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Changes in foot-function parameters during the first 5 months after the onset of independent walking: a longitudinal follow-up study

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Abstract

Foot-function parameters (foot-contact patterns, oscillations of the centre of pressure (COP), peak pressures, relative vertical impulses and foot shape indices) were characterized in 10 toddlers at 1, 2, 3, 4, 6, 8, 10, 12, 16 and 20 weeks after the onset of independent walking. Significant changes were found in foot-contact patterns and COP oscillations. Improvements in balance, reflected in the decreased oscillations of the COP, coincided with changes in foot roll-over. These findings suggest that the development of a ''heel-to-toe'' roll-over pattern after 1 year of walking already starts early after the onset of independent walking. We could not identify any changes in load distribution underneath the plantar surface of the foot, suggesting that maturation of foot loading develops at a slower pace.

Keywords: Toddler; Gait; Foot-function; Pedobarography

1. Introduction

The foot serves three important biomechanical functions in bipedal gait. Firstly, the foot is important accommodating irregularities of the ground and maintaining balance. Secondly, it has to support weight and serve as a shock-absorber and thirdly, to generate forward movement, the foot has to transmit propulsive forces. In addition, its plantar surface plays a very important role in proprioception [2].

The adult human foot is well adapted to perform these functions. The longitudinal foot arch, primarily supported by the strong plantar aponeurosis, is an adaptation to resist load. The foot acts as a lever for transmission of propulsive forces on to the ground. This lever function is reflected in the typical ''heel-to-toe'' roll-over pattern observed in adult gait. The toddler's foot anatomy differs from the adult foot (Fig. 1a and b) and is mainly characterized by its flexibility [3]. Around the age of 1, when toddlers normally start to walk, the foot skeleton consists of a number of partially ossified centres connected by soft tissue. Another important feature of toddler's feet is the absence of a visible longitudinal foot arch. Development of the bony structure of the longitudinal arch only starts approximately 1 year after birth, when the toddlers have learned to stand upright and walk independently and lasts until the age of 5 [4,5]. To protect the fragile cartilaginous tissue, a fat pad is present underneath the foot plantar surface [6,7]. Ossification and changes in shape of the foot skeleton after the onset of independent walking coincide with resorption of this fat pad.

Some important differences between toddlers and adults in foot-function might be expected because of differences in anatomy and because balance and movement coordination are immature in young walkers [8]. Only a few studies have compared foot-function in toddlers [9–11] with that of adults. Foot-function is highly variable in this young age

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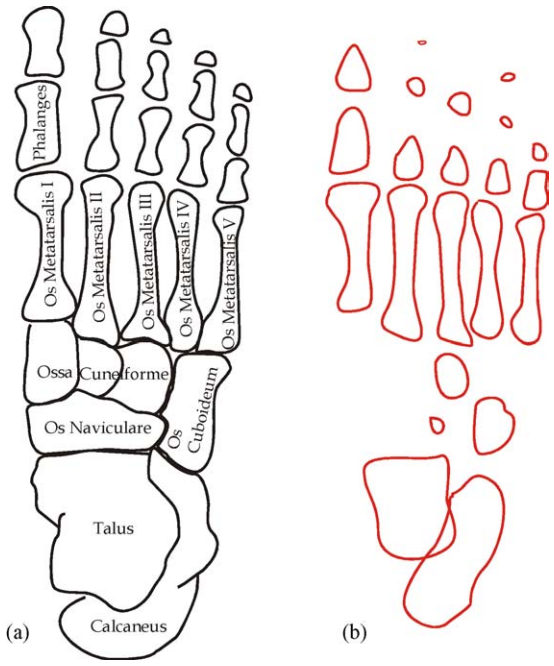

Fig. 1. (a and b) Compare the bony skeleton of the adult and toddler foot. In toddlers, the foot skeleton consists of several ossification centres surrounded by cartilage (after Tanner et al. [19]).

