Kinesiological characteristics of ankle joint and rearfoot motion

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Rezime
Kinesiological analysis of tarsal bones provides better understanding of foot disorders, especially in early childhood, when radiography is hindered by delayed ossification of foot bones. Children begin to walk in the age of 9-15 months, with rearfoot inversion only in initial contact phase, while inversion during terminal stance phase is delayed. Adult walking pattern is usually established at six years of age.
Talocrural joint axis medial slope shifts during movements depending on the what part of talus comes in contact with maleolli. As a result, plantar flexion includes valgus, and dorsal flexion includes varus inclination.
Subtalar joint axis highly varies among individuals: from 200-680 in sagittal and from 40-70 in frontal plane, with impact on coupled lower leg rotation movements around longitudinal axis.
Midtarsal joint has two axes, and their position control the rigidity of forefoot and midfoot kinetic chain. Movement planes of tarsal bones strongly influence walking pattern as well as secure foot development.

Keywords: subtalar joint, midtarsal joint, movement, walking pattern

Introduction
Representing the terminal part of lower extremity, human foot has primarily locomotor function. Its unique anatomical characteristics enable other functions, such as tactile, thermoregulation and proprioception. But, diversity of motor requirements and significant adaptability have made foot an important and highly specialized element of posturation and locomotion, i.e. stance, step and jump. Kinesiological analysis of tarsal bones provides better understanding of foot adaptation to stress and strain, which has significant impact on development of foot disorders, and thus is important in treatment process.

Foot and gait development
Foot development is usually described in two categories: morphological and functional. From the morphological point of view, it is important to state that foot bones in neonates are mostly cartilaginous, although majority of them have primary ossification centers present at birth. An average physiological appearance time of ossification centers is listed in Table 1. Delayed ossification through childhood and adolescence, and marked individual variability of this timeline, hinder radiographic diagnostics. Excessory foot bones are quite common: for example, os supranaviculare is found in 11-15% healthy people, os tibiocuneiform in 4-12%, os trigonum in 1.7-7%.

Functional aspect of postnatal foot development is mainly focused on active mobility. Talocrural range of motion in healthy neonates is significant: average values are 500 of dorsal and 300 of plantar flexion. Active inversion up to 150 is also expected. During first few weeks foot mobility increases, with maximum achieved during second month. Rearfoot inversion slowly increases during first six months, and physiological foot pronation or planovalgus position appears during stance and gait initiation, which is expected between 9 and 15 months. At that time at least 200 of dorsal and 400 of plantar flexion is expected, close to adult physiological range of motion.

At age 2 plantar fat pad atrophy is evident, and longitudinal medial arch becomes apparent. Marked mobility of tarsal bones continues, and we can observe a rearfoot inversion during initial contact phase of gait cycle (coupled with internal lower leg rotation), but still without rearfoot inversion in terminal stance phase.

At age 4 children perform propulsion of stude by plantar flexion at terminal stance phase. Subtalar inversion and eversion range of motion increases, and neutral rotation position of lower leg in swing phase is easily maintained.
At six years of age, with a burst growth period, relative stride length increases, and symmetrical arm movements while walking are present. Evaluation of six determinants of gait (pelvic rotation, pelvic tilt, knee flexion, dorsal and plantar flexion, stride length and width and walking cadence) shows an adult walking pattern.

**TALOCRURAL JOINT**

Talocrural joint belongs to hinge joint type, comprised of talar trochlea articulated with both cubral bones. Movements include flexion and extension, largely addressed as plantar and dorsal flexion, respectively. Stability is secured by several layers of ligaments, and by inherent stability of hinge joint.\(^1\)\(^,\)\(^2\)\(^,\)\(^4\)

Talus has two articular surfaces for malleoli, and they are quite different from the kinesthesiological point of view. On lateral side there is one constant radius through the articular surface, while on medial side there are two: anterior part has smaller radius than posterior part of the surface. It has significant implications on position of joint axis, because that angle changes in relation to what part of talar trochlea is in contact with malleoli. In plantar flexion it is posterior part of trochlea, whose internal radius is bigger than external, while in dorsal flexion situation is opposite. Talocrural movements are thus performed along undulating trajectory: the plane of motion is deviated laterally during plantar flexion and medially during dorsal flexion.\(^4\)\(^5\)

**SUBTALAR JOINT**

Greatest influence on foot kinematics comes from the joint between talus and calcaneus- subtalar joint. Axis of subtalar joint is directed anteriorly, medially and superiorly, showing significant individual variations: from 200-680 in sagittal and from 40-470 in frontal plane. Movements around such an oblique axis do not belong to any of standard planes, and are named inversion and eversion. Its position in closed kinetic chain (i.e. foot is in contact to the ground) universal joint effect - subtalar joint motion is coupled with lower leg rotation around longitudinal axis. Coupling proportion depends on the angle of subtalar joint axis in sagittal plane: if that angle is approximately 450, proportion is 1:1 (a degree of eversion leads to a degree of internal tibial rotation), while large subtalar axis angles close to 700 increase coupling proportion to 1.4 (a degree of eversion is coupled with four degrees of internal tibial rotation).\(^1\)\(^,\)\(^2\)\(^,\)\(^7\)\(^,\)\(^8\)

