SELINUS UNIVERSITY
OF SCIENCES AND LITERATURE

Dissertation Thesis

A Review of Orthopedic Rehabilitation for Flatfoot Patients

in Fulfillment
of the Requirements for the

PhD Degree in Orthopedic Rehabilitation

By
Arianit ILJAZI
Rruga Haxhi H. Dalliu
Tirana, ALBANIA

June 4, 2019,

Pledge

In this paper, every OPINION from someone else has been indicated by a parenthetical citation or reference number. I realize that the mere presence of a parenthetical note or reference number does not avoid plagiarism.

- **Citations:** The exact words, phrases, clauses, or sentences of someone else are placed in *italic*. If the opinions of someone else have been paraphrased, those opinions have been stated in this author's own words (without *italic*).
- **Reference Numbers:** In this thesis quotations and paraphrases are sometimes introduced and, in all cases, have reference number(s) in the sentence(s).

All factual information (common knowledge or uncontested knowledge), though not credited with parenthetical note or reference number, has been stated in my sentence structure. This project is my own first-time work.

Selinus University of Science and Literature
Dr. Adriana Nifosì
Academic Secretariat

SELINUS UNIVERSITY OF SCIENCES AND LITERATURE
MEMENTO AUDERE SEMPER

Signed: Arianit ILJAZI (A. H. ILJAZI)

TABLE OF CONTENT

Note: The phrase noted with an asterisk * in page 19 means that the thought of the author of this thesis was inserted between the original thought of the referenced author

2. Abbreviations

Flat Foot – FF; Flexible Flat Foot – FFF; Acquired Flat Foot – AFF; Short Foot Exercise – SFE; Medial Longitudinal Arch – MLA; Custom Made Insole(s) – CMI(s); Polypropylene – PP; Polyethylene – PE; Computer Aided Design/ Computer Aided Manufacturing – CAD/CAM; Supra Malleolar Orthosis – SMO; Adequate Intake – AI; Daily Reference Intake(s) – DRI(s); Subtalar Arthroereisis – STA; Plantar Fasciae – PF; Recommended Daily Intakes – RDIs; Daily Reference Intakes – DRIs; Ultraviolet B – UVB; Tibialis Posterior Tendon Reconstruction – TPTR; Tibialis Posterior Tendon - (TTP); Orthopedic(s) – Ortho; Congenital Hip Dysplasia – CHD; Right – R; Stretching Exercises – SE; IU - International Units; Ascorbic Acid – AA; Vitamin – Vit.; Peroneus Longus Muscle(s) – PLM(s); Achilles Tendon – AT; Strengthening Exercises – SE; Release exercises – RE; BMD – Bone Mass Density

3. Alternative Words

Fallen Arches - Flat Foot – Pes Planus; Insoles – Inserts; Valgus – Pronation; Disorder – Condition; Prophylactic – Prevention; Dysfunction – Insufficiency; Prognosis – Outcome; Hallux – Big Toe; Plantar flexion - Extension – Stretching; Calcaneal – Heel; Tender – Rigid; Subtalar Arthroereisis - Subtalar Joint Arthroereisis; Plantar Fasciae - Plantar Fascia; Recommended Daily Intakes – Daily Reference Intakes; Digital Foot Scanner(s) - Foot Digitizer(s); Charcot

Foot - Neuropathic Osteoarthropathy; Vitamin C - L-Ascorbic Acid; Big Toe – Hallux

1. Keywords

Flatfoot, pes planus, treatment, conservative treatment, exercises, physical therapy, insoles, vitamins, diet, recommended

5. Introduction

In today's age of super-rapid advancements in technology, human studies and all other aspects of life, the need for more focus, dedication, and specialization is increasingly becoming a priority. Prioritizing in the study, research, and development of all scientific and professional specialties and subspecialties has become the cutting-edge between mediocre practice and the excellence one.

This reality is even more eminent and of a sensitive nature when it comes to medical and health sciences; the UK Medical Council of Medicine points that only in the US there are about 80 medical specialties and more than 110 sub-specialties.[1] From this perspective and for the purpose of advancing the sub-specialty of Orthopedic Rehab and especially that of the Flat Foot Pathology we are developing this research study thesis.

5.1 Orthopedic Rehabilitation Specialty

Medical rehabilitation is the process of reinstating or taking back the psycho-physical well-being and emotional health enjoyed before one disease or a pathological process took place in us. According to

Merriam-Webster dictionary, one of the definitions of the word rehabilitate is: to restore or bring to a condition of health or useful and constructive activity[2]; this process is quite often complex in its nature, and becomes even more so when it comes to Orthopedic Rehabilitation.

Rehabilitation in Orthopedics involves a variety of interventions, modifications, adjustments, programs and not only these; Orthopedic Rehabilitation requires also a well-coordinated and synergized team of compassionate, multidisciplinary, and highly skilled healthcare professionals. These processes and other important ones will be the theme of our study.

5.2 Study purpose

The development of this theme has a multi-layer purpose; as previously stated, its primary aim is to advance the science of Orthopedic Rehab in FF treatment, but not only. It purposes also to deepen personal and public understanding of FF pathology, while providing at the same time a research-based and empirical view of its onset, prognosis and treatment options. This endeavor will also aim to become a respective reference point for healthcare professionals, including physicians, nurses, physical therapists, ortho-prosthetic technicians, pharmacists, radiologists, and dietitians.

In a narrower specter this thesis will attempt to: a) Provide some comprehensive information to FF patients, parents of FF patients, and other people sharing a common interest towards FF pathology and its respective treatment b) Stress the point of the holistic evaluation, treatment, and follow up for all patients in general and especially for FF patients c) Encourage healthcare professionals, patients, and other people to look after, promote, and maintain their health as much holistically as possible and d) Orientate Albanian healthcare students and professionals to a new level of multidisciplinary approach, intercommunication and coordination in patient diagnostics, treatment and follow up.

The effort for this thesis started as a reaction to the scarce holistic literature related to FF conservative treatment and especially to its rehabilitation process. After some consistent and careful research, the data suggested a not so easy path towards accomplishing the task of constructing a solid argument in support of the chosen theme. While relevant material regarding FF etiology, diagnosing and surgical treatment surfaced quite randomly the conservative treatment data appeared much more sporadic.

In these circumstances, both moral and professional obligation, demand to take a stance through a practical approach; this practical approach has to be concurrently narrow in its specific scope (pertaining only to flat foot), and quite expanded in its multifaceted horizon of clinical research and accumulated experience. And since there is nothing impossible with God's help,[3] also this undertaking will be within our grasp as we move step by step through the proceedings of this thesis.

5.3 Hypothesized Path

This thesis will attempt to display a resumed categorization of FF deformity as a minuscule subdivision of musculoskeletal injuries, diseases, and disorders; this study will offer relatively little space to FF Definition, Classification, Prevalence, Etiology, Associated Conditions, Signs, Symptoms, Diagnosing, Prevention, Complications, and Surgical Interventions, but will focus more on FF Conservative Treatment and Rehabilitation.

Conservative Treatment and Rehabilitation chapter will concentrate especially on the elements of Physical Therapy Exercises and Custom-Made Orthopedic Insoles. In the chapter of Conservative Treatment is also included the subchapter Dietary Recommendations; Dietary Recommendations will be considered as unequivocal and integrative components of natural FF treatment.

6. Definition

Flat foot or pes planus (from Latin) is the total or partial deficiency of longitudinal arch of the foot known also as the intermedial arch; the flat foot is uni or bilateral.

7. Categorization

For a better understanding and to categorize the entire spectrum of rehabilitation in orthopedics, it is necessary ta first place to know the main divisions of musculoskeletal injuries, diseases, and disorders.

At this point, it is adequate to mention that in our study, we will discuss only a dozen of utmost common orthopedic conditions; for each of these we will give less space to their respective Definition, Classification, Prevalence, Etiology, Associated Conditions, Signs & Symptoms, Diagnosing, Prevention, and Complications, focusing more on their Conservative Treatment and Rehabilitation.

There are different systems to classify orthopedic conditions, but we will use the one based on the age of affected recipients. On this basis, orthopedic conditions are categorized as: congenital and acquired. Acquired conditions include various forms of fractures, dislocations, and arthritis; on the other hand, congenital conditions composed mainly from developmental disorders.

7.1 Classification

Classified by age, pes planus could be congenital or acquired (during adulthood) and the differential diagnoses would be difficult until the age of three; this confirmation of the diagnoses is mainly due to the fact that the (intermedial) arch develops in childhood, *between the ages of three and 10 years*.[4] Congenital flat foot is more flexible in the first two years of life[5] and it is safe to say that almost all kids are flat feet up to this age.[6]

Based on the prognosis, flat feet will classify as physiologic (or constitutional) and pathologic. On the other hand, based on flexibility

PP can be flexible or not (rigid), with flexible FF accounting for the majority of cases[7]; within the subdivision of flexible FF (short FFF), approximately 25% of cases are associated with a shortness of the Achille's Tendon.[8] Flatt foot can be symptomatic or not; for the best purpose of this study, we will focus only on the symptomatic FF. In all cases, it is worth to underline that the relation structure-functionality remains one of the main bases to not only e classify the FF, but also how to treat it and follow it up.

8. Prevalence and incidence

From the very beginning of this section, it is adequate to mention that mainly due to the lack of a *consensual agreement on the strict clinical or radiographic criteria for defining a flatfoot*[9] there aren't any dependable data regarding the incidence of FF, but approximate estimates point to a percentage of incidence varying from 2.7% to 44%[10] of all adult and pediatric world population. Regardless of this lack of exact incidence global-data, there are more abundant studies in regards to FF prevalence.

These studies report higher recurring rates in male-children and adult females[11] with the tendency for prevalence to decrease sharply after the age of six;[12] from this perspective more prone to develop FF are people of African-American descent. It is also noteworthy that regardless of patient age, it exists a high association between joint hypermobility, increased weight (or obesity) and flat foot prevalence.[13]

Flexible Flatfoot accounts for approximately two-thirds of all FF cases with a drastic incidence of it happening during adolescence and adulthood.[14] It is also worth to mention that a fairly limited number of flat feet develop secondary to neuromuscular deficits from Cerebral Palsy Conditions.[15]

9. Etiology

Symptomatic (pathologic) flat foot in children it is caused by a variety of reasons, but the most severe form of it is Vertical Talus or otherwise known as Congenital Vertical Talus; in this case the talus bone it is not positioned in its normal horizontal position, but vertically causing dorsiflexion of the forefoot and equinus of hindfoot. Because of this anatomical position and posture pattern, CGT is called also Rocker Bottom Foot.

A very common cause of FF is the fusion of the foot bones called otherwise osseous coalition; in FF tarsal coalitions of hindfoot predominate the following fusions: a) talocalcaneal fusion (from the fusion of talus with the calcaneal bone) and b) the calcaneal-navicular fusion (from the fusion of the calcaneal bone with the navicular one). A less common (but not less severe) foot osseous coalition contributing to the FF deformity is also the osseous coalition of navicular bone with the cuneiform ones.

As pertaining to the AAFF (or progressive flat foot), the largest (and broadly accepted) problem causing FF is the Dysfunction or

Insufficiency of Posterior Tibial Tendon even though different late research will characterize it more as an extensive involvement of ligaments… and *a mismatch between active and passive arch stabilizers.*[16] As per the opinion (based also on experience) of the writer of this developing thesis, both the dysfunction of PTT and the insufficiency of other active and passive foot stabilizers are crucial contributors to AAFD. To the aide of this latter statement comes (also) the study of Boerum and Sangeorzan with the assertion that *the main factors that contribute to an acquired flat foot deformity are excessive tension in the triceps surae, obesity, PTT dysfunction, or ligamentous laxity in the spring ligament, plantar fascia, or other supporting plantar ligaments.*[17]

It is thought that loss of connective tissue, such as in the cases of Ehlers-Danlos syndrome and joint hypermobility syndrome, and some neuromuscular conditions (such as cerebral palsy, spina bifida, and muscular dystrophy) are direct contributors to the cause of FF.[18] Other congenital conditions influencing directly to symptomatic or asymptomatic FF are vertical talus, calcaneovalgus and metatarsus adductus.

Family history and different iatrogenic over-or under-corrections are also distinct FF contributors.[19] Among risk predisposing factors for FF, it is important to underline overweight,[20] obesity, age,[21] and high blood pressure;[22] the same is true also for pregnancy. Dr. Merton L. Root, a well renown authority in the world of orthopedic biomechanics, maintains that a short gastrocnemius, the osseous blockage of the ankle joint and above all the ankle in equinus position, are responsible for FF; in this regard Mr. Sgarlato (one of the coresearchers of Dr. Root) adds that not only the shortening of gastrocnemius but also the shortening of soleus it is a potential cause for FF.[23]

Less common causes are Genu Valgus, Foot Injuries, Foot Arthritis, Tight Heel Ligament, Osteogenesis Imperfecta, Diabetes Mellitus, Ligamentous Hyper-Laxity, Charcot Foot (called otherwise also neuropathic osteoarthropathy) as well as previously stated, Cerebral Palsy, Spina Bifida, Muscular Dystrophy, etc.[24]

10. Associated Conditions

The most common conditions associated with FF are Hammertoes, Tendonitis, Plantar Fasciitis, Arthritis of Foot Joints, Bunions, Stress Fractures, shortness of Achille's Tendon, Shin Splints [25] as well as Congenital Vertical Talus and Congenital Calcaneal-Valgus.[26] In cases when FF is caused by Congenital Calcaneal-Valgus Deformity it is quite randomly *associated with Congenital Hip Dysplasia*;[27] with this said it is of primary importance to rule out the existence of CHP if Congenital Calcaneal-Valgus Deformity diagnosis is confirmed.

Another (less common) condition associated with FF is the Accessory Navicular Syndrome (a congenital condition) which consists in an extra bone (called Accessory Navicular) attached to the navicular one; the Accessory Navicular bone contributes in the worsening of (already present) edema and pain.[28] A high incidence of flat foot is noticed also in patients with neurogenic hypertension center,[29] and in the cases of pediatric hypermobile FF it is quite randomly associated with pediatric bunions.[30]

Even though overpronation is often described as a mere sign of flat foot, the fact of the matter is that FF and overpronation are distinct medical conditions which are remarkably associated with one another (especially evident in the cases when FF falls into the category of FFF).[31] When this close relation exists, the body is more prone to structural conditions such as excessive lumbar lordosis, functional scoliosis, pelvic misalignment, and degenerative changes. At this point, it is made obviously clear that *the biomechanics of the foot influence the alignment and function of more proximal joints and even the whole locomotor apparatus;*[32] with other words, it is correct to say that quite often as a result of moderate or severe FF deformity we can observe that ankles, knees, coxo-femoral bones and (not rarely) also columnar vertebrae painful and/or deformed at various degrees.

11. Signs and Symptoms

The main predominant signs and symptoms, of which flat foot patients complain are foot fatigue, pain,[33] posture instability, edema, deformity (especially on the medial ankle aspect), difficulty in ambulation and walk impairment. In moderate and severe cases, pain is sensed quite randomly over the medial malleolus, around the navicular bone (including the accessory navicular bone[34] when this later one is present). The patient does describe the pain as a dull aching discomfort underfoot (especially during weight bearing), which feels like a collapse of the foot's arch.[35] Pain is increased considerably while the FF patient suffers also from a short and tender Achille's Tendon and consequently from Achille's Tendonitis.[36] Most of the above symptoms are generally related or caused by the inability of the posterior tibial tendon to maintain both foot and ankle in normal anatomic positions.

According to American Orthopaedics Foot & Ankle Society, other common symptoms of FF are *progressive flattening of the arch, shifting of the heel so that it is no longer aligned underneath the rest of the leg, rotation, and deformity of the forefoot, tightening of the heel cord, development of arthritis, and deformity of the ankle joint.*[37]

Fig. 1 Eversion of R.

An obvious sign observed during walk shows an outward shift of the heel and the whole foot; in medical terms, this is called eversion, valgus position or overpronation of the foot in the sagittal plane. In the most severe cases, the sole of the foot is presented with a clear convexity.

It is to be considered worthwhile and fairly precautionary when we learn to distinguish and be aware when FF is caused by the neuropathic osteoarthropathy condition; in this case, when Diabetes Mellitus is confirmed as the primary cause of Charcot Foot we need to approach it with a double standard of care. *Recognition* (of the combination of these conditions)* *and timely management can prevent lifelong deformity or amputation.*[38]

Other accompanying signs manifested with mild and severe forms of FF are Hyperextension of shin bones and misalignment of hips and knees; the misalignment of the knees on its part has the potential to cause grinding of medial meniscus especially in cases of severe FF. There is also a hypothesized relationship between standing planus foot morphology and increased postural stress on other tibiofemoral and patellofemoral tissues;[39] this increased postural stress on tibiofemoral and patellofemoral tissues is one of the contributing factors for the causation of both recurvatum and jump knee gaits.[40] More biomechanical details pertaining to the dynamic particularities of walk pattern in FF patients is discussed in the next section.

