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The Bone Morphology of the World's Largest Feet by 3D Axial Tomography

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ABSTRACT

Pituitary gigantism is a rare endocrine disease characterized by unusually tall stature with rapid growth velocity that occurs before the closure of the epiphyseal growth plates due to excess growth hormone often as a result of a benign secreting pituitary tumor. Three Dimensional Axial Tomography were performed on the feet of a patient diagnosed with pituitary gigantism. His right and left foot measurements are 40.55 cm (1.33 feet) and 40.47 cm (1.32 feet) respectively. A 28-year-old Venezuelan man was diagnosed at age 10 with pituitary gigantism through physical exams, brain imaging and laboratory tests. He received medical treatment and did not undergo surgical removal of the pituitary tumor. A study of the osseous morphology of his oversized feet was performed using Three Dimensional Axial Tomography. The assessed parameters included foot length, truncated foot length, foot breadth, arch height, arch index inter-metatarsal and measurements of all bones of the foot. Early findings and treatment of foot pathologies are possible through the use of 3D Axial Tomography. As far as we know, this is the first report on bone morphology images of oversized feet (currently, the world's largest feet among the living).

Keywords: Acromegaly, bone´s foot morphology, oversized foot, pituitary gigantism.

INTRODUCTION

Approximately three million years ago, our Australopithecine ancestors commenced to live upright. Some 600,000 years ago, Homo sapiens began to walk in a manner very similar to that of today[1]. Humans developed complex foot morphological attributes to adjust to the needs of various activities, such as upright standing, walking, and running. As the direct complex contact area between the lower extremities and the ground/interface, the human foot plays an important role in supporting body mass in both static and dynamic upright locomotion. Anatomists, clinicians, surgeons, anthropologists and palaeontologists have been interested in the human foot morphology for centuries due to its centrality in bipedal walking [1,2]. The human foot, essential for locomotion, is one of the most important parts of the human body. It consists of a total of 26 bones. These foot bones and relevant muscles, ligaments, and tendons played significant roles in preserving their general shape and ensured their functions under static or dynamic conditions [2]. In general, the foot is the first to grow during early childhood and adolescence. The human foot is a compound structure that is based on transverse and longitudinal arches. These are shaped and maintained by interlocking tarsals that are connected by ligaments and reinforced via muscular action[1,2]. During bipedal

locomotion, the foot is the interface between the rest of the body and the substrate and vertical forces in the foot when moving at comfortable walking gaits exceed 1.1 times body mass. Weight fluctuations, in addition to other variables, such as age, sex, and height, could affect foot morphology [3]. Also, some diseases, such as diabetes and pituitary gigantism, could secondarily affect foot morphology [2,3]. The foot´s anatomy is intricately associated with the functions of the foot, and thus, various parameters help us better understand the structure-function relationship. Multiple parameters influence the basic functioning of the foot. These have been extensively investigated worldwide and across various investigations [4,5]. They include foot length, truncated foot length, foot breadth, arch height, arch index inter-metatarsal, and many more. The human foot, due to its unique anatomical arrangement, has always been the subject of study among researchers worldwide [3,5]. On another note, in connection with the overgrowth of the human body and particularly limbs; Pituitary gigantism is a rare endocrine disorder characterized by uncommonly increased height and growth velocity before the closure of the epiphyseal growth plates due to excess growth hormone (GH) produced by benign growth hormone-secreting pituitary tumors or pituitary hyperplasia. Ninety per cent of the cases are related to monoclonal adenomas in the pituitary. This abnormal growth is associated with progressive disfigurement mainly affecting the face and extremities [6]. Other organs may be impacted. When the increased production of GH starts in adulthood (after the closure of the epiphyseal growth plates), it produces a different clinical syndrome known as Acromegaly [6,7]. In 1567, the Dutch physician Johannes Wier described in detail the first case of gigantism. Pierre Marie, a French neurologist, published the first description of the disease and its pathology in 1886 [6]. The incidence of pituitary tumors in children is approximately 0.1 in one million, and only between 1 and 10% of childhood pituitary tumors secrete GH [7]. The synthesis and secretion of GH are regulated by stimulation and inhibition from the hypothalamus. The excess of GH manifests itself differently through the life span: gigantism in childhood and acromegaly in adulthood. The several pituitary neuroendocrine tumors that produce GH give rise to distinct clinical, biochemical and radiological findings[8]. In this case report oversized feet are the consequence of pituitary gigantism. This rare disease features large hands and feet. Additional associated findings may include pubertal delay, visual problems, headache, excessive appetite, hyperhidrosis and metrorrhagia, prognathism and coarse facial characteristics. Most patients with pituitary gigantism patients are male. Large tumors may be difficult to control [9,10]. Human foot morphology is an important subject for physical anatomical analysis in several biomedical disciplines, including anatomists, orthopedics, foot surgeons, orthotic design and sports sciences. This case report aims to investigate the bony morphology of the world's largest feet using 3D CT in a pituitary gigantism patient.