group. Variability is reflected in the absence of the typical ''heel-to-toe'' roll-over pattern, favoured in adult gait (Fig. 2). Hallemans et al. [11] have shown that toddlers with an ''independent-walking'' experience from 0 to 8 weeks had three different foot-contact patterns (Fig. 2). In initial forefoot-contact (IFC), first contact was made by the metatarsal heads, and then the midfoot and heel were placed on the ground. After a period of plantar contact, roll-over was initiated by heel-off and resulted in push-off by the hallux. In flat foot-contact (FFC), heel and forefoot were placed on the ground simultaneously. Again roll-over started with heel-off and ended in push-off by the hallux. In initial heel contact (IHC), a short initial contact occurred and the rest of the foot rapidly came into contact with the ground. Roll-over was identical to that seen in the IFC and FFC patterns. Balance problems in toddlers, suggested by their wide base of support, guard position of the arms and a prolonged phase of double support [12], was evident from the large oscillations of the centre of pressure (COP) [11] and the increase in areas contributing to load bearing [9]. Peak pressures underneath the heel and metatarsal heads are reduced when toddlers are compared to adults [9,11]. This can be explained partly by the slow average walking speed observed in toddlers. The soft character of the toddler's foot and the lower body weight to foot-contact-area ratio are also important factors reducing peak pressures. On the other hand, pressures are high underneath the midfoot region because of the absence of the longitudinal foot arch in toddlers [9,11].

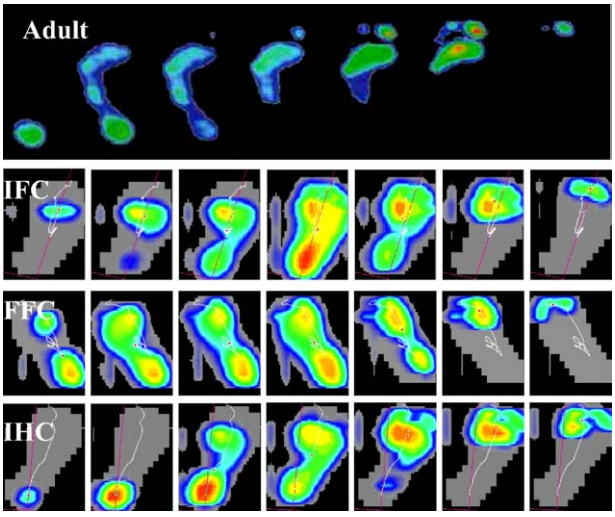

Fig. 2. The top panel shows subsequent pressure prints (recorded with a Footscan Pressure Pad) of a typical adult ''heel-to-toe'' roll-over pattern (left foot), starting with foot-contact made by the heel and ending in push-off by the hallux. High pressure areas are shown in red, low pressures in green and blue. The bottom panels show similar pressure recordings of the three different foot-contact patterns that can be observed in toddlers (IFC: initial forefoot-contact, right foot; FFC: flat foot-contact, left foot; IHC: initial heel contact, right foot). (For interpretation of the references to colour in this figure caption, the reader is referred to the web version of the article.)

Based on kinematic observations, maturation of gait is divided into two phases: a first rapid development phase spanning the first 3–5 months after the emergence of independent walking and a second slower maturation phase lasting until the age of 8 [13]. The question arises whether maturation of foot-function follows the same time course. Changes in step–time parameters and joint kinematics occurring during this period can significantly alter loading and roll-over of the foot. Recently, Bertsch et al. [1] published a study on foot-function in toddlers in which they were followed for 1 year after the onset of independent walking. Pedobarographic recordings were made every 3 months. Changes, apart from general growth of the foot, leading to increased contact areas, were found in foot anatomy indicating an early development of the medial longitudinal arch. Improvements in motor control led to changes in roll-over and foot loading. After 1 year of walking, the flat-footed contact, observed at the onset of independent walking, was replaced by a heel-to-toe roll-over pattern. Loads were shifted from the midfoot to the fore- and hindfoot, leading to higher values of contact area, maximum force, impulse and peak pressures underneath these regions.

The 3 monthly data collection intervals from the study by Bertsch et al. [1] were not sufficient to detect early changes in foot-function occurring rapidly after the onset of independent walking. Therefore, we choose to perform a longitudinal study on foot-function focussing on the first 5 months of walking to investigate rapid changes in foot-function and our study can be considered complementary to the study of Bertsch et al. [1].