12. Diagnosing

Diagnostics of FF vary depending on the severity of factors such as the age of the subject, grade of the condition, and awareness in its regard; among different diagnostic methods, the easiest and the most popular is the wet-test or the ink method. This method is 100% conservative, natural, and extremely cost-effective; it can be performed personally with literally just water (or whatever safe liquid) and paper. After merging in the liquid, the foot leans over a dry paper. The paper in the wet imprint will show with accuracy the bottom relief of the foot; this relief does show even clearer if we impose the paper in the direction of the sun, a light bulb or an equal luminescent source.

Fig. 2 Steps of performing the Ink-Method

The ink method provides (generally) a sufficient diagnostic caliber in regards to grades of FF when this pathology is present in the subject evaluated. Grades of FF prescribed in more detail below are divided into three categories: Grade 1 is the dynamic or supple FF, Grade 2 is hypo-dynamic or partially supple and Grade 3 nondynamic or the rigid (contracted) FF.

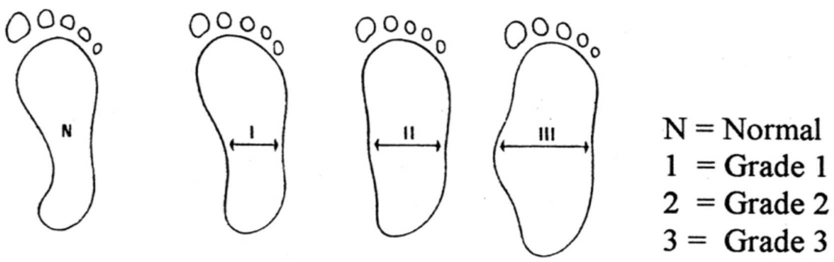

Fig. 3 Denis Method Classification Grades Of The Plantar Footprint (Picture Courtesy Of American Academy Of Pediatrics)[41]

As it is clearly visible from Figure 2, both the 2^{nd} and 3^{rd} grades lack totally the inner arch's concavity with the 3^{rd}one having a very noticeable convexity and the 2^{nd} having an (approximately) straight line from the base of the Hallux to the inner aspect of the heel. The 1^{st} grade shows a minimal inner arch (concavity) between the (imaginary) line drawn from Hallux to the inner aspect of the heel.

Flat foot grades and their anatomic implications are understood better when studied along with (both) the dynamics and biomechanics of the foot and ankle during the walking process. For example, if we are well aware that the first strike of the foot is made with the heel, we have a main mean to distinguish the flat foot's 1^{st}strike with both heel and medial part of midfoot which has, in this case, a full contact with the ground; in this instance the forefoot will be in abduction position to the rear foot.

Generally, for a properly verified and differentiated diagnosis are necessary these steps: 1) physical examination 2) observation(s) and 3) lab and/or diagnostic tests.

12.1 Physical Examination

During the physical examination_we check the patient mainly in a static position and manually for muscle strength, potential tender areas and flexibility during passive ROM's. A widely used test while performing physical examination for FF is Jack's Test (or Hubscher's maneuver);[42] this test consists in the dorsiflexion of the Hallux and observation of the flexibility of inter-medial curb of the foot (longitudinal arch); this method is especially adequate in determining the flexibility or rigidity thereof of the confirmed flatfoot.

Confirmed flatfeet recipients can perform the standing tiptoe test which in many cases will be a crucial test to differentiate between Flexible and Rigid Flat Feet conditions. The standing tiptoe test consists in the patient standing over the tip of his/her toes; if the heel corrects from valgus to neutral position and the arch is well visible, then the flat foot is flexible; to the contrary, if during tiptoe standing the calcaneus does not correct and the intermedial arch does not become distinctly visible, then the condition is determined as a Rigid Flat Foot.

12.2 Observation

During the observation, we analyze all components of gait, posture, and walk. If these analyses indicate any specific abnormality, it is important to determine the cause and extent of the abnormality and its consequences. One of the most valuable tools for the examination and confirmation of an FF diagnosis, is Foot Posture Index (FPI) is; this Index is the optimal blend of physical examination and observation of the foot in both static and dynamic positions.

Even though the FPI provides sufficient information for most of the foot deformities, in our study we will focus only on FPI’s specific scoring criteria for the FF; these are respectively: palpation of Talar head, evaluation of supra and infra lateral malleolar curvatures, the position of Calcaneal frontal plane, the prominence in the talonavicular joint region, congruence of intermedial arch of the foot and abduction/ /adduction positions of the forefoot related to the rearfoot.[43]

While palpating the talar head_of the FF patient its medial side will be normally palpable, but its lateral side will be only slightly or not at all palpable. During observation of supra and infra lateral malleolar curvatures_of a FF patient, it is evident that the supra lateral malleolar curvature is slightly or significantly more concave than Supra and infra lateral malleolar curvature. In the evaluation of Calcaneal frontal plane position_of FF patients, it is observed a valgus position with an eversion of ≥5°; this eversion causes, in turn, tibial internal rotation, creating a mechanism for excessive transverse friction at the knee joint.[44]

Observation of the talonavicular joint in an FF patient shows distinctly the prominence of this articulation. In an FF patient, the height of the intermedial arch is low or missing completely in its central part; this central part does have partial or full contact with the surface below the foot. While looking from the back, the position of the forefoot related to the rearfoot of an FF patient, we can notice that in contrast to the medial toes, which are little or no visible at all, the lateral ones are clearly or very clearly visible.

12.3 Diagnosing Devices

To determine a positive FF diagnosis, exist a multitude of diagnostic devices including Podoscopes, Podoscanometer Platforms, Digital Foot Scanners (Foot Digitizers), Mechanical Foot Scanners as well as more complicated ones such as Ultrasounds, MRIs, X-rays and CT scans. X-rays and especially CT scans have a high cost and radiation exposure; for these very reasons, the medical staff should be very conservative and reserved while prescribing and/or recommending such procedures.

Fig. 4 Foot Digitizer with pins

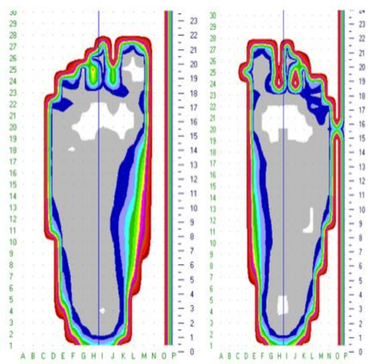

Fig. 5 Foot Digitizer Image

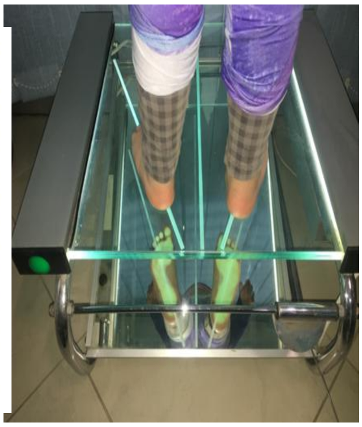

Fig. 6 Podoscope

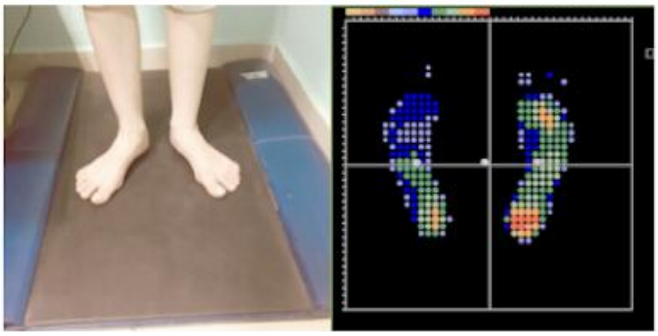

Fig.7 Podoscanometer' Platform and Image

Another handy tool to determine the cause of an abnormal motion (which as a consequence affects gait and posture) is fine-wire EMG (Electromyography) analyses;[45] this analysis will determine the function of both tibialis posterior and tibialis anterior muscles in relation to a flat foot deformity. The most advanced fine-wire EMG analyzers do evaluate also the mechanical proprieties of foot muscles such as muscular stiffness, elasticity, relaxation, viscosity, and tonus.[46]

Fig. 8 FF Lateral X-Ray [47]

13. Prevention

In regards to congenital FF, it is quite safe to admit that (so far) there is no scientific possibility to prevent it; a few exceptions exist in this regard though. The first exception is the suggestion to strap all infants' feet with adhesive tape into a position of varus a few days after birth for a period of one month.[48] This hypothesis has remained an isolated suggestion and there are not any known scientific researches, studies or shreds of evidence to support it; in ancient China people believed in a more traumatic and superstitious practice; their belief was that the girls' feet would become *more beautiful in the future if broken (first) and then wrapped up at an age of 5-7.*[49]

The other suggestion is based upon a relevant study, which asserts that *the increased static arch height index in children and adolescents growing up barefoot … is in accordance with lower incidences of flat feet reported for habitually barefoot children using static measures*.[50] This suggestion tends to be as a matter of fact a double standing phenomenon, holding ground in both prevention and the treatment of Acquired and Flexible FF.[51] If proved successful (the suggested) treatment of walking barefoot in the future must be applied with a well distinct precaution to preserve feet from potential foreign dangerous objects.

In contrast with congenital FF prevention, the odds and results of prophylactic treatment differ when it comes to the condition of Adult Flat Foot Deformity; from this perspective the prevention of AAFD falls more in the category of treatment and consists in a variety of interventions which focus on the recovery of an already partial or total loss of the intermedial (longitudinal arch). In these circumstances and as pre-established in our guideline, our study will advance to the chapter-section of complications.

14. Complications

Some FF-affected patients can experience persistent discomfort, pain, and edema in both feet and ankles if this condition is left untreated or its treatment fails; this phenomenon is more frequent in patients whose FF falls in the grade 3 (severe category). When a timely and adequate remedy for aggravated pathology presentations (discomfort, pain, and/or edema) is not achieved, these presentations can be counted also as complications.

Even though it is commonly accepted that FF itself does not have any other complications (apart from what was just mentioned in the previous paragraph), it is worth to mention some other potential complications. Potential complications of fallen intermedial arches are Tibialis posterior dysfunction, Hallux valgus, Metatarsalgia, Plantar fasciitis, Knee and Low Back pain.[52] Much of the literature which displays these suggested complications provides a satisfactory clinical narrative but lacks considerably the due backup of in-depth research and as such remains in the hypothesis ground.

The term complication (in regards to FF) it is used almost exclusively for post-surgery undesired outcomes; these undesired outcomes *include, but are not limited to: infection, pain (temporary or permanent), swelling, hematoma, bleeding, blood clot, poor wound healing, incision breakdown, poor bone healing (delayed union, nonunion), malunion, nerve injury, disability, recurrence, hallux varus, metatarsalgia, unsightly scar, stiffness, shortness of toe, weakness, hardware problems, need for revisional surgery, and/or catastrophic loss.*[53]

Some of these complications result from poor or gone-wrong surgery procedures, but since these procedures are not the primary focus of our study, the complications of these procedures will be sidelined and mentioned shortly under the section of surgical treatment. Even though there are all these complications, low MLA is considered a benefactor in cases of foot stress fractures, reducing the gravity of respective bone and surrounding tissue structures.[54]

15. Treatment

It is a well-known fact that FF is treated with nonsurgical (conservative) and invasive (surgical) methods; these methods are used sometimes in consecutive time-frames, sometimes concurrently, and some other times only one method is used. Prior of proceeding with a detailed overview of FF treatment, is necessary to mention that conservative treatment is not just the main component for FF prevention, but also a very favored approach for the treatment of already developed FF.

1.1 Conservative Treatment of FF

The conservative treatment of FF is widely favored mainly for two reasons: first, its implementation does not constitute any potential risk to the patient (always assuming that proper conservative treatment was given); secondly, its implementation is relatively cheap and much less traumatic both physically and emotionally. Conservative treatment of FF intends primarily to prevent further deformation in both symptomatic and asymptomatic FF cases; the second goal is that hopefully conservative treatment will finally correct the already existing FF condition.

Conservative treatment of asymptomatic FF it is recommended *with discretion* in *asymptomatic non-developmental pediatric* cases;[55] instead, for both asymptomatic developmental pediatric FF and asymptomatic adult FF it is recommended patient (and/or parental) education, footwear modifications and monitoring.

In regards to symptomatic FF, only its flexible category is treated successfully by conservative means; conservative treatment of symptomatic FF includes patient (and/or parental) education, footwear modifications, monitoring, *activity modification… orthoses, stretching* *and strengthening exercises and nonsteroidal anti-inflammatory medications (in more severe cases).*[56] On the other hand, conservative treatment of rigid FF it is not sufficient to reverse deformities, but can be used in all development stages to soothe symptoms and improve clinical outcomes.

The means of FF conservative treatment differ and depend on FF severity, choice of attending physician, as well as patient and family compliance with the therapeutic regime. The most known conservative means for FF treatment are physical therapy, orthopedic shoes, insoles, and foot orthoses. For each of these means, there are specific advantages; the facts about these advantages are supported by multiple-data accumulated along year-long studies.

1.1.1 Physical Therapy

Physical Therapy for FF can be done easily on a personal basis; this will avoid too many appointments at the physical therapist and will lower respective treatment-costs. Physical therapy for FF consists on those exercises which stimulate the *flexibility and strengthening … of the hips, knees, and ankles,*[57] and more importantly on exercises which strengthen the Tibialis Posterior, Tibialis Anterior, and other foot muscles (namely flexor digitorum longus and flexor hallucis longus).

Other FF physical therapy interventions include exercises for the hallux (big toe), as well as stretch and/or massage for tight muscles, tendons, and ligaments. Stretch exercises are performed mainly to soften tender Gastrocnemius and Soleus (calf) muscles; on the other hand, the massage therapy is exercised mostly to achieve the release of tight peroneal muscles, Achilles tendon, and plantar fascia ligaments. To provide more comfort and satisfactory results, a combination of stretching and massage therapy it is practiced on respective anatomical structures.

Strengthening exercises for tibialis posterior, tibialis anterior, flexor digitorum longus, and flexor hallucis longus have been performed effectively through *high-repetition exercises, aggressive plantarflexion activities, and an aggressive high-repetition home exercise program that included gastro-soleus tendon stretching.*[58]

Since Tibialis Posterior Tendon has been (largely) identified as the main contributor of FF, its *eccentric and concentric progressive resistive exercises* which *reduced pain and improved perceptions of function*,[59] are assumed to contribute also to a more structured and healthy medial longitudinal arch (MLA). This idea is almost identical in nature with a study performed by Korean Research Society of Physical Therapy, which states *that foot intrinsic muscle and tibialis posterior muscle of extrinsic muscle strengthening exercises may improve plantar pressure distribution and dynamic balance ability in adults with flexible pes planus.*[60]

1.1.1.1 Strengthening Exercises

As follows, there is a concise display of various SE for FF, and a more detailed description and analysis regarding the top recommended one. SE for FF include: toe spread, toe squeeze, toe alternation, raise and lowering of the heels, as well as Short Foot Exercises.

15.1.1.1.1 Toe spread and squeeze

While keeping the feet either in the air wither slightly leaning on the floor, we spread and then squeeze the toes for 3-4 seconds in regular intervals up to 7 times in a row. Repeat these exercises up to 4 times per day. Toe spread and squeeze exercises will contract and activate the muscles responsible for the toe control.[61]

Fig. 9 Spread Toes

Fig. 10 Normally Held Toes

Fig. 11 Squeezed

15.1.1.1.2 Toe alternation

The big toe and the other ones shift interchangeably upwards and downwards in 2-3 seconds intervals; the exercise can be done in both feet simultaneously if the person has bilateral FF and can coordinate bilateral toe alternation concurrently.

Fig. 12 Toe alternation

15.1.1.1.3 Raise and lowering of the heel(s)

Raise and lowering of the heel(s) exercise can be done either over a flat-floor surface either over a stable stool either over a step; Over the step performance has the advantage of allowing the heel to go backward in a much steeper angle. Raise and lowering of the heel(s) exercise will strengthen both foot and calf muscles.