Case presentation

JR (the initials of the patient's name) is a 28-year-old Venezuelan man, who was born in Maracay, Aragua state, in Venezuela. He grew up in a family of limited resources. His father is 5 feet 7 inches (1.70 mts) tall and his mother is 5 feet 3 inches (1,60 mts). He has three brothers and one sister (who died from complications of cerebral onchocerciasis). He is the youngest of four brothers. The male siblings' heights are between 1,60 and 1,73 mts. (within the normal range for Venezuelan males). He has a high school diploma. JR is single and has no children. He freelances mostly on digital advertising in social media (Figure 1). There is no history of pituitary gigantism in his paternal or maternal family. JR was first diagnosed with gigantism at age 10, but concerns around his great height had been worrying his parents for over four years in particular his height and the size of his feet. He was diagnosed with pituitary gigantism disease by physical examination, brain magnetic resonance imaging and laboratory tests. He did not undergo surgical removal of the pituitary tumor. Other related medical problems have been identified such as hypothyroidism, visual problems, headache, and excessive appetite. JR also has oral manifestations like the presence of diastemas and microdontia. Because of his myopia, he wears corrective lenses. He has a holosystolic heart murmur II/IV. His electrocardiogram reports left ventricular hypertrophy with no other cardiac alterations.

Figure 1: JR (the initials of the patient's name in this case report) and the author´s paper: Rafael Romero-Reverón,

MATERIALS AND METHODS

Three Dimensional Axial Tomography were performed on the feet of a patient diagnosed with pituitary gigantism. His right and left foot measurements are 40.55 cm (1.33 feet) and 40.47 cm (1.32 feet) respectively. 3D CT scans were performed on JR's feet in June 2024. The scans of the feet were done on a Philips Incisive 128 Slice CT Scanner (Royal Philips Medical Systems, Netherlands). The patient was placed supine on the scanner bed, with both knees fully extended and feet in plantar position. From the virtual images, three-dimensional views were created showing the exact characteristics of the bone structures. This facilitated bony morphology identification and diagnosis much more accurately than with other more traditional techniques.

RESULTS

The parameters included in this study were foot length, truncated foot length, foot breadth, arch height, arch index inter-metatarsal and many more. Also, each of the 26 bones of the feet was measured by a 3D CT scan (Table 1).

Table 1: Measurement of the bones of the foot I

Bones (in inches).	Left foot	Right foot
Calcaneus	43,7 (AP) x 25,9 (CC) x 27,6 (T)	44,0 (AP) x 25,9 (CC) x 25,5 (T)
Talus	37,4 (AP) x 17,3 (CC) x 22,8 (T)	38,9 (AP) x 18,1 (CC) x 21,2 (T)
Cuboid	15,3 (AP) x 17,7 (CC) x 18,1 (T)	15,7 (AP) x 16,5 (CC) x 18,5 (T)
Navicular	11,8 (AP) x 16,1 (CC) x 21,6 (T)	12,5 (AP) x 17,3 (CC) x 20,8 (T)
Medial wedge	13,3 (AP) x 17,3 (CC) x 13,7 (T)	14,5 (AP) x 18,5 (CC) x 9,0 (T)
Media wedge	8,6 (AP) x 17,3 (CC) x 7,4 (T)	8,6 (AP) x 14,5 (CC) x 7,4 (T)
Lateral wedge	12,5 (AP) x 15,7 (CC) x 12,9 (T)	12,5 (AP) x 11,0 (CC) x 9,8 (T)
1 MT	33,3 (AP) x 14,9 (CC) x 12,5 (T)	33,4 (AP) x 12,5 (CC) x 11,4 (T)
2 MT	37,4 (AP) x 12,5 CC) x 8,6 (T)	37,4 (AP) x 9,4 (CC) x 8,6 (T)
3 MT	35,4 (AP) x 10,2 (CC) x 7,8 (T)	34,2 (AP) x 11,8 (CC) x 7,4 (T)
4 MT	37,0 (AP) x 9,8 (CC) x 9,0 (T)	35,0 (AP) x 10,2 (CC) x 7,4 (T)
5 MT	36,6 (AP) x 9,8 (CC) x 10,2 (T)	35,4 (AP) x 9,4 (CC) x 10,2 (T)
Medial sesamoid	8,2 (AP) x 6,2 (CC) x 1,6 (T)	7,4 (AP) x 4,7 (CC) x 6,2 (T)
Lateral sesamoid	7,8 (AP) x 3,9 (CC) x 5,5 (T)	7,4 (AP) x 4,7 (CC) x 6,6 (T)