The orientation of subtalar joint axis also enables significant compensation for functional forefoot and midfoot deformities. For example, if a foot eversion deformity is present, it is compensated by excessive rearfoot eversion when the foot is placed on the ground, with several consequences: deceleration of cuboid groove for peroneus longus tendon, increased forefoot range of motion with the risk for stress fracture of second metatarsal, strain at anterior transversal arch which leads to plantar fasciitis, dysfunction of propulsion lever in terminal stance phase with Achilles tendon and tibialis posterior tendon overuse syndrome, increased internal tibial rotation leading to anterior knee pain syndrome.\(^8\)\(^,\)\(^9\)\(^,\)\(^5\)

Forefoot valgus deformity leads to an opposite effect-excessive rearfoot inversion during weightbearing. This leads to increase in foot rigidity, limited range of midtarsal joint motion, excessive load to peroneus longus tendon with peroneal tendinitis, limited ground force absorption of transversal arch which increases the chance for ankle strain injury, and a tendency to external tibial rotation which leads to iliotibial tractus load and trochanteric pain syndrome.\(^8\)\(^,\)\(^7\)\(^,\)\(^8\)\(^,\)\(^9\)\(^,\)\(^10\)

**Midtarsal Joint**

Chopart or midtarsal joint is consisted of two joints: talonavicular joint (pivot type) medially and calcaneonavicular joint (varies from flat to saddle type) laterally, so two axes of rotation are defined: longitudinal and oblique. But, difference in joint types and the presence of numerous ligaments significantly restrain movements, which has substantial kinesthesiological importance. Longitudinal midtarsal joint axis goes through talonavicular joint and is directed around 150 superiorly and 90 medially, and movements of pronation and supination are performed around that axis. Oblique axis goes through talus and calcaneus at the level of anterior articular area, and is

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**TABLE 1**

<table>
<thead>
<tr>
<th>INTRAUTERINE AND POSTNATAL OSSIFICATION OF FOOT BONES</th>
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</thead>
<tbody>
<tr>
<td><strong>Primary ossification centre</strong></td>
</tr>
<tr>
<td>Calculus</td>
</tr>
<tr>
<td>Talus</td>
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<tr>
<td>Metatarsal bones metaphysis</td>
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<tr>
<td>Cuboid bone</td>
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<tr>
<td>Toes II-IV diaphysis</td>
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<tr>
<td>Toe V-proximal phalanx</td>
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<tr>
<td>Lateral cuneiform bone</td>
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<td>Medial cuneiform bone</td>
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<tr>
<td>Intermedial cuneiform bone</td>
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<tr>
<td>Navicular bone</td>
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<tr>
<td>Sesamoid bones of the 1st ray</td>
</tr>
</tbody>
</table>

*Secondary ossification centre*

| Phalanges | 2-7. year |
| Metatarsal bones | 3-4. year |
| Calcaneal apophysis | 7-10. year |

*Fifth metatarsal bone apophysis* | 7-14. year |
directed anteriorly, superiorly and medially from 520-570 in both horizontal and sagittal plane. Around that axis compound movements are performed: plantar or dorsal forefoot flexion along with rearfoot inversion or eversion, depending on what part of kinetic chain is closed (i.e. on what side of the fulcrum lies).1,2,4,8,9,10,11,12

**CONCLUSION**

Anatomy and function of all human organs influence each other. It is certainly the case with the foot, which configuration in children goes through various stages of development, and influenced by increasing motorical tasks. In addition, gait pattern are greatly individual, reflecting the diversity of locomotor system configuration in human population. Because of that, examining the way a person stands or walks can provide essential information about foot morphology in the assessment of deformity and decision of best treatment method and timing. Improvement of stable stance and balanced walking ability is ultimate goal in foot treatment.

**REZIME**

**KINEZIOLOŠKE KARAKTERISTIKE POKRETA ŠKOCNJOG ZGLOBA I ZADNJEĐEGLA STOPLA**

Kineziološka analiza tarzalnog dela stopala omogućava bolje razumevanje deformiteta stopala, naročito u najranijem uzrastu, kada je radiografska dijagnostika otežana usled usporene osifikacije kostiju stopala.

Deca upostavljaju hod u uzrastu od 9-15 meseci, ujedno i u tri faze: faze neaktivnosti, odnosno faze aktivnosti, bez aktivnosti, a na to je potreban usledni foki i dobavljanje. Adultni obrazac hoda se upostavlja oko šest godina života.

Osnovna talokrunzna zglobova na gajgu u frontalnoj ravni zavisio od dela talusa koji ostvaruje kontakt sa maleolusima. Usled toga je planar nedouške deli i do valgusne, a pri dorznalnoj foki do varingne inklinacije.

Osnovna talokrunzna zglobova pokazuju znatne individuualne varijacije: od 200-800 u sagitalnoj i od 40-470 u frontalnoj ravni, tučenci u uzdužne pokrete rotacije potkornice pri oslenju.

Srednji tarzalni zglobovima dve osnovne rotacije, čiji medijus obložen turčisk na rigidnost kinetičkog lanca prednjeg i srednjeg dela stopala.

Pokreti tarzalnih kostiju imaju znakoj uticaj na obrazac hoda i na pravilan razvoj stopala.

**REFERENCE**


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