Fig. 13 Heel Raise

Fig. 14 Heel Lowering

First, the heel is raised leaning over the tip of the toes creating a weight-charged plantarflexion; the foot is held in this position for 2-3 seconds. Second, the heel is lowered gradually to an approximate 30° angle in dorsiflexion; the foot is held in this position for 2-3 seconds. Repeat this exercise 4-5 times in a session for up to 15 times per day.

1.1.1.2 Short Foot Exercise

As aforementioned we will dedicate special space to the top recommended of these exercises which is the Short Foot Exercise. Short Foot Exercises do not rank just *more effective than … arch support insoles,* but when performed alongside these later ones lead to a clear improvement of both medial longitudinal arch and dynamic balance ability.[62]

Short Foot Exercise consists on pulling the toes backward (toward the heel) while maintaining their normal flat-touch with the ground and forcing a lift on the medial part of the foot (especially on the MLA) for five to seven seconds. SFE is recommended to be performed in either sitting or standing positions; SFEs performed in standing position will require more efforts than SFEs performed in sitting position and while the former ones are repeated up to 20 times in 5-seconds sessions, the latter ought to be done 25-30 times in 7-seconds sessions. Sessions are repeated for a minimum of 2, and up to 4 times per day.

Fig. 15 Relaxed-foot leaning over floor **Fig. 16** Contracted foot during SFE

In a study published in the Journal of physical therapy science Moon Et al. conclude that the performance of SFE improved immediately the dynamic stability of the patient, consequent to increase of patient's Limit of Stability, and not only; SFE improved also voluntary muscle activities.[63] Referring also to a study performed by Janda and VaVrova,[64] Moon Et al. concludes that improvement of both dynamic stability and voluntary muscle activities were achieved by increasing afferent stimulation of bottom-foot proprioceptors through SFE regime.

15.1.1.3 Big Toe Exercise

Next, in importance-range of strengthening exercises rank toe movements such as toe alternation, toe spread, toe squeeze, and especially big toe exercises. Big-toe exercises aim to make the hallux toe stronger so that it can improve flexion and extension, to assist in this way the lift of foot's medial longitudinal arch. Lean and stretch the big toe onto a wall or another firm surface for 20-30 seconds depending on age and effort-tolerance; when the plantar structures stretch to the point of a firm contracture, then it is release-time. The exercise is repeated 2 or 3 times in a raw, for a total of 9 times per day.

15.1.1.4 Stretching Exercises

As mentioned previously stretching exercises for Soleus and Gastrocnemius aim to soften the tenderness of these two calf muscles and increase the range of both plantar and dorsiflexion; normal ROM for these two movements (in sagittal plane) is *between 65 and 75°, moving from 10 to 20° of dorsiflexion through to 40–55° of plantarflexion.*[65] A very good exercise which contributes both to the normal stretch of calf structures and the strengthening of the big toe is the Ankle Range of Motion.

There are different ways to do Ankle Range of Motion, but one of the easiest is alphabet writing in -air by foot.[66] First, we sit in a high (enough) chair or couch so that our feet do not touch the ground; then we start writing (hypothetically) the alphabet in the air with our big toe playing the tip-part of the pen. The exercise is repeated 2-3 times in a session for a maximum of six times per day.

Other stretching exercises are those pertaining to stretching of Achilles Tendon; among a variety of AT stretching exercises, the most common is the towel exercise. In this exercise, the towel is looped around the metatarsals and pulled up (towards the body) until the foot is dorsiflexed to an approximate 15-20°*.* Apart from stretching, towel exercise can attain also the conservative release of the AT; this release is obtained by plantarflexing the foot (up to *55°)* and pushing it down against towel resistance.

Fig. 17 Towel exercise

Towel exercises can be performed in chair-sitting or flor-sitting positions; to maximize the effectiveness of these exercises it is necessary to align the *torso and knees … straight*.[67] After reaching maximal dorsiflexion (20°) hold the foot firm for 7-8 seconds, then begin the plantarflexion. After reaching maximal plantarflexion (55°) hold the foot firm for 7-8 seconds. Repeat these movements for 2-3 times per session for a maximum of nine times per day.

15.1.1.5 Release exercises

Release exercises for FF are performed mostly over the peroneus longus muscles, plantar fasciae, and Achilles tendons.

15.1.1.5.1 RE for Peroneus Longus MMs

Since PLMs are responsible for the plantarflexion and eversion of the ankle, among other functions they play a very important role as direct stabilizers of the big toe; as such PLMs along with the peroneal tendons serve also as stabilizers to MLA, ankle and entire foot. Rigid PLMs contribute to the collapse of MLA and cause the foot to invert. In these cases, along with stretching and resistance exercises, it is necessary to attend to the release of the PLMs.

Fig. 18 PLM Release exercise

There are different ways to achieve the release of PLMs; the easiest self-performing exercise it is by pressuring the lateral part of the calf over a massage or tennis ball while moving the ankle circularly for up to 3 minutes; repeat the exercise up to 3 times during a session for a maximum of 9 times per day.

15.1.1.5.2 RE for Plantar Fasciae

Plantar fascia performs three main functions: it serves as a shock absorber, stabilizer of foot longitudinal arches, and as a facilitator for the flexion of the first metatarsal; facilitating the flexion of the first metatarsal, the plantar fasciae enable *the first*

Fig. 19 PF Release exercise

metatarsal to carry the majority of the body weight.[68] A study conducted by Chang et. Al, concluded that plantar fasciae provide *the highest relative contribution to arch stability (followed by plantar … and spring ligament).*[69]

When PF is contracted, its functions are altered; among these altered functions is impaired stabilization of MLA. Impaired stabilization of MLA in its turn will cause the foot to collapse inwardly; to avoid this consequence, we perform the release exercises for PF. For such a task we can use a rounded object such as a tennis or a massage ball, a plastic bottle (filled with liquid or air), or a moderately soft rubber cylinder. To begin with, we place the part of plantar fascia over the chosen structure, and while applying moderate pressure roll the foot back and forth. Continue this movement for up to 3 minutes and repeat the exercise up to 3 times per session for a maximum of 9 times per day.

15.1.1.5.3 RE for Achilles tendons

Apart from the towel exercise described previously (pg. 35-36) another simple and effective release exercise for AT will be the ball rolling exercise. While sitting on the floor, position Achilles tendon over a massage or tennis ball; in this position

Fig. 20 AT Release Exercise

apply pressure with our hands over the shin part opposite to AT. Then *rock the foot from side to side for 1-3 minutes*[70] per session; repeat the exercise up to 3 times per session for a maximum of 9 times per day.

In addition to physical therapy and specific exercises, conservative treatment of FF includes the use of orthopedic shoes, insoles, and other kinds of orthotics. All of these interventions are part of the therapeutic regime and can be applied separately or concurrently. The orthotic treatment of FF has found wide clinical applications as an integral component to reinstate the normal biomechanics of MLA, ankle and entire foot.

1.1.2 FF Orthopedic Shoes

In regard to orthopedic shoes, there is an ongoing discussion as it pertains to their efficacity to treat FF. Many scholars believe that conservative treatment of FF with shoes is not needed[71] because *it is not effective on development of foot arches*[72] and does not cure.[73] Staheli & Giffin, doubling down toward this path assert that *shoe modifications not only* are *ineffective but* are *uncomfortable and embarrassing for the child and* are *associated with lowered self-esteem in adult life.*[74]

These researches have been reinforced also by a radiographic study in which the flatfeet of 10 children were compared while barefoot and while using *Thomas heel, … an over-the-counter insert, …* and *two* *specially molded plastic foot orthoses;*[75] the study concluded that there was found *not a significant change radiographically of these feet by the utilization of any of the appliances.*[76] Another similar study discovered that some cases of *painful pes planovalgus deformity* were *recalcitrant to prolonged conservative management.*[77]

Although the mainstream studies have shown no indication that orthopedic shoes alone can correct the FF condition, footwear modification and orthopedic shoes remain among the basic conservative interventions for the prevention of further MLA collapse and control of symptoms (especially tiredness and pain). In different cases, customized orthopedic shoes are recommended (especially when the FF is of severe and non-operable); in all cases, one of the main characteristics of FF shoe is that its counter should be rigid.[78]

Apart from the rigid counter, FF orthopedic shoes include also the Thomas Heel and an inner (partial) MLA support. Thomas heel is the calx part of the shoe that has the inner part approximately 2 cm longer than the outer part; its thickness is generally 3-4 mm. Thomas Heel along with the inner partial shoe support lifts MLA from the characteristic FF-valgus to a neutral position.

The newly-acquired neutral position, prevents the *depression in the region of the head of the talus,*[79] allowing in this way the ankle joint to relax and properly align with the hindfoot and the knee. These changes pertaining (especially) to the ankle joint and hindfoot alignment *are considered* consequential *to compensatory changes following alterations in lower limb alignment.*[80]

Fig. 21 FF Orthopedic Shoe

At this point, to the support of footwear effectiveness comes also a study conducted by Cornwall & McPoil; among other discussions they state that *footwear or foot orthotics decrease maximum tibial internal rotation compared with barefoot walking*; in the same study Cornwall & McPoil infer the *use of shoes, an accommodative orthosis, and an inflatable medial longitudinal arch support*, brought a decrease to the velocity and the acceleration of the internal tibial rotation.[81]

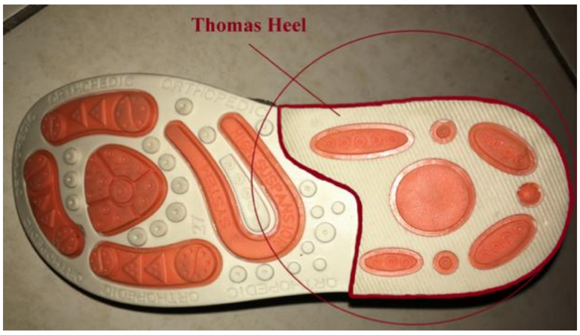

Fig. 22 Thomas Heel (R) FF Shoe

Before jumping into the insoles' section, it is necessary to lay out other criteria for FF orthopedic shoes. Apart from the rigid (heel) counter and Thomas Heel, other requirements for FF orthopedic shoes include stable shank support, standard heel elevation, stable fastening, and fit as well as comfortable, transpiring and porous materials. FF orthopedic shoes are mainly recommended for Grade 1 and 2 of FF; if the FF patient suffers from grade 3, FF orthopedic shoes are used together with FF insoles or FF orthotics.

15.1.3 Orthopedic insoles for FF

Another recommendation for conservative-treatment of FF is the use of orthopedic inserts (or insoles called otherwise); orthopedic insoles can be off-the-shelf or customized ones. A quantitative study of thirty-four FFF adults, which evaluated gait characteristics and time-distance parameters, concluded that *over-the-counter insoles have no beneficial effect in normalizing forces acting on the foot and on the entire lower extremity in adults with flexible flatfoot.*[82]

Fig. 23 Insole Blocks for CMIs

The effectiveness of off-the-shelf insoles versus customized-therapeutic ones was compared in a study conducted by Kido et al.; the resultswere evaluated calculating respective changes over MLA bones of eight subjects with mild FF. Among other conclusions, this study inferred that *therapeutic insoles significantly suppressed the eversion of the talocalcaneal joint.*[83] In support to this idea comes also the Takata et al. study which concluded that the insoles used on the level-ground *were effective in stabilizing standing balance in both flat-footed and normal-footed subjects.*[84]

For Grade 2 FF, sometimes it is recommended the use of both FF insoles and FF orthopedic shoes; 11 FF-affected adults wearing both orthopedic insoles and shoes were the subject of a study conducted by the Institute of Biomedical Engineering of National Cheng Kung

University in Taiwan. This study measured the ratio of the navicular height to the foot length as a mean of assessment for the longitudinal arch; from the evaluation of acquired measurements the authors concluded that *wearing shoes and insoles significantly reduced* both the angle and the moment of ankle plantarflexion.[85]

Since the use of customized insoles has been deemed so important and effective in FF treatment, we will take the time to study their varieties, main components and their production means. This study, will not describe manufactured foot-beds, such as inlays and support soles, but will focus instead, on the description of the most used custom-made insoles for FF patients, which are foot-beds and supplements.

Before detailing the components of custom-made insoles, it is appropriate to mention their main capabilities in relation to the functions over FF deformities. The design of FF custom-made insoles is made in such a way that they will correct mechanically the foot eversion by supporting the MLA; CM Insoles are designed to provide more stability for foot and ankle, as well as to obtain pressure distribution, compensate foot length discrepancies and prevent further MLA collapse (especially during the early developmental stages).

15.1.3.1 Structure, materials, and methods for FF CMI

The knowledge regarding the structure, materials and methods of FF CMI's it is of strategic importance when the conservative treatment is the only necessary approach; a solid understanding of structure, materials and methods for CMI production will help also podiatrists, orthopedic technicians, and other (involved) healthcare professionals for a more qualitative treatment of FF patients even when the conservative treatment is not the only option. For these reasons, and to display a more comprehensive pathophysiology and biomechanical sensitivity of FF deformity nature, in the following pages will be provided specific details related to structure, materials and production methods of FF CMIs.

15.1.3.1.1 Structure of FF CMI

Structural components of FF CMI vary and are used in different combinations; these structural components are a) Longitudinal Arch Support b) Supination Wedges c) Lateral Retaining Wall d) Medial Ankle Reinforcement and e) Relief of foot’s ball pressure. The most important and ever-present structural component of FF insoles is the Longitudinal Arch Support. LAS can be partial or total; partial LAS is made in cases when only the heel bone leans in valgus position. This partial LAS supports the navicular bone, the sustentaculum tali, and the medial Chopard joint line. Instead, when both heel and midfoot are in valgus, then the LAS should be extended along the whole length of MLA.

15.1.3.1.2 Materials for FF CMIs

Materials used for FF CMIs are the same or technologically similar to the materials used for off the shelf insoles or CMIs addressing other foot deformities such as Pes Cavus, Pes Equinus, Metatarsus Adductus, Calcaneus Spur, etc. FF CMI' materials range from the very soft ones such as silicone Shore 00 of 20 density up to the very hard ones such as carbon fiber Shore D of 90 or 100 density.

Sometimes, for the production of one pair of FF CMIs, it is necessary the concurrent-use of different materials; this combination of materials ensures that functionality, performance, and comfort are achieved simultaneously. Consequently, to make the right choice of material' combination remains a very delicate task which needs to be based on sound discernment, critical thinking, and experience.

Fig. 24 Manufactured CMI

As a matter of fact, for the perfect therapeutic combination of FF CMI materials it is necessary to make several considerations, especially in regards to MLA supports' height, width, and thickness; as a rule of thumb, when the support is very high the thickness should be up to moderate; consecutively, when the support's height is moderate then its thickness should be either moderate either sturdy. Severe cases of FF will need MLA with very high and rigid materials; the rigid material can be covered by a soft one to facilitate both comfort and compliance.

Apart from carbon fiber and silicone, for the production of FF CMIs, there are used also thermoformable materials such as polypropylene and polyethylene; this latter one will provide a softer alternative compared to the polypropylene. Other materials used for FF CMI are also ethylene vinyl acetate (EVA) materials of various densities; shore A 20-40 density of EVA materials it is used in insoles for Grade I FF deformities; shore A 45-70 density it is used in insoles for Grade II FF deformities; instead for FF insoles of Grade III are used shore A 75-100 densities.

The thermoformable plastic materials are especially good to construct the LAS part of FF CMIs; shore A 20-30 density of EVA materials, 3D textiles and leather are good lining materials to serve as the cover of the FF CMIs top surface. Low-density EVA materials along with Plastazote, Polysynthetic Leather, and latex are good materials to be used as cushioning ones; these cushioning materials can be used when patients apart from Pes Planus suffer also from Metatarsalgia, Calcaneus Spur Plantar Fasciitis or Hammer Toes.

15.1.3.1.3 Production Methods for FF CMIs

Production methods for FF CMIs can be manual or assisted by CAD/CAM technology; CAD/CAM technology stands for the technology, which processes the FF CMIs (and not only) by Computer Aided Design and Computer Aided Manufacturing. Manual methods for FF CMIs production are made by taking the feet's sole "negatives" of molds; these molds (or "negatives") are taken through a Vacuum Cushioning, a Foam Box, as well as through Alginate, Wax and Plaster Casts; after the negative is taken, we can create the positive (cast) by pouring plaster in the negative (mold) form. Both manual and CAD/CAM production of FF CMIs offer advantages and disadvantages.

