3           | 7                  | 35    |
|                     |        | >50     | 11     | 3           | 12                 | 26    |
|                     | F      | 30–50   | 39     | 1           | 3                  | 43    |
|                     |        | >50     | 4      | 4           | 3                  | 11    |
| Total               |        |         | 150    | 15          | 34                 | 199   |

supernumerary facet is not a constitutional risk factor for hallux valgus.

#### Discussion

Hallux rigidus and diffuse osteoarthritis of the first metatarsal were as rare in our historical population as they are today. Hallux valgus, in contrast was common, most notably in individuals older than 50 years of age.

Our method for diagnosing hallux valgus based on degenerative lesions of the sesamoid facets cannot be readily compared to the clinical diagnostic methods used for modern epidemiological studies, which rely chiefly on the intermetatarsal angle. Direct examination of articular facets may disclose degenerative lesions that were asymptomatic during life, as shown for elbow osteoarthritis [21]. However, we used the same method for all the metatarsals in our population. Therefore, although the prevalences may be difficult to compare to those found today, our comparisons across genders, age groups, and periods remain valid.

The prevalence of hallux valgus was significantly higher in males than in females in the 16th/17th centuries, in contradiction with prevalence data from European populations [15]. The higher prevalence of hallux valgus in the more recent period compared to the Middle Ages cannot be ascribed to an increased proportion of older men, since the age group distribution showed no significant changes between the two periods.

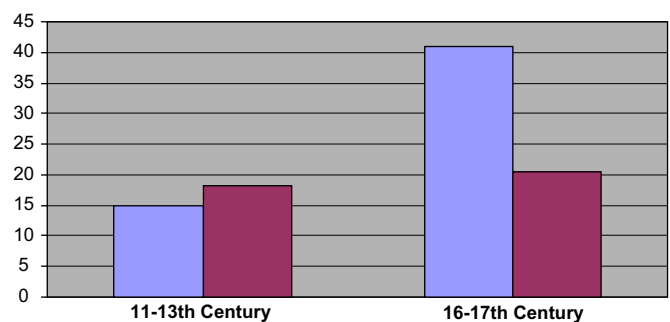


Fig. 1. Prevalence of hallux valgus in males and females from the 11th/13th centuries and 16th/17th centuries at the Notre-Dame-du-Bourg burial site in Digne (Alpes-de-Haute-Provence, France). Male are in Blue and female in Red.

**Table 4**  
Development of exostosis at the medial aspect of the head of the first metatarsal by hallux valgus severity stage

| Hallux valgus severity stage | Exostosis |        |        | Total |
|------------------------------|-----------|--------|--------|-------|
|                              | Type 1    | Type 2 | Type 3 |       |
| Stage 1                      | 20        | 10     | 2      | 33    |
| Stage 2                      | 13        | 13     | 9      | 33    |
| Stage 3                      | 6         | 15     | 29     | 66    |
| Total                        | 40        | 40     | 43     | 132   |

Similarly, in a study of two archeological sites in the UK, hallux valgus was found in none of 47 individuals buried in the 9th–11th centuries compared to 14 of 192 individuals buried in the 13th/16th centuries [22].

The continuity of the burial-site population from one period to the next was established by anthropological studies. Therefore, the changes over time cannot be ascribed to genetic differences. The absence of hallux valgus in younger individuals in all five periods also militates against a role for genetic factors. Therefore, a reasonable assumption is that the prevalence increase in older men after the Middle Ages was caused by one or more environmental factors. Styles of footwear have been shown to make a key contribution to the pathogenesis of hallux valgus [2]. Footwear changed considerably from medieval to premodern times [23]. The overall shape of shoes and the materials used to construct them (i.e., leather and wood) changed as a result of technical advances and fashion. Shoe designs used in historical times have been described as less harmful to proper bone alignment than contemporary shoes used in western industrialized countries [24]. In medieval Europe, shoes were flatter, with no heel and a rounded toe box. The top of the shoe was made of soft leather, which was stitched to a thicker piece of leather that served as the sole. Thus, shoes were softer but less watertight than modern shoes. To lift the foot above muddy or snowy ground, wooden patterns attached to the shoe by leather straps were introduced in the 14th century [25]. The poulaine became popular in western Europe in the 12th and 13th century. This style was characterized by long pointed toes that were probably influenced by the footwear found by Crusaders in the Middle East [23]. The points were made by rolling the flexible leather to avoid having to cut it, thereby reducing the number of seams. The toe constriction related to the pointed shape was limited by the softness of the leather. Over time, the toe became longer and longer, to the point of absurdity. The poulaine was considered frivolous and was banned by Charles V of France, Edward IV of England, Pope Urban V, the council of Paris in 1212, and the Council of Antwerp in 1365. The fad disappeared in the 16th century with the Renaissance, when a broad rounded or square toe box became fashionable. The emergence of hallux valgus in 13th/16th century remains in the UK was ascribed to the use of pointed shoes. In our study, however, the prevalence of hallux valgus was highest in the 16th/17th centuries, when pointed shoes were no longer used. In addition, a round-toed shoe and a poulaine from the 14th century, both displayed at the London Museum, show