MT= Metatarsal; AP= anterior-posterior; CC= cranial-caudal; T= transverse

These findings can be seen bilaterally: loss of convexity of the talus about the flattening of the tibiotalar joint with the presence of prominence of the posterior process (Stieda's process); the presence of os navicularis type 3; the presence of os peroneus about the fibular longus tendon adjacent to the cuboid bone; presence of accessory navicular bone (os tibiale externum); fusion of distal and middle phalanges of the 5th toe; left internal plantar arch: 122°and right 124°.; left external plantar arch: 148° and right 141°). Other foot measures were: (a) Foot length, (b) Distance from the heel to the 1st metatarsal, (c) Distance from the heel to the 5th metatarsal, (d) Metatarsal width, (e) Forefoot width, (f) Heel width, (g) Ball height, (h) Instep height, (i) Arch height (Table 2).

Table 2: Measurement of the bones of the foot II

Bones	Left foot	Right foot
Instep Height	13,6 cm (5,3 inches)	13,4 cm (5,2 inches)
Instep Distance	16,4 cm (6,4 inches)	14,9 cm (5,8 inches)
Heel Width	11,7 cm (4,6 inches)	11,5 cm (4,5 inches)
Heel Circumference	52,5 cm (20,6 inches)	49,5 cm (19,4 inches)
Ball Height	8,0 cm (3,1 inches)	7,5 cm (2,9 inches)
Ball Width	15,4 cm (6,0 inches)	14,7cm (5,7 inches)
Ball Circumference	40,7cm (16,0 inches)	38,7cm (15,2 inches)
Arch Length	25,4 cm (10,0 inches)	25,5 cm (10,0 inches)
Lateral Metatarsal Length	22,7 cm (8,9 inches)	22,9 cm (9,0 inches)
Medial Metatarsal Length	28,0 cm (11,0 inches)	27,3 cm (10,7 inches)
Foot Width *	13,2 cm (5,1 inches)	13,8 cm (5,4 inches)
Foot Length *	38,4 cm (15,1 inches)	38,4 cm (15,1 inches)

*Measurements taken only on the foot bones in a ventral decubitus position, these measures do not include muscles, ligaments, other soft tissues or skin, which determines a smaller measurement than that obtained standing upright.

JR's feet have an Egyptian digital type (the hallux being longer than the other toes). Except for the hallux, the rest are claw-shaped. However, he has no calluses on his feet. Upon standing, the length of his right foot is 39.6 cm (155,9 inches) and that of his left foot is 39,1 cm. (153,9 inches). According to the footprint on the podogram, he has flat foot grade IV/IV. However, the measurements of his medial longitudinal arches are within normal limits. Because they were taken in a ventral decubitus position without support, it is considered that he has an unstructured flat foot. In addition to the morphologic changes already described and shown in Tables 1 and 2, no other noteworthy or significant morphological alterations were found.

DISCUSSION

Pituitary gigantism is a rare endocrine disease characterized by unusually tall stature with rapid growth velocity that occurs before the closure of the epiphyseal growth plates due to excess GH produced by a secreting pituitary benign tumor or pituitary hyperplasia. The age of onset may be during infancy, childhood or adolescence. Some cases are hereditary with various patterns of inheritance such as autosomal dominant and X-linked. Excessive secretion of growth hormone leads to increased synthesis of somatomedins in the liver and peripheral tissues, mainly somatomedin C called insulin-like growth factor 1. This kind of somatomedin C stimulates cell proliferation in target tissues, causing hypertrophy of soft tissues and bones. In children and young people without a completed growth process, in whom the epiphyses of the long bones have not yet closed, the increased concentration of insulin-like growth factor 1 leads to excessive height, i.e., gigantism [11,12]. Unlike in acromegalic adults, in whom discreet pituitary adenomas are present in the overwhelming majority, several different pathologic mechanisms underlie childhood growth hormone hypersecretion. This relates to the concept that pituitary gigantism represents a distinct entity, with different characteristics in terms of pituitary morphology and function. In young patients, growth hormone-secreting