Manual methods for FF CMIs production offer an easier way to create and use a template on the basis of a positional-corrected foot; these methods are both time-consuming and expensive for the most parts. On the other hand, CAD/CAM technology offers the advantages of a speedy and automatic procession without neglecting precision and custom adaption. Orthopedic Technologists and/or Pedologists should choose wisely the method for the production of FF CMIs; this choice should be done after a careful evaluation of both specific needs and possibilities of each FF' affected individual.

The Vacuum Cushioning method of producing a foot positive it is recommended when foot measurement should be taken in a load-corrected position.[86] For this method, there are needed two separate (or united) vacuum cushions connected to the vacuum machine. The feet are positioned so that the MLA can be lifted in normal position correcting in this way also the valgus when present. The patient should stay seated during the procedure until the feet reliefs are completely formed in the cushions. After this, the positive cast is formed by pouring plaster and corrected more if necessary.

Foam Box method of producing FF CMIs uses very low density (imprintable) foam material contained in boxes; the foot is inserted in the same way as we walk (aka heel stroke, medial foot stroke and then forefoot). If the measurement ought to be taken in a corrected position the patient should stay seated; this will facilitate the correction of both MLA collapse and foot pronation (when present).

Fig. 26 Foot Measurement, Imprint, and Molding by Foam Box Method

Another method for producing FF CMIs uses Alginate, which is a salt variety (its exact name is Sodium Alginate);[87] this material derives from Alginic Acid which is *an organic polymer derived from the stems of seaweed.*[88] Alginate (which is used also in food, cosmetic, dentistry and pharmaceutical industries) has desirable attributes for taking precise impressions of cavities and body structures. As such, we use it by pouring it over the Foam Box or Vacuum Cushion to attain a highly accurate foot impression.

Fig. 25 Vacuum Cushioning

The Alginate method of FF CMI's can be used while the patient is partially weight bearing or at a non-weight bearing position; the foot should sink mildly and not too deep in the foam (or vacuum cushion) and then the alginate is poured carefully over the foot. To allow proper penetration of the alginate, it is important that its liquid preparation is of adequate fluidity (four measures of lukewarm H_2O and one measure alginate powder) while the patient facilitates the process by gently moving the toes.

After all the Alginate has been poured and penetrated completely between the toes, the patient should stop the movement and allow the substance to harden. When the Alginate has hardened (approximately 5-6 minutes) the patient should remove the foot from the box (or vacuum cushion). Differently for Foam Box and Vacuum Cushioning methods in the Alginate method (of FF CMIs) the plaster should be poured immediately into the negative obtained, otherwise *the alginate will shrink and lose the form*.[89]

Wax Method of producing FF MCIs is one of the most precise ones; the wax-plate (otherwise known as paraffin-plate) should be inserted for 3-4 minutes in a tepid water filled container. After this, the wax plate is removed from the container and positioned over a flat (low-density) EVA foam or silicone; over the EVA block can be inserted also a jersey cloth which will facilitate a better osculation of the foot with the wax while this latter one is pushed and rubbed against the former.

During the rubbing phase of measurement, the patient should wear thin stockings and stand in a half-loading position; this latter one will allow optimal measurement of the foot's relief. After the wax form cools down its shape can obtain some additional corrections in an off-load position. Before pouring the plaster, we position the wax form in a sand-filled container; some sand needs to cover the sides of the wax form for counterpressure to not allow its deformation. After the plaster is poured and hardened, it is removed from the wax-form and the positive is ready for processing.

Plaster Cast Method is not only one of the best ways for the production of FF CMI's, but also the most used method to obtain a foot "negative" for custom made orthotic devices. As pertaining to FF CMI's the Plaster Cast should be obtained up to the ankle joint; the measurement can be taken unloaded or loaded. If the foot is easily corrected (due to flexibility) then the Plaster Cast can be taken even with a total weight-bearing position.

On the other hand, the Plaster Cast is obtained unloaded when FF deformity is combined with other foot deformities that need multiple corrections; Plaster Cast is obtained unloaded also in the cases when the foot cannot correct (due to its rigidity), as well as when the foot cannot and/or should not be loaded. Sometimes when the foot is completely stiff there will be no substantial difference between taking a Plaster Cast in a loaded or unloaded position. Below we will display shortly how the Plaster Cast measurement is taken.

First, it is necessary to prepare the required items for the measurement: a bowl of warm water, 10 cm wide plaster bandages (long up to 3 meters), protective rubber for the cut-line, knife, copying pencil, thin synthetic sock(s), Shore 00 of 30-40 density EVA foam, Vaseline, and a spirit level. The measurement will be made as below.

A) Mark with copying pencil the prominences of the first and fifth metatarsal bases (this will help during the process of modeling after the positive is molded). B) Apply Vaseline over the patient's foot (or feet). C) Position the protective rubber for the cut-line from hallux, to the dorsal part of the foot and up to the shin. D) Have the patient wear the thin synthetic sock(s) over the protective rubber and lean the foot over the EVA block.

E) After holding the plaster bandage in the warm water (approximately 7 seconds), submerge it and squeeze moderately so that almost no water would drop afterward. F) Start wrapping the plaster bandage from toes upward. G) After bandaging up to the ankle go down bandaging for a second time. H) Let the plaster dry and draw the position lines by using the spirit level. J) Cut the negative, pull from foot and seal the cutting line with a double folded (10 cm wide) plaster bandage (making sure that the position reference lines fit on each side). K) Pour prepared liquid plaster to form the positive cast.

1.1.3 FF Orthosis

FF orthosis could be off the shelf and customized; even though there are not yet enough studies to conclude definitively about the superiority of customized orthosis, different pieces of research point to better results of customized one in regards to eversion velocity.[90] As already mentioned in the chapter of Orthopedic shoes for FF, the customized accommodative orthosis along with inflatable MLA support, served as restrainers to the internal tibial rotation.

Apart from accommodative orthosis, two other custom-made orthoses for FF deformities are the semi-rigid and the rigid ones. As a start, we will describe their specific functions. The *accommodative orthosis cushions and relieves pressure from a painful or injured area on the bottom of the foot;*[91] semi-rigid FF orthosis serves to protect and cushion the foot, and also to provide support, control, and weight redistribution. On the other hand, the rigid orthosis offers exclusive arch support.[92]

FF *accommodative type of orthosis is good for a patient who has little or no deformity; these orthoses use* soft, moldable materials such as Soft cross-linked polyethylene foams, pen-cell polyurethane foams, sponge rubber, and closed cell expanded rubber.[93] On the other hand, semi-rigid FF orthoses are used generally in grade 2 FF; these orthoses are made from a combination of two or more materials, such as ethylene vinyl acetates, cork composites, and cross-linked polyethylene foams.

Rigid FF orthoses are especially prescribed when the Grade III FF is flexible; these kinds of orthosis are not moldable and are made generally from thermoplastic or carbon fiber. The attributes of these three kinds of orthoses differ widely; as already mentioned the accommodative ones offer abundant comfort (cushioning), but not high support; instead the rigid FF orthoses offer the opposite attributes of the accommodative ones. As per semi-rigid FF orthoses they provide a middle-ground satisfactory combination of shock-absorption, stability and cushioning.

15.1.4.1 Different Orthoses for FF treatment

Apart from the insoles, there are other orthotic solutions for the treatment of FF. These other kinds of orthotics come in the form of prefabricated or customized ones. As in the case of insoles, customized FF orthoses are produced manually and/or assisted by CAD/CAM technology. In all cases, the most used materials are polypropylene (PP) and polyethylene (PE). PP is used mostly in the moderate and severe cases of FF; PE instead it is used almost exclusively in moderate FF cases where both flexibility and durability are required.

Both PP and PE have different quality variables within their classes. PP has its homopolymer and copolymer derivates; the first is more adequate in severe cases of FF where rigidity is a must. PP copolymer, on the other hand, it is used widely in moderate FF cases, where flexibility and rigidity find the best application.[94] The thickness of PP and PE materials used for FF orthoses varies (general range 1-6 mm); its selection must be carefully chosen by evaluating FF grade, weight, age, posture, footwear and activity level of the subject.

15.1.4.1.1 Supra-Malleolar Orthosis (SMOs)

SMO's are the most common and preferred orthotic treatment for grade III FF, whose treatment with insoles and FF orthopedic shoes has not shown the desired results. Even as the name itself suggests

Fig. 27 SMO

SMOs are orthosis which support both malleoli (ankle joints), in their medial and lateral aspects. As mentioned in the above section, SMOs can be made of PP or PE materials and to secure optimal foot comfort the inner part can contain a soft (shore A 20-40 density) EVA material. Sometimes the EVA material covers only the inner malleolar part of the SMO.

To take the plaster cast for SMO production there are additional steps to the ones described during the Plaster Cast Method of FF CMI's. Mark with copying pencil the prominences of the medial and lateral malleoli, as well as the lateral prominences of the first and fifth metatarsal bases (this will help during the process of modeling after the positive is molded). When taking the plaster cast for SMO's, we wrap it slightly higher than 1/3rd of the calf.

Before pouring the plaster, we insert a (bent) solid steel bar inside (and in the midst of) the negative; the bent-form of the steel bar and its angle should correspond to the form and angle of foot-ankle-shin profile. To fix the steel-bar in the upper part of the plaster-cast we use a plastic clip; this plaster clip is removed after the plaster dries up. After the plaster dries up, we remove also the dried plaster cast bandage to get the positive. After this, the positive undergoes some remodeling so that both the pronation and the low MLA might correct.

Fig. 28 Marking of the Foot

Fig. 29 Casting of the Foot

Fig. 28 Marking of the Foot

Fig. 29 Casting of the Foot

15.1.5 Dietary Recommendations

Regardless of the lack of a direct relation between diet and FF, it is widely accepted that dietary factors play an important role (especially) towards *bone mineral density*[95] and bone-surrounding structures. In this regard, it is of primary importance the intake of the dairy products which contain not only *potassium, phosphorus, protein, vitamins A, D and B12, riboflavin, and niacin (niacin equivalents),*[96] but are also a good source of *energy and calcium*.[97]

On the other hand a balanced dietary intake is one of the main factors for an overall healthy organism; balanced dietary intakes are also the best basis to secure an optimal absorption, synthesis and interaction between all nutrients, including proteins, vitamins and minerals. To address respective Daily Reference Intakes (DRIs) for dietary values of relevant vitamins and minerals to foot and bone health we will be using the Adequate Intake (AI), the Estimated Average Requirement (EAR), the Recommended Dietary Allowance (RDA), and the Tolerable Upper Intake Level (UL) values.

15.1.5.1 Calcium

Calcium received through diet (and especially dairy), has proven to play *a pivotal role in the regulation of energy metabolism* and can influence (in a tangent-way) energy-consumption in FF patients.[98] A balanced and reduced energy consumption (aided also through insoles)[99] is one of the primary goals in addressing the tiredness symptom of affected FF patients. FF patients ought to become aware also that the *best sources of dietary calcium are milk, yogurt and cheese*.[100]

Apart from dairy products, other calcium-rich foods recommended for FF patients are seeds, sardines, beans, lentils, almonds, spinach, rhubarb, and figs.[101]

Table 1:[102] (RDAs) for Calcium

Age	Male	Female	Pregnant	Lactating
0-6 months*	200 mg	200 mg		
7-12 months*	260 mg	260 mg		
1-3 years	700 mg	700 mg		
4-8 years	1,000 mg	1,000 mg		
9-13 years	1,300 mg	1,300 mg		
14-18 years	1,300 mg	1,300 mg	1,300 mg	1,300 mg
19-50 years	1,000 mg	1,000 mg	1,000 mg	1,000 mg
51-70 years	1,000 mg	1,200 mg		
71+ years	1,200 mg	1,200 mg		

To attain the RDI of calcium, it is important the miscellaneous intake of the above-mentioned foods. In the section below this paragraph, is shown the table of Dietary Reference Intakes for Calcium published by the Institute of Medicine's Food and Nutrition Board. The table displays the Recommended Dietary Allowances (RDAs) of Calcium for both genders and for all ages; contains also specificities regarding RDAs for pregnant and lactating women.

Other dietary components for a healthy bone metabolism[103] and good prognosis for FF patients, are vitamin D, phosphorus, magnesium, protein, and fluoride; in addition to these, the following *vitamins and minerals for* the *metabolic processes related to bone* health are *manganese, copper, boron, iron, zinc, vitamin A, vitamin K, vitamin C, and the B vitamins.*[104] These vitamins and minerals are deemed crucial not only for the integrity of (foot) bones but also for the health of the entire body. For these reasons, this study will dedicate considerable space to their Recommended [or Reference] Daily Intakes (RDIs) doses and their respective best or richest sources.

15.1.5.2 Vitamin D

Vitamin D is one of the most natural vitamins considering the ways how the human body receives it; it *is a fat-soluble vitamin* that helps the *body absorb calcium and phosphorus.*[105] Natural intake of Vitamin D is done through ultraviolet B (UVB) sunlight rays in the form of vitamin D3 (cholecalciferol),[106] and through diet. To secure a sufficient Vitamin D natural-intake it is important to randomly include in the diet, Vitamin D- rich foods, such as fatty fish, beef liver, and egg yolks; vitamin D is found also in infant formulas and in the form of fortified and/or enriched foods such as fortified milk, cereals and orange juice.[107]

The best timeframe to achieve vitamin D synthesis (D3 – (cholecalciferol) through sun exposure is between 10 a.m. and 1 p.m.; this time-span corresponds also to the minimal-risk hours for cutaneous malignant melanoma.[108] Sun time-exposure for optimal vitamin D benefits varies from such factors as the amount of skin exposed, skin darkness/lightness, season, location, age,[109] and altitude.

The principle of sun time-exposure can be resumed as: you need more sun exposure if you are further from the equator, if your skin is darker, if you are not exposing a lot of skin to sunlight, if it is wintertime, if you are obese and if you are older.[110] A direct sun exposure requirement varies from 5 minutes up to an hour depending on the above-mentioned factors; a median direct sun exposure should last approximately 15-20 minutes a day.

The RDI for vitamin D is 600 IU (International Units) up to age 70 with an increase to 800 IU daily for people over the seventies. The Institute of Medicine set the upper daily dosage level of adult vitamin D intake to 4,000 IU. In severe cases of vitamin D deficiency physicians can prescribe with due caution the daily dosage higher than 4,000 IU.[111] In all cases a well-coordinated intake of vitamin D from sunlight, food, and supplements remains the best approach for balanced vitamin D normal levels.

15.1.5.3 Proteins

The DRI (Dietary Reference Intake) is 0.8 grams of protein per kilogram of body weight, or 0.36 grams per pound (weight).[112] Milk, yogurt and cheese mentioned already as very good sources of calcium are also very good sources for proteins; other healthy protein sources include seafood, eggs, beans, white meat poultry, lentils, soy, oats, tuna, broccoli, etc…

15.1.5.4 Phosphorus

Phosphorus is one of the three macro-elements present in literally every living cell of the human-body. Phosphorus plays a prime function in the formation, maintenance, and integrity of proteins, teeth, and bones, as well as in the metabolism of carbohydrate and fats; among other attributes, Phosphorus assists in muscle contracture becoming in such way a vital factor in the function and prosperity of the musculoskeletal health. [113] Phosphorus is found abundantly in diary products, meats, bean, lentils and nuts.[114]

Adequate Intake of Phosphorus for infants 0 through 6 months is 100 mg (3.2 mmol)/day; 7 through 12 months, 275 mg (8.9 mmol)/day; RDI for both Boys and Girls 1-3 years old 460 mg/day RDI for both Boys and Girls 4-8 years old 500 mg/day RDI for both Boys and Girls 9-18 years old 1,250 mg/day RDI for both Men and Women > 19 years old1,000 mg/day.[115]

15.1.5.5 Magnesium

Even though Magnesium is the scarcest of the serum electro-lytes, it is deemed to be *extremely important for the metabolism of* many human-body' elements, *for the intracellular homeostasis and for activation of thiamine and therefore, for a very wide gamut of crucial body functions.*[116] Among the wide complex of crucial body functions to which dietary Magnesium is of a primary importance, are also the musculoskeletal functions such as *grip strength, indices of skeletal muscle mass, and BMD*.[117]

Natural foods rich in Magnesium are tofu, whole grains, fatty fish, bananas, leafy greens, almonds, beans, peas, chickpeas, soybeans, Brazil nuts, avocadoes, cocoa, etc.[118] Magnesium RDAs[119] are displayed below.