**Table 5**  
Development of medial exostosis of the head of the first metatarsal in normal first metatarsals and in first metatarsals with hallux valgus, by age at death

| First metatarsal | Age (y) | Normal bone or type 1 exostosis | Type 2 or 3 exostosis | Total |
|------------------|---------|---------------------------------|-----------------------|-------|
| Normal           | <30     | 48                              | 2                     | 50    |
|                  | 30–50   | 224                             | 5                     | 229   |
|                  | >50     | 38                              | 6                     | 44    |
| Hallux valgus    | <30     | 0                               | 0                     | 0     |
|                  | 30–50   | 9                               | 19                    | 28    |
|                  | >50     | 15                              | 18                    | 33    |
| Total            |         | 334                             | 50                    | 384   |

signs typical for hallux valgus, indicating that pointed footwear was not the only cause of the deformity [25].

In the late 16th century and early 17th century, horses were increasingly used for riding and drawing vehicles in all the socioeconomic strata. As a result, heeled boots were developed for men [23]. The heel was intended to prevent the foot from slipping through the stirrup when mounting. The increased height and lumbar lordosis induced by the heel elevation were felt to add grandeur to the rider’s bearing. Very high heels soon appeared. Stiff leather was used, not only for the sole in order to incorporate the heel, but also for the upper. A soft slipper of fine leather was worn inside the boots in the 16th century to protect the foot. These early boots were identical for the two feet and therefore placed major constraints on the forefoot. Each day, the wearer switched sides to ensure that wear was symmetrical. Boots designed specifically for the right and left feet appeared in the mid-18th century. Although wealthier individuals were able to purchase well-fitting boots or to have their boots custom-made, most men wore boots that were bearable rather than comfortable. Because riding boots were difficult to remove without help, they were often worn all day. Thus, for several centuries, the boot was an essential component of the male wardrobe and a key fashion indicator but improved only slowly in terms of comfort. Shoes for men, chiefly in the wealthier strata of society, were also made with heels to increase height. High-heeled boots and shoes for men disappeared in the late 18th century in France, at the time of the French revolution, because they were perceived as associated with aristocracy. Shoes with moderately sized heels were used universally. Only the military and horseback riders used boots. Boot makers learned to use softer leathers, which improved comfort. Thus, men in France from the Renaissance to the Revolution wore stiff leather shoes and

**Table 6**  
Dorsal and medial exostosis of the head of the first metatarsal by hallux valgus severity stage

| First metatarsal | Medial exostosis | Dorsal exostosis |             | Total |
|------------------|------------------|------------------|-------------|-------|
|                  |                  | None or Type 1   | Type 2 or 3 |       |
| Normal           | 0 and 1          | 395              | 18          | 413   |
|                  | 2 and 3          | 31               | 1           | 32    |
| Hallux valgus    | 0 and 1          | 33               | 9           | 42    |
|                  | 2 and 3          | 66               | 11          | 77    |
| Total            |                  | 525              | 39          | 564   |



Table 7  
Supernumerary facet at the lateral aspect of the first metatarsal by hallux valgus severity stage

| Facet | Normal bone | Hallux Valgus | Total |
|-------|-------------|---------------|-------|
| No    | 299         | 83            | 382   |
| Yes   | 130         | 33            | 163   |
| Total | 429         | 116           | 545   |

boots with heels that placed mechanical constraints on the foot similar to those seen with contemporary female footwear.

Heeled shoes for women were introduced in France from Vienna but were initially made of soft leather and fabric. From the 18th century onward, wealthier women wore heeled shoes with pointed toes made of stiff leather. These shoes had harmful effects on foot alignment similar to those seen with modern shoes. Because few artifacts were found in the Notre-Dame-du-Bourg site, were unable to determine the social status or occupations of the individuals who were buried there. Nevertheless, the overall fashion trends seen in southern France probably governed lifestyles in Digne. Leather shoes and boots were expensive, and clogs or sandals, which were less constricting, were probably used by poorer individuals. This may explain the lower prevalence of hallux valgus among premodern males in our study than among contemporary women. In this historical population, examination of the first metatarsals showed changes in the prevalence of hallux valgus through time. The results suggest a strong role for environmental factors. Thus, styles of footwear may have influenced the prevalence of hallux valgus. Hallux valgus became more common in men after the introduction of stiff high-heeled shoes and boots, which were nearly as harmful as contemporary women's shoes.

## Appendix A. Supplementary material

Supplementary material associated with this article can be found at <http://www.sciencedirect.com>, at doi:10.1016/j.jbspin.2006.03.011.

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