tumours are usually larger and more aggressive. In establishing the diagnosis, 80% of somatotroph adenomas are macroadenomas, of which >70% have a diameter >20 mm [13,14]. Heights above 97% (around 2 SD above the mean height for age and sex merit investigation. Nevertheless, patients with pituitary gigantism invariable have heights greater than three standard deviations above the mean. Currently, JR receives medical treatment with levothyroxine 150 mgrs, sandostatin 30 mgrs, and pegvisomant 10 mgrs. and cabergoline 0,5 mgrs. Currently, JR is 7 feet 3 inches tall (2,38 mts). His body mass index is 29.13 (overweight range). His right and left foot measurements are 40.55 cm (1.33 feet) and 40.47 cm (1.32 feet) respectively. This would be a U.S. size 26 or UK size 36 or approximately European and Venezuelan size 70. His weight is 165 kilos (363,76 pounds). However, a few years ago he weighed 230 kg (507 pounds). He has bilateral flat foot grade IV/IV. Because there are no shoes in his size, he occasionally receives help from people who custom-make them for him. JR is not the tallest person in the world. That record still belongs to 8 feet 2 inches tall to Sultan Kösen, a Turkish citizen. JR is the second tallest person in the world and the tallest in Venezuela. Nevertheless, JR holds the record for the largest feet among the living since 2018 [15]. The record for the biggest feet ever goes to Robert Wadlow, an American citizen who wore a size 37AA shoe (his feet measured 18.5 inches each). He was 8 foot 11 inches tall and lived from 1918 to 1940. His condition was attributed to pituitary gigantism [16]. Pituitary gigantism aetiology and clinical characteristics had been poorly understood. Genetic and genomic causes have been identified in recent years that explain about half of cases of pituitary gigantism. Treatment of pituitary gigantism is often deferred. This increases the dangerous effects of growth hormone excess, such as disproportionate stature and symptom burden. Prompt diagnosis and specific treatment are important [13,14]. The following findings can be seen bilaterally: loss of convexity of the talus about the flattening of the tibiotalar joint with the presence of prominent posterior processes; the presence of os navicularis type 3 and os perineum about the fibular longus tendon adjacent to the cuboid bone; accessory navicular bone (os tibiale externum); a fusion of distal and middle phalanges of the 5th toe. No other bone morphology variations were found although the large dimensions of each foot´s bones were reported. The foot´s arches were reduced while standing upright due to changes in soft tissues and ligamentous support (an unstructured flat foot). A collapse of the medial longitudinal arch could become a problem for walking.

Conclusions

A 28-year-old Venezuelan man was diagnosed at age 10 with pituitary gigantism through physical exams, brain imaging and laboratory tests. He received medical treatment and did not undergo surgical removal of the pituitary tumor. A study of the osseous morphology of his oversized feet was performed using Three Dimensional Axial Tomography (3D CT scans). The assessed parameters included foot length, truncated foot length, foot breadth, arch height, arch index inter-metatarsal and others. Bilateral findings were: loss of convexity of the talus; the presence of os navicularis type 3, os peroneum and os tibiale externum; a fusion of distal and middle phalanges of the 5th toe; and an unstructured flatfoot was reported. Early findings and treatment of foot pathologies are possible through the use of 3D Axial Tomography. As far as we know, this is the first report on bone morphology images of oversized feet (currently, the world's largest feet among the living). A detailed analysis of the 3D foot shape, allowed by geometric morphometry, can provide insight into foot variations in three dimensions that cannot be obtained from 2D footprints. The use of 3D CT scans in the feet, could allow for early findings and the provision of treatment before deformities ensue. The images could be used in the individualized custom manufacture of footwear thus improving fit and potentially preventing future lower limb problems and improved quality of life. Adequate hormonal disease control is achieved in most cases of pituitary gigantism, allowing a life expectancy similar to that of the general population. However, even if patients are cured or well-controlled, sequelae (joint pain, deformities and altered quality of life) often remain.

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Ethical Board Review statement: The written patient´s consent and the approval of the committee JM Vargas Medical School, Faculty of Medicine, Universidad Central de Venezuela were obtained for this case report. Each author certifies that his institution approved the human protocol for this investigation and that all investigations were conducted in conformity with the ethical principles of research. Moreover, the patient´s informed consent for participation in the study was obtained. Also written consent for publication of images was obtained from the patient.

Author Contributions: Conceptualization and editing RRR; data collection CM; data analysis RRR and CM, writing original draft preparation RRR; writing review RRR and CM. Authors have read and agreed to the published version of the paper.

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