Table 2: Magnesium RDAs:

Category	Recommended Dietary Allowance (RDA)
CHILDREN	
1-3 years	80 mg/day
4-8 years	130 mg/day
9-13 years	240 mg/day
FEMALES	
14-18 years	360 mg/day
19-30 years	310 mg/day
31 years and over	320 mg/day
Pregnant	*Under 19 years*: 400 mg/day *19 to 30 years*: 350 mg/day *31 years and up:* 360 mg/day
Breastfeeding	*Under 19 years*: 360 mg/day *19 to 30 years*: 310 mg/day *31 years and up:* 320 mg/day
MALES	
14-18 years	410 mg/day
19-30 years	400 mg/day
31 years and up	420 mg/day

15.1.5.6 Fluoride

Fluoride is a mineral not only good for teeth, but also for the bones. It has been proven that Fluoride lowers the density of cortical (legs and arms) bones, and increases the density of trabecular (spinal) ones. For the above-mentioned reasons, it is necessary to maintain a balanced intake of Fluoride mineral. Some of the foods rich in Fluoride are shrimp, blue crab, grape juice, coffee, black tea, raisins, table wine, etc.[120]

Australia's National Health And Medical Research Council provides the following Fluoride dietary recommendations.[121]

Table 3: Fluoride dietary recommendations from birth to 8 years old

Age	AI
0-6 months*	-
7-12 months*	0.5 mg/day
1-3 yr*	0.6 mg/day
4-8 yr*	1.1mg/day

Table 4: Fluoride dietary recommendations for children & adolescents

Age	AI
All	
Boys	
9-13 yr	2.0 mg/day
14-18 yr	3.0 mg/day
Girls	
9-13 yr	2.0 mg/day
14-18 yr	3.0 mg/day

Table 5: Fluoride dietary recommendations for adults

Age	AI
Men	
>19	4 mg/day
Women	
>19	3 mg/day

15.1.5.7 Manganese

As a start, we should emphasize that taking calcium along with zinc, and iron[122] as well as taking high levels of fat[123], can decrease the amount of manganese absorption; consequently, for a balanced manganese intake could be more adequate and safer to reference to the UL levels. UL daily levels of oral manganese are: *children 1 to 3 years, 2 mg; 4 to 8 years, 3 mg; 9 to 13 years, 6 mg; 14 to 18 years (including pregnant and breastfeeding women), 9 mg; for adults 19 years and older (including pregnant and breastfeeding women), 11 mg.*[124]

Among other attributes Manganese serves also as the cofactor of the glycosyltransferases necessary in the synthesis of proteoglycans that are needed for the formation of heal-thy cartilage and bone.[125] Rich natural-sources of Manganese are Cloves, Oats. Brown Rice, Garbanzo Beans, Spinach, Pineapple, Pumpkin Seeds, Rye, Tempeh, Soybeans; these foods provide respectively the following DRI values: Cloves 110%, Oats 83%, Brown Rice 77%, Garbanzo Beans 73%, Spinach 73%, Pineapple 67%, Pumpkin Seeds 64%, Rye 63%, Tempeh 63%, and Soybeans 62%.[126]

15.1.5.8 Zinc

The intake of dietary zinc causes an increase in bone mass and its deficiency results (among others) in bone growth retardation[127] affecting in this way foot bones as well. Dietary zinc is found abundantly in dairy products, fish, and oysters which are also very good sources of calcium and magnesium. Zinc is found also in protein-rich foods such as legumes, meat, poultry, whole grains, and nuts.

Daily UL levels for 0 to 6 months are 4 mg/day and for ages 7 to 12 months: 5 mg/day;1 to 3 years: 7.0 mg/day; 4 to 8 years: 12 4 mg/day; 9 to 13 years: 23 mg/day; 14 to 18 years: 34 mg/day; 19+ years: 40 mg/day.[128] Regardless of these UL doses, intakes *larger than 25 mg may cause anaemia ... copper deficiency*[129] cramps, diarrhea, gastric irritation, headaches, irritability, lethargy, etc.[130] For this reason, 23 mg/day can be considered as a safe daily dosage for ages 9 years and above unless there is the case of a confirmed zinc deficiency.

15.1.5.9 Iron

The AI for Iron infants 0-6 months is 0.2 mg/day; the EAR for infants 7-12 months is 7 mg/day; the EAR for children 1-8 years old is 4 mg/day; for ages 9-13 years the EAR is 6 mg/day; for ages 14-18 years the EAR is 8 mg/day. For males 19 years and older the EAR is 6 mg/day; for females 19-50 years old the EAR is 8 mg/day and after 50 years old decreases to 5 mg/day.[131] Foods rich in Iron include spinach, Broccoli, Tofu, Quinoa shellfish,[132] Shrimp, Clams, Scallops, Sweet potatoes Peas, String Beans, Beef, Lamb, Turkey, Chicken, Veal, Bran Cereals, Corn Meal, Tomato Products, Dried Peas, Dried Beans, Lentils, etc.[133]

15.1.5.10 Copper

Copper DRA values are as described in the table below.

Table 6: Recommended Dietary Allowance (RDA) for Copper[134]

Life Stage	Age	Males (µg/day)	(µg/day)
Infants	0-6 months	200 (AI)	200 (AI)
Infants	7-12 months	220 (AI)	220 (AI)
Children	1-3 years	340	340
Children	4-8 years	440	440
Children	9-13 years	700	700
Adolescents	14-18 years	890	890
Adults	19 years and older	900	900
Pregnancy	all ages	-	1,000
Breast-feeding	all ages	-	1,300

The main dietary sources of copper are nuts, organ meats, seafood, legumes, and vegetables… as well as *drinking water.*[135]

15.1.5.11 Boron

In a study conducted by Rainey et al. is reported that *daily dietary boron intakes were 0.75 mg for infants aged 0–6 months and 0.99 mg for infants aged 7–11 months.*[136] The UL of boron for children 1 to 3 years old, is 3 mg per day, for 4-8 years old, 6 mg per day; for 9-13 years old, the UL is 11 mg per day. On the other hand, the UL of Boron for adolescents 14 to 18 years of age and pregnant or breastfeeding women 14 to 18 years of age, is 17 mg per day.[137] Dietary boron is found abundantly in nuts,[138] fruit, seeds, stalks, barks, and leafy green vegetables.[139]

15.1.5.12 Vitamin A

Dietary Vitamin A comes is found as the preformed vitamin A and provitamin A carotenoids.[140] Vitamin A is found in foods from animal sources, including dairy products, fish … meat,[141] eggs, liver, halibut fish oil … and kidneys.[142]

Table 7:[143]

Life Stage	Age	Males: mcg/day (IU/day)	Females: mcg/day (IU/day)
Infants (AI)	0-6 months	400 (1,333 IU)	400 (1,333 IU)
Infants (AI)	7-12 months	500 (1,667 IU)	500 (1,667 IU)
Children	1-3 years	300 (1,000 IU)	300 (1,000 IU)
Children	4-8 years	400 (1,333 IU)	400 (1,333 IU)
Children	9-13 years	600 (2,000 IU)	600 (2,000 IU)
Adolescents	14-18 years	900 (3,000 IU)	700 (2,333 IU)
Adults	19 years and older	900 (3,000 IU)	700 (2,333 IU)
Pregnancy	18 years and younger	-	750 (2,500 IU)
Pregnancy	19 years and older	-	770 (2,567 IU)
Breast-feeding	18 years and younger	-	1,200 (4,000 IU)
Breast-feeding	19 years and older	-	1,300 (4,333 IU)

15.1.5.13 Vitamin K

Vitamin K is known widely as the coagulation vitamin due to its high contribution to the synthesis of some proteins (factors II, VII, IX and X) which facilitate blood coagulation. Blood coagulation is not the only contribution in which vitamin K plays an important role; vitamin K serves also as an essential cofactor in transforming anticoagulation and bone proteins into their biological active-form.[144] The bone (Vitamin K-dependent) proteins (osteocalcins)are among the most abundant bone-proteins[145] and play a pivotal role in bone formation,[146] and hip fracture prevention.[147]

Vitamin K is found abundantly in green leafy vegetables, scallions, cabbage, broccoli, Brussel Sprouts, cucumbers, prunes, etc.[148] The AI levels of vitamin K are as follows: infants 0-6 months 2.0 µg/day; infants 7-12 months 2.5 µg/day; children 1-2 years/old 25 µg/day; children 4-8 years/old 35 µg/day; 9-13 years/old 45 µg/day; 14-18 years/old 55 µg/day. AI of vitamin K level for females 19 years old and over is 60 µg/day, and the AI level for males 19 years old and over is 70 µg/day.[149]

15.1.5.14 Vitamin C

Vitamin C, (L-ascorbic acid), is a water-soluble essential vitamin well known for its attributes in reducing the symptoms of the common cold;[150] nevertheless vitamin C (AA) is also a *vital modulator of osteogenic and chondrogenic differentiation*… and its deficiency can cause *spontaneous fracturing, impaired bone growth and impaired* *bone healing.*[151] Some of the richest Vitamin C - foods *are guavas, bell peppers, kiwifruit, strawberries, oranges, papayas, broccoli, tomatoes, kale, and snow peas.*[152]

Table 8: Recommended Dietary Allowances (RDA) for Vit. C [153]

Age	Male	Female	Pregnancy	Lactation
0–6 months	40 mg*	40 mg*		
7–12 months	50 mg*	50 mg*		
1–3 years	15 mg	15 mg		
4–8 years	25 mg	25 mg		
9–13 years	45 mg	45 mg		
14–18 years	75 mg	65 mg	80 mg	115 mg
19+ years	90 mg	75 mg	85 mg	120 mg
Smokers	Individuals who smoke require 35 mg/day more vitamin C than nonsmokers.			

15.1.5.15 Vitamin B Complex

B Vitamins (otherwise known as Vitamin B Complex) are a group of eight vitamins: B1 (thiamin), B2 (riboflavin), B3 (niacin), B5 (pantothenic acid), B6 (pyridoxine), B7 (biotin), B9 (folic acid) and B12 (cobalamin).[154] Vitamin B deficiency can result as a risk factor for decreased bone[155] and muscular health with such consequences as hip fracture(s),[156] [157] osteoporosis,[158] and sarcopenia.[159]

Vitamin B is found abundantly in brown rice, barley, millet, red meat, poultry, fish, eggs, milk, cheese, beans, lentils, sunflower seeds, almonds, citrus fruits, avocados, bananas and dark leafy vegetables such as broccoli, spinach and kai lan.[160]

Recommendations for B vitamin RDA/AI levels are as follows: Thiamin - for infants and kids up to four years old 0.5/0.7 mg/day; for ages above 4 years old 1.5 mg/day. Riboflavin - for infants and kids up to four years old 0.6/0.8 mg/day; for ages above 4 years old 1.7 mg/day. Niacin - for infants and kids up to four years old 8/9 mg/day; for ages above 4 years old 20 mg/day. Pantothenic acid - for infants and kids up to four years old 3/5 mg/day; for ages above 4 years old 10 mg/day.[161]

Pyridoxine RDA and AI recommendations for infants and kids up to four years old are 0.1–0.3/0.5 mg/day; Pyridoxine recommendation for kids above 4 years old is 2 mg/day. Biotin - for infants and kids up to four years old 50/150 mcg/day; for ages above 4 years 300 mcg/day. Folic acid - for infants and kids up to four years old 100/200 mcg/day; for ages above 4 years 400 mcg/day. Vitamin B12 - 2/3 mcg/day; for ages above 4 years 6 mcg/day.[162]

Vitamin B recommendations for women who are pregnant or nursing are as follows: Thiamin - 1.7 mg/day; Riboflavin - 2.0 mg/day; Niacin - 20 mg/day; Pantothenic acid - 10 mg/day; Pyridoxine - 2 mg/day; Biotin - 300 mcg/day; Folic acid - 800 mcg/day; Vitamin B12 - 8 mcg/day.[163]

1.2 Surgical Treatment

There are several types of surgical interventions for FF treatment; these interventions include: Lateral Column Lengthening, Medial Column Stabilization (Arthrodesis), Medial Cuneiform Opening Wedge

Osteotomy, First Tarsal-Metatarsal Fusion,[164] Medialized Calcaneal Osteotomy, Tibialis Posterior Tendon Reconstruction,[165] Synovectomy, Tendon Transfer, Excision, and Arthroereisis. Some of these interventions are performed concurrently to ensure a successful outcome and/or to address other present deformities (apart from FF ones).

15.2.1 Lateral Column Lengthening

To have a better idea of this procedure, it is adequate to know first some anatomic and structural details of its structure. Lateral Column along with the Middle, and Medial ones, compose the triple-column structure of tarso-metatarsal joints which in themselves are part of the midfoot joints. The lateral column is composed by the fourth and the fifth metatarsal as well as the cuboid bone.

The lateral column is lengthened by inserting a bone graft wedge in the front of the heel bone which is cut beforehand.[166] The bone graft (usually between 4-12 mm in length)[167] could be taken from the patient's hip bone, iliac crest, a cadaver or another source (such as artificial graft). This procedure is performed especially for FF with a flat pitch angle of calcaneovalgus deformities[168] and it is offered quite random concurrently with calcaneal osteotomy.[169]

The first six weeks the patient needs to walk with crutches in non-weight-bearing (especially at the heel); the next 6 weeks the patient can walk with crutches weightbearing (including the heel).

Total recovery can take up to 18 months and *will require physiotherapy to help with the rehabilitation process.*[170]

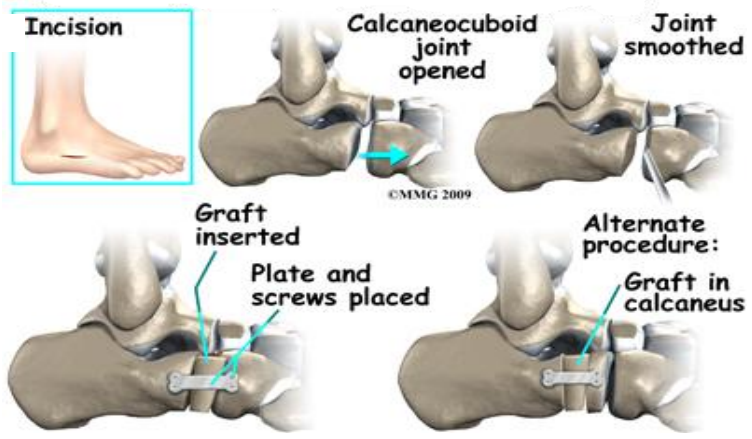

Fig. 32 Lateral Column Lengthening Poster Courtesy by eOrthopod.com

15.2.2 Medial Column Stabilization (through Arthrodesis)

The medial column is composed by the first metatarsal, medial cuneiform and the navicular bone. Arthrodesis is the immobilization (by fusion) of two or more bones over their joints. Medial arthrodesis it is done over a single-joint it or over multiple ones; the single-joint medial arthrodesis procedures are: navicular-medial cuneiform arthrodesis and medial cuneiform-first metatarsal arthrodesis.

More complex arthrodesis can be a combination of single-joint medial arthrodesis procedures and even the inclusion of a talonavicular arthrodesis. All these methods have a common denominator: stabilization of the medial column by supporting and recreating the longitudinal arch; these procedures are less invasive compared to triple arthrodesis and are becoming more and more popular[171] use randomly single molded plates over foot's plantar surface.[172]

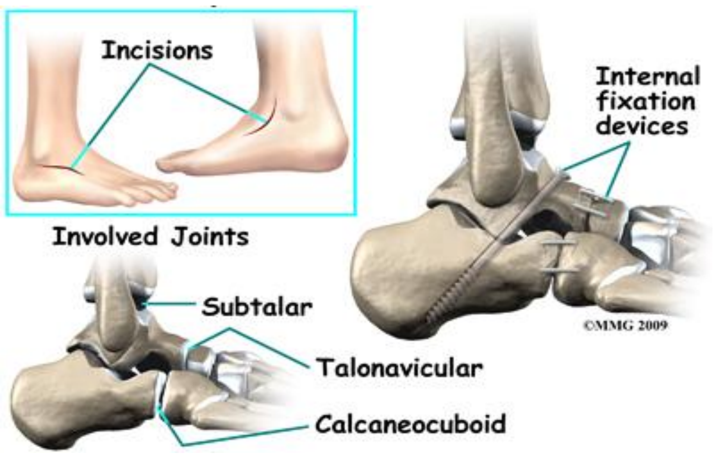

Fig. 33 Triple Arthrodesis Poster Courtesy by eOrthopod.com

15.2.3 Medial Cuneiform Opening (Wedge Osteotomy)

Medial Cuneiform Opening Wedge Osteotomy is called also Cotton Osteotomy; in this procedure a bone wedge is placed over the top of the medial cuneiform. After this placement, a fixation by screw can be done or a press fit non-fixation technique can be applied; both methods are found effective in the treatment of AAFF.[173]

15.2.4 First Tarsal-Metatarsal Fusion

First Tarsal-Metatarsal Fusion is a procedure very similar to Cotton Osteotomy; this procedure is performed in the midfoot not only to correct FF deformities, but also to treat different types of Arthritis and joint damage. After performing an outer incision (3-4 cm), some joints' surfaces are reshaped, removed, and fused together by pins, staples or screws. After surgery a below the knee (up to the toes) plaster is applied; the patient will walk with crutches and plaster without bearing any weight on the affected foot for the first two weeks.[174]

After the second week, the patient can bear half weight on the affected foot and continue to walk on crutches and plaster. After eight weeks from surgery the patient can bear full weight with plaster and no need of crutches. After 12 weeks if the fusion has consolidated, the plaster is taken off and the patient is considered fully recovered. If the fusion has not consolidated, plaster can be held an additional month or replaced by a post-surgery moon boot.[175]

15.2.5 Medializing Calcaneal Osteotomy

Medialized Calcaneal Osteotomy is an extra-articular, joint-sparing procedure[176] where calcaneus is cut and shifted inward.[177] This procedure is used not only for the correction of the FF deformity, but also in the correction of the cavo-varus deformity.[178] After the inward shift of calcaneus securing the hindfoot alignment a plate or screws are used to fix the calcaneus in the corrected ortho-position.

After the surgery, a splint, cast or moon boot is held for up to 6 weeks while the patient should walk with crutches and without bearing any weight on the affected foot. After the sixth week, the patient can bear weight progressively as the condition improves and edema decreases considerably;[179] at this time the cast can be taken off and the patient can begin partial weight bearing on crutches or a walker. Normal shoe wear can start 8 or 10 weeks after surgery and after eight weeks full recovery can occur.[180]

A restart of regular daily activities can take six to twelve months and the process can be facilitated and accelerated through ankle-stretching and strengthening exercises; other helpful exercises be will be the strengthening exercises for the calf, gluteus maximus, glut medium, as well as quality of gait pattern.[181]

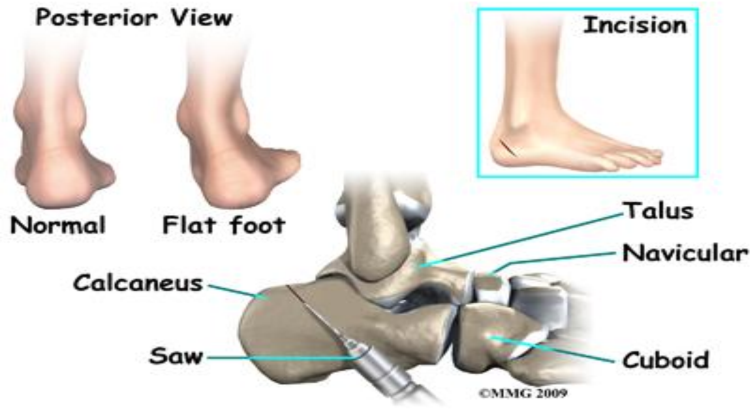

Fig. 34 Calcaneal Osteotomy Poster Courtesy by eOrthopod.com

15.2.6 Tibialis Posterior Tendon Reconstruction

TPTR is prescribed as surgical intervention when the patient has a severe grade of FF and other conservative treatments have either failed, either proved insufficient. In this case the Tibialis Posterior Tendon (TTP) is strengthened by the use of another tendon (e.g. flexor digitorum longus); other tendons help the small joints of the toes to bend… and so the TTP *is not really missed when it is used.*[182] In some other cases the TTP has to be removed due to its excessive thickness and/or tear; this procedure will be discussed in the Tenonectomy section.

Post-operatively it is important that the foot is kept elevated for the first three days while the dressings are kept dry and intact. The patient should wear a boot or plaster for 6 weeks while bearing the weight in back slab touch for the first 2 weeks and in Aircast walking boot, partial weight bearing (up to 30 kgs.), for 4 weeks. After six weeks the patient can start physical therapy; in six to nine months can return to most of the activities[183] while a full recovery can be expected in approximately 10-12 months.

15.2.7 Synovectomy

During this procedure the tendons' protective covering (the synovial sheaths) are removed. The removal of the synovial covering will ease the respective inflammation.

15.2.8 Tendon Transfer

In different cases the transfers of flexor digitorum longus (FDL) and flexor hallucis longus (FHL) have brought considerable positive results; in some instances, *a peroneus brevis transfer is typically used to supplement small FDL or FHL transfer donors or in revision...*[184]

15.2.9 Excision

In some cases when younger patients experience painful spasmodic flat foot of recent origin the excision of the calcaneo-navicular bar is a justifiable procedure...[185]

15.2.10 Double and Triple Arthrodesis

There are two types of arthrodesis: double and triple. Triple arthrodesis is the surgical fusion of calcaneocuboid (CC) talocalcaneal (TC), and talonavicular (TN) foot joints. On the other hand, double arthrodesis excludes from such a fusion the calcaneocuboid joint. The surgical procedures of double and triple arthrodesis are used as a last resort to correct stiff and nonflexible flatfoot. Even though both of these interventions have been proven effective, *triple arthrodesis has been advocated for significant hindfoot deformity that is irreducible.*[186]

Different studies have shown satisfactory results of double and triple arthrodesis in function of gait improvement,[187,188] and pain reduction.[189] After surgery there will be necessary 6-8 weeks of no weight bearing, and the ankle will have a well-sustained union in 12-14 weeks.[190] Arthrodesis' complications include *bone and/or soft-tissue infection, wound dehiscence, and failure of fixation.*[191] *Failure of fixation* or a non-union is greater for double arthrodesis,[192] while the talonavicular joint was *the most likely joint to obtain nonunion in triple arthrodesis subjects.*[193]

15.2.11 Arthroereisis

Arthroereisis is an ankle surgery that restricts excessive subtalar joint motion (for a ROM up to 5%) ... *while preserving joint functionality;*[194] this is the reason why it has been called also Subtalar Arthroeresis or Subtalar Joint Arthroeresis (STA). STA is considered *as a minimally-invasive, effective and low-risk procedure in the treatment of flatfoot… in* both *children* and *adults*; STA can be *a standalone or adjunctive procedure, and is indicated in the treatment of flexible flatfoot, tibialis posterior tendon dysfunction, tarsal coalition and accessory navicular syndrome.*[195]

It is important to underline (and clarify) that STA is entirely an extra-articular procedure that can be performed since the age of three, with the child getting (even) a number 6 or 7 stent[196] inserted into the main axis of the sinus tarsi[197] with the device supposed to remain permanently in its insertion place. STA will work best as a standalone surgery for mild and moderate cases of FF while more severe (FF) cases *are better served with a combination of arthroereisis and rearfoot reconstructive procedures.*[198]

STA for FF can be performed using different devices some of which are listed in the following table:[199]

Table 9: Classification of Arthroereisis Devices

Device Type	Named Example
Silicone non bespoke	Swanson™
Silicone bespke	Viladot™
Seated (within calcaneus)	STA-peg™ Koning™
Free floating bioresorbable	Giannini
Free floating non resorbable	MBA™ Kalix™ Hyprocure™

STA is performed generally as an outpatient surgery or with an overnight stay; a splint is applied and the patient should hold it for six weeks while mobilizing in a non-weightbearing mode (for the affected foot). After this period the patient can walk bearing partial weight in a walking boot up to the third month post-surgery. After three months full weight-bearing is allowed while the patient wears *a lace-up or stirrup ankle brace* and *full recovery may take up to 1 year.*[200]

STA stent complications and removal rates differ between absorbable and non-absorbable materials. Complications and removal rates for all STA stents in children can range, respectively from 4.8% to 18.6% and 7.1% and 19.3%.[201] On the other hand the removal rates for STA stents in adults can be higher (~22%),[202] and the total removal rates can rage between 30% and 40%.[203] Nonetheless STA has proven to be an effective and simple way to treat FF in both adults[204] and children.[205,206]

2. Conclusions

As in all rehab and especially in the orthopedic one, conservative treatment is more than worthy; it is supposed to be the avant-garde of treatment and care. Since our bodies are created in a wonderfully interwoven way of internal dynamics, then all our body's problems should be treated as holistically as possible. Even though the evidence for the success of holistic treatment in regard to FF treatment still needs to be scientifically proven, it is quite distant clinically from being harmful.

Since FF conservative treatment is not harmful and its use as a start-up has proven to be effective (at least in symptoms' relieve, then it is safe to conclude that FF conservative treatment is a wise choice with due discretion in all FF cases. This due discretion consists in choosing the right means and extent of FF conservative treatment; in some cases, exercises might be the only part which should be addressed; in some other cases, a more thorough and holistic approach should be taken. All these measures depend directly from the specific condition of each affected patient.

Apart from the effectiveness of the conservative treatment, another conclusion that can be drawn from this study is that: persistence and adherence to the therapeutic regime play a vital role in the good prognosis of FF. Muscular mass gain and especially strengthening of Tibialis Posterior, Tibialis Anterior, Digitorum Longus, and Flexor Hallucis Longus muscles through respective exercises play a crucial role in restraining further collapse of MLA and ankle pronation; in certain cases strengthening exercises combined with stretch and release exercises have proven very effective in preventing and treating FF.

The adherence to wearing regularly specific-orthopedic-shoes as well as off-the-shelf or CMIs has proven to be a determining factor in mild and moderate FF cases that underwent treatment from very early and early stages. The gradual increase of the MLA's altitude in MCIs and specific FF shoes is one factor that has shown to make a difference in the progressive decrease of FF symptoms, such as tiredness and pain; the step by step increase of MLA height and short foot exercises have also shown to be one important factor in contributing to the permanent arch increase of the FF patients.

The use of orthotics has shown beneficiary and especially the treatment with SMOs. Accommodative-SMOs in cases of mild FF deformities have proven to be gratifyingly corrective and comfortable. In moderate FF deformities, semi-rigid FF SMOs protect and cushion the foot, while providing simultaneously support, control, and well-balanced weight redistribution. In cases of severe FF deformity, the use of rigid-FF-SMOs (made of carbon fiber or thermoplastic) offers the steadiest arch support even though their comfort is of the lowest degree compared with the accommodative and semi-rigid SMO's.

The intake and maintenance of adequate levels of some specific Vitamins and Minerals which have proven substantial to the overall bone health can affect positively the treatment of FF patients which otherwise suffer bad musculoskeletal health. The appropriate intake of Protein, Calcium, Phosphorus, Potassium, Magnesium, Manganese, Copper, Iron, Fluoride, Boron, as well as the proportional intake of Vitamin A, C, B-Complex, D, and K, can become a safety cushion in the conservative treatment of FF.

When all the conservative treatment measures have not yielded their desired results, surgical intervention is used as the last resort. Surgical intervention is prescribed generally for Grade III FF-patients whose deformity is of a rigid nature and symptomatic. The surgery method is chosen by orthopedic surgeons after a thorough medical evaluation; this evaluation includes determination of the specific etiology, symptoms, needs, potential complications, and projected outcome(s) for each affected individual.

17. Acknowledgments

I thank first and above all God the Almighty for His strength, wisdom, and guidance in the accomplishment of this dissertation thesis. Second, I would like to thank my dear and devoted wife Dr. Valbona ILJAZI, for her unwavering and compassionate support. I would like to thank also my father Dr. Harun ILJAZI and our family's friend Dr. Artid DUNI for their valuable counsels and mentorship throughout the project.

18. Conflicts of Interests

There are not any conflicts of interests to declare

19. References

1 Specialties, sub-specialties and progression through training the international perspective. (2011, August). Retrieved May 9, 2019, from https://www.gmcuk.org/static/documents/content/Specialties_subspecialties_and_progression_through_training___the_international_perspective.pdf_45500662.pdf

2 Rehabilitate. (n.d.). Retrieved May 9, 2019, from https://www.merriam-webster.com/dictionary/rehabilitate

3 Matthew., The apostle (Ed.). (n.d.). Gospel according to Matthew. Retrieved May 14, 2019, from https://www.biblegateway.com/passage/?search=Matthew%2019:26&version=NKJV

4 Robinson, F. (n.d.). The Flat Foot. Retrieved May 8, 2019, from http://www.cambridgefootandankle.com/flat-foot.shtml

5 Hunter, G., Dr. (2002, June). Pes Planus [Flat Foot]. Retrieved May 8, 2019, from http://www.wsiat.on.ca/tracITDocuments/MLODocuments/Discussions/pes_planus.pdf

6 Flat Feet. (n.d.). Retrieved May 9, 2019, from https://www.thefootdocs.com/services/flat-feet

7 Nambiar, Satheesha & Alagesan, Jagatheesan. (2017). Prevalence and incidence of flat foot among Middle East and Asian Population:An Overview. *International Journal of Pharmaceutical Sciences and Health*. 7. 1-12.

8 Flatfoot. (2017, April). Retrieved May 13, 2019, from https://www.seattlechildrens.org/pdf/PE1235.pdf

9 Mosca, V. S. (2010). Flexible flatfoot in children and adolescents. *Journal of Children's Orthopaedics*, *4*(2), 107–121.

10 Pourghasem, Mohsen & Kamali, Nematollah & Farsi, Mir & Soltanpour, Nabiollah. (2016). Prevalence of flatfoot among school students and its relationship with BMI. *Acta Orthopaedica et Traumatologica Turcica*. 50(5)

11 P,. Rithanya, T,.Babu, K,. Ganesh, K,. Assessment of Plantar Arch Index and Prevalence of Flat Feet among South Indian Adolescent Population. J. Pharm. Sci. & Res. Vol. 9(4), 2017, 491

12 Vergara-Amador, Enrrique, Serrano Sánchez, Rafael Fernando, Correa Posada, Juan Rafael, Molano, Adriana Carolina, & Guevara, Oscar A. (2012). Prevalence of flatfoot in school between 3 and 10 years. Study of two different populations geographically and socially. *Colombia Médica*, *43*(2), 141-146. Retrieved May 12, 2019

13 Evans AM, Rome K. A Cochrane review of the evidence for non-surgical interventions for flexible pediatric flat feet. *Eur J Phys Rehabil Med*. 2011 Mar;47(1):69-89.

14 Mosca VS. Flexible flatfoot in children and adolescents. *Journal of children's orthopaedics* 2010;4(2):107–121.

15 Yoo WJ, Chung CY, Choi IH, Cho TJ, Kim DH. Calcaneal lengthening for the planovalgus foot deformity in children with cerebral palsy. J Pediatr Orthop. 2005;25:781–785.

16 Buchanan, M., MD. (2016, June 7). Pes Planus (Flatfoot) (G. C. Berlet MD, FRCSC, FAOAO & A. E. Johnson MD, FAOA, FACS, Eds.). Retrieved May 16, 2019, from
https://emedicine.medscape.com/article/1236652-overview?pa=OeC3RvJjW4MwGplDn7cyisfLJiKxxW/9fKZRjmimoXhTxdi8vlPi4ue5sVZwL1nQ56MI7dGTgNawPfsOtJla9Q

17 Van Boerum DH, Sangeorzan BJ. Biomechanics and pathophysiology of flat foot. *Foot Ankle Clin.* 2003 Sep;8(3):419-30.

18 B. (Ed.). (n.d.). Flat feet. Retrieved May 14, 2019, from https://www.bofas.org.uk/Patient-Information/Flat-feet

19 Wilson, M. J., Mr, & Body, W., Mr. (2008, September). Pes Planus. Retrieved May 13, 2019, from

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/384538/pes_planus.pdf

20 Evans A. M. (2011). The paediatric flat foot and general anthropometry in 140 Australian school children aged 7 - 10 years. *Journal of foot and ankle research*, *4*(1), 12.

21 Flat feet. (2018, September 18). Retrieved May 17, 2019, from https://www.nhs.uk/conditions/flat-feet/

22 M. (2018, April 24). Flatfeet. Retrieved May 17, 2019, from https://www.mayoclinic.org/diseases-conditions/flatfeet/symptoms-causes/syc-20372604

23 E Lee, W. (2001). Podiatric Biomechanics: An historical appraisal and discussion of the root model as a clinical system of approach in the present context of theoretical uncertainty. *Clinics in podiatric medicine and surgery.* 18. 555-684; discussion 685.

24 B. (Ed.). (n.d.). Flat feet. Retrieved May 14, 2019, from https://www.bofas.org.uk/Patient-Information/Flat-feet

25 Nordqvist, C. (2018, July 27). Flat feet: Symptoms, exercises, diagnosis, and treatment (W. Morrison MD, Ed.). Retrieved May 10, 2019, from https://www.medicalnewstoday.com/articles/168608.php

26 Moyer, C. (2019, March 17). How Flat Feet or Pes Planus Can Be Treated (R. N. Fogoros MD, Ed.). Retrieved May 17, 2019, from https://www.verywell.com/flat-feet-causes-and-associated-medical-problems-1337682

27 Portinaro, N., Prof. (n.d.). Calcaneovalgus Foot - Prof. Nicola Portinaro - Orthopedic Suregon. Retrieved May 17, 2019, from https://www.nicolaportinaro.com/calcaneovalgus-foot/

28 ACFAS. Accessory Navicular Syndrome. Retrieved May 17, 2019, from https://www.foothealthfacts.org/conditions/accessory-navicular-syndrome-(1)#

29 Denormandie, P., Payet, E., Pansard, E., Schnitzler, A., Mailhan, L., Genet, F., Causes of flat foot valgus original proposal central and neurological therapy. *Annals of Physical and Rehabilitation Medicine* Volume 56, Supplement 1, October 2013, Page e392

30 Fahim, Ramy & Thomas, Zachary & A Didomenico, Lawrence. (2013). Pediatric Forefoot Pathology. Clinics in podiatric medicine and surgery. 30. 479-90.

31 James. (2013, July 9). The Difference Between Flat Feet and Overpronation. Retrieved May 17, 2019, from https://www.fixflatfeet.com/the-difference-between-flat-feet-and-overpronation/

32 Hintermann, Beat & Nigg, Benno. (1998). Pronation in runners. Implications for injuries. Sports medicine (Auckland, N.Z.). 26. 169-76.

33 Flat Feet Pain Treatment & Symptoms. (n.d.). Retrieved May 17, 2019, from https://www.afacc.net/foot-problems/flat-foot/

34 American College of Foot and Ankle Surgeons. (n.d.). Accessory Navicular Syndrome. Retrieved May 10, 2019, from https://www.foothealthfacts.org/conditions/accessory-navicular-syndrome-(1)

35 Downey, D. J., Simkin, P. A., Mack, L. A., Richardson, M. L., Kilcoyne, R. F., & Hansen, S. T. (1988). Tibialis posterior tendon rupture: A cause of rheumatoid flat foot. *Arthritis & Rheumatism,31*(3), 441-446. doi:10.1002/art.1780310319

36 Edwards, J. (n.d.). Pes Planus - Flat Feet. Retrieved May 17, 2019, from https://physioworks.com.au/injuries-conditions-1/pes-planus-flat-feet

37 Acquired Adult Flatfoot Deformity. (n.d.). Retrieved May 17, 2019, from http://legacy.aofas.org/footcaremd/conditions/ailments-of-the-midfoot/Pages/Acquired-Adult-Flatfoot-Deformity.aspx

38 Lee M.S., Vanore J.V., Thomas J.L., Catanzariti A.R., Kogler G., Kravitz S.R., Miller S.J., Gassen S.C. *Diagnosis and treatment of adult flatfoot*. J. Foot Ankle Surg. 2005; 44:78–113

39 Gross, K. D., Felson, D. T., Niu, J., Hunter, D. J., Guermazi, A., Roemer, F. W., … Hannan, M. T. (2011). Association of flat feet with knee pain and cartilage damage in older adults. *Arthritis care & research*, *63*(7), 937–944.

40 Ip, D. (2007). Orthopedic Rehabilitation, Assessment, and Enablement. Orthopedic Rehabilitation, Assessment, and Enablement. 1-647. 10.1007/978-3-540-37694-1.

41 Garcı́a-Rodrı́guez, A., Martı́n-Jiménez, F., Carnero-Varo, M., Gómez-Gracia, E., Gómez-Aracena, J., & Fernández-Crehuet, J. (1999, June 01). Flexible Flat Feet in Children: A Real Problem? Retrieved May 18, 2019, from https://pediatrics.aappublications.org/content/103/6/e84.full

42 Kennedy, S., BEng (Mech), CPed. (2018, February). CONDUCTING A BIOMECHANICAL EVALUATION, PART II. *The O&P EDGE*.

43 Redmond, A. C., Crane, Y. Z., & Menz, H. B. (2008). Normative values for the Foot Posture Index. *Journal of foot and ankle research*, *1*(1), 6. doi:10.1186/1757-1146-1-6

44 Maxey, L., & Magnusson, J. (2013). *Rehabilitation for the postsurgical orthopedic patient*(3rd ed.). St. Louis, MO: Elsevier.

45 Davis. R. B., Õunpuu. S., DeLuca. P., Romness. Mark. J. Clinical Gait Analysis and Its Role in Treatment Decision-Making - *Medscape - Sep 01, 1999.*

46 Diasu | Myoton III. (n.d.). Retrieved May 18, 2019, from https://sanicorporate.wixsite.com/diasu/myoton-iii

47 Zhou, B., Tang, K., & Hardy, M. (2014, December 14). Talocalcaneal coalition combined with flatfoot in children: Diagnosis and treatment: A review. Retrieved May 18, 2019, from https://josr-online.biomedcentral.com/articles/

48 Cozen LN. Prevention of Flat Feet. *California and Western Medicine*. 1941;55(1):6.

49 Donn, L. (n.d.). Foot Binding Ancient China for Kids. Retrieved May 14, 2019, from https://china.mrdonn.org/footbinding.html

50 Hollander K, de Villiers JE, Sehner S, Wegscheider K, Braumann KM, Venter R, Zech A. Growing-up (habitually) barefoot influences the development of foot and arch morphology in children and adolescents. *Sci Rep 2017*; 7: 8079

51 Lowth, M., Dr. (2016, January 19). Pes Planus (Flat Foot). Learn about Pes Planus (PP). (J. Cox Dr, Ed.). Retrieved May 14, 2019, from https://patient.info/doctor/pes-planus-flat-feet

52 Luciani, E., Dr. (2017, May 14). Flatfoot. Retrieved May 14, 2019, from https://www.osteofisioluciani.com/en/blog/flatfoot-rome-osteopathy

53 Blitz, N., Dr. (2016, March 26). Flat Foot... Retrieved May 14, 2019, from https://bunionsurgeryny.com/procedures/flat-foot-surgery/

54 Milgrom, Charles & Giladi, Michael & Stein, M & Kashtan, H & Y Margulies, J & Chisin, Roland & Steinberg, R & Aharonson, Z. (1985). Stress fractures in military recruits. A prospective study showing an unusually high incidence. *The Journal of bone and joint surgery. British volume. 67*. 732-5.

55 Evans, Angela. (2007). The flat-footed child - To treat or not to treat - What is the clinician to do?. Journal of the American Podiatric Medical Association. 98. 386-93.

56 Halabchi, F., Mazaheri, R., Mirshahi, M., & Abbasian, L. (2013). Pediatric flexible flatfoot; clinical aspects and algorithmic appro-ach. *Iranian journal of pediatrics*, *23*(3), 247-60.

57 Skills for Action. (2016, June). Retrieved May 14, 2019, from https://skillsforaction.com/flat-feet

58 Alvarez, R. G., Marini, A., Schmitt, C., & Saltzman, C. L. (2006). Stage I and II Posterior Tibial Tendon Dysfunction Treated by a Structured Nonoperative Management Protocol: An Orthosis and Exercise Program. *Foot & Ankle International*, *27*(1), 2–8.

59 Kornelia Kulig, Stephen F Reischl, Amy B Pomrantz, Judith M Burnfield, Susan Mais-Requejo, David B Thordarson, Ronald W Smith; Nonsurgical Management of Posterior Tibial Tendon Dysfunction With Orthoses and Resistive Exercise: A Randomized Controlled Trial, *Physical Therapy*, Volume 89, Issue 1, 1 January 2009, 26–37.

60 Lee D-B, Choi J-D. The Effects of Foot Intrinsic Muscle and Tibialis Posterior Strengthening Exercise on Plantar Pressure and Dynamic Balance in Adults Flexible Pes Planus. *Physical Therapy Korea.* 2016;23(4):27-37.

61 Kian. (2019, April 11). Fix Flat Feet & Fallen Arches (Best Methods, Tips & Exercises). Retrieved May 15, 2019, from https://www.drbodygadget.com/flat-feet/

62 Kim EK, Kim JS. The effects of short foot exercises and arch support insoles on improvement in the medial longitudinal arch and dynamic balance of flexible flatfoot patients. *J Phys Ther Sci*. 2016;28(11):3136-3139.

63 Moon DC, Kim K, Lee SK. Immediate Effect of Short-foot Exercise on Dynamic Balance of Subjects with Excessively Pronated Feet. *J Phys Ther Sci*. 2014;26(1):117-9.

64 Janda V, VaVrova M: Sensory motor stimulation. In: Liebenson C (Ed.), Rehabilitation of the Spine. Baltimore: Williams & Wilkins, 1996, pp 319–328.

65 Brockett CL, Chapman GJ. Biomechanics of the ankle. *Orthop Trauma*. 2016;30(3):232-238.

66 Foot and Ankle Conditioning Program - OrthoInfo - AAOS. (2012, October). Retrieved May 15, 2019, from https://orthoinfo.aaos.org/en/recovery/foot-and-ankle-conditioning-program/

67 Wellons, J. (n.d.). Exercises to Correct Flat Feet in Adults. Retrieved May 15, 2019, from https://www.livestrong.com/article/416886-exercises-to-correct-flat-feet-in-adults/

68 Network, H. M. (Ed.). (2015, April 13). Plantar aponeurosis. Retrieved May 15, 2019, from https://www.healthline.com/human-body-maps/plantar-aponeurosis#1

69 Huang, C.-K., Kitaoka, H. B., An, K.-N., & S., E. Y. (1993). Biomechanical Evaluation of Longitudinal Arch Stability. *Foot & Ankle*, *14*(6), 353–357.

70 Wong, M. (2019, January 23). How to fix Flat Feet (Pes planus). Retrieved May 15, 2019, from http://posturedirect.com/how-to-fix-flat-feet/

71 *Walczak M, Napiontek M.* Flexible flatfoot in children--a controversial subject. *Chir Narzadow Ruchu Ortop Pol. 2003; 68(4):261-7.*

72 Kanatlı U, Aktas E, Yetkin H . Do corrective shoes improve the development of the medial longitudinal arch in children with flexible flat feet? *J Orthop Sci 2016*;21:662-666.

73 Price CT. Shoes don't "cure" flatfeet. *J Fla Med Assoc* 1982;69:853-7.

74 T Staheli, L & Giffin, L. (1980). Corrective shoes for children: A survey of current practice. Pediatrics. 65. 13-7.

75 Penneau, K., Lutter, L. D., & Winter, R. D. (1982). Pes Planus: Radiographic Changes with Foot Orthoses and Shoes. *Foot & Ankle*, *2*(5), 299–303.

76 IDEM with 75

77 Murphy RF, Mooney JF. Orthobiologics in Pediatric Orthopedics. The Orthopedic Clinics of North America. *48: 323-331*.

78 E.Toullec Orthopaedics & Traumatology: Surgery & Research, Volume 101, Issue 1, Supplement, February 2015, Pages S11-S17

79 Miller-Keane Encyclopedia and Dictionary of Medicine, Nursing, and Allied Health, Seventh Edition.

80 Jeong, B. O., Baek, J. H., & Song, W. (2017). Changes in the Ankle Joint and Hindfoot Alignment Following Varus Deformity Correction of the Knee with Total Knee Arthroplasty. *Foot & Ankle Orthopaedics*.

81 Cornwall MW, McPoil TG. Footwear and foot orthotic effectiveness research: a new approach. *J Orthop Sports Phys Ther.* 1995;21

82 Kulcu, D. G., Yavuzer, G., Sarmer, S., & Ergin, S. (2007). Immediate Effects of Silicone Insoles on Gait Pattern in Patients with Flexible Flatfoot. *Foot & Ankle International*, *28*(10), 1053–1056

83 Kido, M., Ikoma, K., Hara, Y., Imai, K., Maki, M., Ikeda, T., Fujiwara, H., Tokunaga, D., Inoue, N., … Kubo, T. (2014). Effect of therapeutic insoles on the medial longitudinal arch in patients with flatfoot deformity: a three-dimensional loading computed tomography study. *Clinical biomechanics (Bristol, Avon)*, *29*(10), 1095-8.

84 Takata, Y., Matsuoka, S., Okumura, N., Iwamoto, K., Takahashi, M., & Uchiyama, E. (2014). Standing balance on the ground -the influence of flatfeet and insoles. *Journal of physical therapy science*, *25*(12), 1519-21.

85 Chen, YC, Lou, SZ, Huang, CY. Effects of foot orthoses on gait patterns of flat feet patients. Clin Biomech 2010; 25: 265–270.

86 NVOS-Orthobanda. ORTHOPEDISCHE SCHONTEKNIEK. Boek 6: Orthopedische schoenvorzieningen. Uitgeverij De dienst 2002

87 What is Alginate? (n.d.). Retrieved May 15, 2019, from https://dalchem.com.au/how-to/what-is-alginate

88 What is Alginate? (n.d.). Retrieved May 18, 2019, from https://accu-cast.us/alginates/all-about-alginate/what-is-alginate/

89 Lifecasting Questions. (n.d.). Retrieved May 18, 2019, from https://www.reynoldsam.com/category/faqs/lifecasting-questions/

90 Zifchock RA, Davis I. A comparison of semi-custom and custom foot orthotic devices in high and low arched individuals during walking. *Clin Biomech 2008*;23(10):1287-1293

91 Functional and Accommodative Foot Orthoses. (n.d.). Retrieved May 15, 2019, from http://www.podiatrynetwork.com/common-disorders/205-functional-and-accommodative-foot-orthoses

92 Janisse, D.J., Janisse E. Shoe modification and the use of orthoses in the treatment of foot and ankle pathology. *J Am Acad Orthop Surg.* 2008;16(3):152–58.

93 IDEM with 88

94 Plastics for Orthotics & Prosthetics. (2017). Retrieved May 15, 2019, from https://www.curbellplastics.com/Research-Solutions/Technical-Resources/Technical-Resources/Plastics-for-Orthotics-Prosthetics

95 Wadolowska, L., Sobas, K., Szczepanska, J. W., Slowinska, M. A., Czlapka-Matyasik, M., & Niedzwiedzka, E. (2013). Dairy products, dietary calcium and bone health: possibility of prevention of osteoporosis in women: the Polish experience. *Nutrients*, *5*(7), 2684-707.

96 Master, W. (n.d.). Dairy Nutrition Facts. Retrieved May 15, 2019, from https://www.midwestdairy.com/nutrition-and-health/dairy-nutrition/

97 Dairy and alternatives in your diet. (2018, January 6). Retrieved May 15, 2019, from https://www.nhs.uk/live-well/eat-well/milk-and-dairy-nutrition/

98 Michael B Zemel; Role of calcium and dairy products in energy partitioning and weight management, *The American Journal of Clinical Nutrition*, Volume 79, Issue 5, 1 May 2004, Pages 907S–912S,

99 Karimi, M. T., Fereshtehnejad, N., & Pool, F. (2013). The Impact of Foot Insole on the Energy Consumption of Flat-Footed Individuals During Walking. *Foot & Ankle Specialist*, *6*(1), 21–26.

100 Milk and Milk Products (Dairy Products). (2015, February 16). Retrieved May 15, 2019, from

https://www.myvmc.com/lifestyles/milk-and-milk-products-dairy-products/

101 Jennings, K., MS, RD. (2018, July 27). Top 15 Calcium-Rich Foods (Many Are Non-Dairy). Retrieved May 15, 2019, from https://www.healthline.com/nutrition/15-calcium-rich-foods#section13

102 Institute of Medicine (US) Committee to Review Dietary Reference Intakes for Vitamin D and Calcium; Ross AC, Taylor CL, Yaktine AL, et al., editors. Dietary Reference Intakes for Calcium and Vitamin D. Washington (DC): National Academies Press (US); 2011. Available from: https://www.ncbi.nlm.nih.gov/books/NBK56070/

103 Bergman C, Gray-Scott D, Chen JJ, Meacham S. What is Next for the Dietary Reference Intakes for Bone Metabolism Related Nutrients Beyond Calcium: Phosphorus, Magnesium, Vitamin D, and Fluoride? *Crit Rev Food Sci Nutr.* 2009 Feb;49(2):136-44.

104 Palacios C. The role of nutrients in bone health, from A to Z. *Crit Rev Food Sci Nutr.*2006;46:621–628.

105 Cholecalciferol (Vitamin D3) Oral : Uses, Side Effects, Interactions, Pictures, Warnings & Dosing. (n.d.). Retrieved May 15, 2019, from https://www.webmd.com/drugs/2/drug-6152/cholecalciferol-vitamin-d3-oral/details

106 Nair, R., & Maseeh, A. (2012). Vitamin D: The "sunshine" vitamin. *Journal of pharmacology & pharmacotherapeutics*, *3*(2), 118-26.

107 How do I get the vitamin D my body needs? (n.d.). Retrieved May 15, 2019, from https://www.vitamindcouncil.org/about-vitamin-d/how-do-i-get-the-vitamin-d-my-body-needs/#.XNwWY44zaUl

108 Moan J, Grigalavicius M, Dahlback A et al. Ultraviolet-radiation and health: optimal time for sun exposure. Adv Exp Med Biol 2014;810: 423–8.

109 Lin, S., Dr, Balzak, H., Tammy, Freilich, I., Crumbley, L., & Lavanur, B. (2018, September 22). Vitamin D Through Sun: 9 Tips to

Optimize Your Levels. Retrieved May 15, 2019, from https://www.drstevenlin.com/optimize-vitamin-d-through-sun/

110 No – 10 minutes per day of sun-UVB is NOT enough. (n.d.). Retrieved May 15, 2019, from https://vitamindwiki.com/No – 10 minutes per day of sun-UVB is NOT enough

111 Institute of Medicine (US) Committee to Review Dietary Reference Intakes for Vitamin D and Calcium; Ross AC, Taylor CL, Yaktine AL, et al., editors. Dietary Reference Intakes for Calcium and Vitamin D. Washington (DC): National Academies Press (US); 2011. Available from: https://www.ncbi.nlm.nih.gov/books/NBK56070/

112 Gunnars, K., BSc. (2018, July 5). Protein Intake – How Much Protein Should You Eat Per Day? Retrieved May 15, 2019, from https://www.healthline.com/nutrition/how-much-protein-per-day

113 Phosphorus in diet: MedlinePlus Medical Encyclopedia. (n.d.). Retrieved June 2, 2019, from https://medlineplus.gov/ency/article/002424.htm

114 Food Sources of Phosphorus. (2016, June 30). Retrieved June 2, 2019, from https://www.dietitians.ca/Downloads/Factsheets/Food-Sources-of-Phosphorus.aspx

115 Vipercore-13. (2005, January 01). Phosphorus. Retrieved May 15, 2019, from https://www.nrv.gov.au/nutrients/phosphorus

116 Johnson S. The multifaceted and widespread pathology of magnesium deficiency. *Med Hypotheses.* 2001 Feb;56(2):163-70.

117 Welch, A. A., Skinner, J., & Hickson, M. (2017). Dietary Magnesium May Be Protective for Aging of Bone and Skeletal Muscle in Middle and Younger Older Age Men and Women: Cross-Sectional Findings from the UK Biobank Cohort. *Nutrients*, *9*(11), 1189.

118 Spritzler, F., RD, CDE. (2018, August 22). 10 Magnesium-Rich Foods That Are Super Healthy. Retrieved June 2, 2019, from https://www.healthline.com/nutrition/10-foods-high-in-magnesium#section1

119 Magnesium Supplements: Benefits, Deficiency, Dosage, Effects, and More. (n.d.). Retrieved May 15, 2019, from https://www.webmd.com/diet/supplement-guide-magnesium#1

120 Whitbread, D., MScN. (2019, April 29). Top 10 Foods and Drinks Highest in Fluoride. Retrieved June 2, 2019, from https://www.myfooddata.com/articles/high-fluoride-foods-and-drinks.php

121 Vipercore-13. (2017, March). Fluoride (updated 2017). Retrieved May 15, 2019, from https://www.nrv.gov.au/nutrients/fluoride

122 Minich, D. (2018, October 19). Vitamin and Mineral Interactions: The Complex Relationship of Essential Nutrients. Retrieved June 2, 2019, from https://www.deannaminich.com/vitamin-and-mineral-interactions-the-complex-relationship-of-essential-nutrients/

123 Effects of a low-fat diet on mineral absorption in small-bowel disease. Scand J Gastroenterol. 1983 May;18(4):551-4.

124 Manganese: MedlinePlus Supplements. (2018, September 25). Retrieved May 15, 2019, from https://medlineplus.gov/druginfo/natural/182.html

125 Higdon, J., Ph.D. (2019, January 02). Manganese (V. J. Drake Ph.D. & M. Aschner Ph.D., Eds.). Retrieved June 2, 2019, from https://lpi.oregonstate.edu/mic/minerals/manganese

126 Manganese. (n.d.). Retrieved June 2, 2019, from http://www.whfoods.com/genpage.php?tname=nutrient&dbid=77

127 Yamaguchi M. Role of nutritional zinc in the prevention of osteoporosis. *Mol Cell Biochem.* 2010 May;338(1-2):241-54

128 Lehman, S., MS. (2016, September 10). Zinc Requirements and Dietary Sources. Retrieved May 15, 2019, from https://www.verywellfit.com/zinc-requirements-and-dietary-sources-2507738

129 Water Treatment Solutions. (n.d.). Retrieved May 15, 2019, from https://www.lenntech.com/recommended-daily-intake.htm#ixzz5hWd1ddB1

130 Willacy, H., Dr. (2019, April 26). Zinc Deficiency, Excess and Supplementation. Zinc problems (C. Tidy Dr., Ed.). Retrieved June 2, 2019,from: https://patient.info/doctor/zinc-deficiency-excess-and-supplementation-pro

131 Vipercore-13. (2005, January 01). Iron. Retrieved May 15, 2019, from:
https://www.nrv.gov.au/nutrients/iron

132 Spritzler, F., RD, CDE. (2018, July 18). 11 Healthy Foods That Are Very High in Iron. Retrieved June 2, 2019, from
https://www.healthline.com/nutrition/11-healthy-iron-rich-foods#section2

133 Iron-Rich Foods. (n.d.). Retrieved June 2, 2019, from
https://www.redcrossblood.org/donate-blood/blood-donation-process/before-during-after/iron-blood-donation/iron-rich-foods.html

134 Higdon, J., Ph.D., & Prohaska, J. R., Ph.D. (2019, January 02). Copper (V. J. Drake Ph.D. & B. Delage Ph.D., Eds.). Retrieved May 15, 2019, from https://lpi.oregonstate.edu/mic/minerals/copper#RDA

135 Strand, Tor & Lillegaard, Inger & Frøyland, Livar & Haugen, Margaretha & Henjum, Sigrun & Løvik, Martinus & Stea, Tonje & Holvik, Kristin. (2018). Assessment of Copper Intake in Relation to Tolerable Upper Intake Levels. *European Journal of Nutrition & Food Safety*. 8. 193-194.

136 Toxicological Profile for Boron. (1992, July). Retrieved May 15, 2019, from https://www.atsdr.cdc.gov/toxprofiles/tp26-c6.pdf

137 Boron: MedlinePlus Supplements. (2018, June 4). Retrieved May 15, 2019, from https://medlineplus.gov/druginfo/natural/894.html

138 M. R. Naghii and S. Samman, The role of boron in nutrition and metabolism.*Prog. Food Nutr. Sci. 1993 Oct-Dec; 17(4):331-49.*

139 Devirian, T.A., Volpe, S.L.; The Physiological Effects of Dietary Boron *Critical Reviews in Food Science and Nutrition*, vol. 43, no. 2, pp. 219–231, 2003.

140 Johnson EJ, Russell RM. Beta-Carotene. In: Coates PM, Betz JM, Blackman MR, et al., eds. *Encyclopedia of Dietary Supplements. 2nd ed. London and New York: Informa Healthcare*; 2010:115-20.

141 Office of Dietary Supplements - Vitamin A. (2018, October 5). Retrieved May 15, 2019, from

https://ods.od.nih.gov/factsheets/VitaminA-HealthProfessional/

142 Bradford, A. (2015, August 25). Vitamin A: Sources & Benefits. Retrieved May 15, 2019, from https://www.livescience.com/51975-vitamin-a.html

143 Engel, P., Dr. (2017, August 31). Vitamin A Intake Recommendations - Nutri-Facts (A. Wyss, Ed.). Retrieved May 15, 2019, from https://www.nutri-facts.org/en_US/nutrients/vitamins/a/intake-recommendations.html

144 Bowen, R. (n.d.). Vitamin K. Retrieved May 15, 2019, from http://www.vivo.colostate.edu/hbooks/pathphys/topics/vitamink.html

145 Zoch, M. L., Clemens, T. L., & Riddle, R. C. (2015). New insights into the biology of osteocalcin. *Bone*, *82*, 42-9.

146 Delmas,P.D. 1990.Biochemical markers of bone turnover for the clinical assessment of metabolic bone disease. *Endocrinol. Metab. Clin. N. Am.* 19:1-18.

147 Rodrigues AM, Caetano-Lopes J, Vale AC, et al. Low osteocalcin/collagen type I bone gene expression ratio is associated with hip fragility fractures. *Bone* 2012; 51:981–989.

148 Link, R., MS, RD. (2018, June 11). Top 10 Vitamin K Foods. Retrieved May 15, 2019, from https://draxe.com/vitamin-k-foods/

149 Vipercore-13. (2005, January 01). Vitamin K. Retrieved May 15, 2019, from https://www.nrv.gov.au/nutrients/vitamin-k

150 What's the RDA for Vitamin C? (n.d.). Retrieved May 15, 2019, from https://www.jigsawhealth.com/vitamin-c-rda/

151 Aghajanian P, Hall S, Wongworawat MD, Mohan S. The Roles and Mechanisms of Actions of Vitamin C in Bone: New Developments. *J Bone Miner Res. 2015 Nov; 30(11):1945-55. Epub 2015 Oct 7.*

152 Whitbread, D. (2019, May 02). Top 10 Foods Highest in Vitamin C. Retrieved May 15, 2019, from https://www.myfooddata.com/articles/vitamin-c-foods.php

153 Office of Dietary Supplements - Vitamin C. (2018, September 18). Retrieved May 15, 2019, from https://ods.od.nih.gov/factsheets/VitaminC-HealthProfessional/

154 Brown, J. J., PhD, & Grieger, L., Grieger, RDN,CDE. (2018, January 05). 8 Surprising Health Benefits of B Vitamins | Everyday Health. Retrieved May 15, 2019, from https://www.everydayhealth.com/pictures/surprising-health-benefits-b-vitamins/

155 Robert R. McLean, Paul F. Jacques, Jacob Selhub, Lisa Fredman, Katherine L. Tucker, Elizabeth J. Samelson, Douglas P. Kiel, L. Adrienne Cupples, Marian T. Hannan; Plasma B Vitamins, Homocysteine, and Their Relation with Bone Loss and Hip Fracture in Elderly Men and Women, *The Journal of Clinical Endocrinology & Metabolism*, Volume 93, Issue 6, 1 June 2008, Pages 2206–2212.

156 Dai, Z., Wang, R., Ang, L.W. et al. Osteoporos Int (2013) 24: 2049.

157 Carbone LD, Bůžková P, Fink HA, Raiford M, Le B, Isales CM, Shikany JM, Coughlin SS, Robbins JA. Association of Dietary Niacin Intake with Incident Hip Fracture, BMD, and Body Composition: The Cardiovascular Health Study. *J Bone Miner Res.* 2019 Apr;34(4):643-652.

158 Le B, Bůžková P, Fink H, Robbins J, Raiford M, Isales C, Shikany J, Coughlin S, Carbone L. Association of Niacin Intake with Osteoporosis.

the Cardiovascular Health Study [abstract]. *Arthritis Rheumatol.* 2018; 70 (suppl 10).

159 Cheong, T. (2016). Food Tips. Retrieved May 15, 2019, from https://www.healthxchange.sg/food-nutrition/food-tips/vitamin-b-best-food-sources-signs-deficiency

160 Aytekin, N., Mileva, K., & Cunliffe, A. (2018). Selected B vitamins and their possible link to the aetiology of age-related sarcopenia: Relevance of UK dietary recommendations. *Nutrition Research Reviews*, 31(2), 204-224

161 Healthcommunities.com, E. A. (Ed.). (2013, January 23). Vitamin B Complex. Retrieved May 15, 2019, from http://www.healthcommunities.com/vitamins-minerals-supplements/b-vitamins.shtml

162 IDEM with 161

163 IDEM with 161 and 162

164 Flatfoot Surgical Correction. (n.d.). Retrieved May 15, 2019, from http://legacy.aofas.org/footcaremd/treatments/Pages/Flatfoot-Surgical-Correction.aspx

165 Flat Foot Reconstruction Surgery. (n.d.). Retrieved May 15, 2019, from https://www.fortiusclinic.com/conditions/flat-foot-reconstruction-surgery

166 5 Different Types of Flat Feet Surgery. (2017, February 08). Retrieved May 15, 2019, from http://www.hyprocure.com/5-different-types-of-flat-feet-surgery/

167 R Dinucci, Kent & Christensen, Jeffrey & A Dinucci, Kris. (2004). Biomechanical consequences of lateral column lengthening of the calcaneus: Part I. Long plantar ligament strain. *The Journal of foot and ankle surgery: official publication of the American College of Foot and Ankle Surgeons.* 43. 10-5.

168 Dellenbaugh, S., MD. (2018, April 22). Lateral Column Lengthening. Retrieved May 15, 2019, from

https://footeducation.com/lateral-column-lengthening/

169 Chi, T.D., Toolan, B.C., Sangeorzan, B.J., and Hansen, S.T. Jr. The lateral column lengthening and medial column stabilization procedures. *Chin Orthop Relat Res*. 1999; 365: 81–90

170 Uglow, M. (n.d.). Lateral Column Lengthening. Retrieved May 15, 2019, from http://ugloworthopaedics.com/?page_id=698

171 Chang, T. J. (2001). Medial Column Fusions. 88-93. Retrieved March 21, 2019, from http://www.podiatryinstitute.com/pdfs/Update_2001/2001_15.pdf

172 de Moraes Barros Fucs, P. M., Svartman, C., de Assumpção, R. M., Yamada, H. H., & Simis, S. D. (2011). Surgical technique: Medial column arthrodesis in rigid spastic planovalgus feet. *Clinical orthopaedics and related research*, *470*(5), 1334-43.

173 Wang C.S., Tzeng YH2, Lin C.C., Chang M.C., Chiang C.C. Comparison of screw fixation versus non-fixation in dorsal opening wedge medial cuneiform osteotomy of adult acquired flatfoot. *Foot Ankle Surg*. 2019 Feb 11. pii: S1268-7731

174 Tarso-metatarsal (midfoot) fusion. (2014, May). Retrieved May 15, 2019, from https://www.nbt.nhs.uk/sites/default/files/attachments/Tarso-metatarsal (midfoot) fusion_NBT002188.pdf

175 Sterling, G. (n.d.). Midfoot (Tarsometatarsal) Fusion. Retrieved May 15, 2019, from https://www.gregsterling.com.au/pdfs/midfoot-tarsometatarsal-fusion/

176 Tennant, J. N., Carmont, M., & Phisitkul, P. (2014). Calcaneus osteotomy. *Current reviews in musculoskeletal medicine*, *7*(4), 271-6.

177 Castro, M., DO, & Panchbhavi, V., MD (Eds.). (2018, February 20). Calcaneal Osteotomy. Retrieved May 15, 2019, from https://footeducation.com/calcaneal-osteotomy/

178 Jastifer, J. R., & Coughlin, M. J. (2015). Hindfoot Deformity and Calcaneal Tuberosity Osteotomies. *Foot & Ankle Specialist*, *8*(1), 50–58.

179 Heel Bone Osteotomy and Tendon Transfer. (n.d.). Retrieved May 15, 2019, from http://www.iskinstitute.com/kc/ankle/posterior_tibial_tendon_disorder/t3.html

180 Demetracopoulos, C. A., Nair, P., Malzberg, A., & Deland, J. T. (2015). Outcomes of a Stepcut Lengthening Calcaneal Osteotomy for Adult-Acquired Flatfoot Deformity. *Foot & Ankle International*, *36*(7), 749–755.

181 PT18: Evans calcaneal lengthening. (n.d.). Retrieved May 15, 2019, from https://www.childrenscolorado.org/globalassets/departments/orthopedics/pt-protocols.pdf

182 Tibialis Posterior Tendon Dysfunction (Flatfoot). (n.d.). Retrieved May 15, 2019, from https://www.sportsmed.com.au/tibialis-posterior-tendon-dysfunction-acquired-flatfoot/

183 Wines, A., Dr, MBBS FRACS. (n.d.). Tibialis Posterior Tendon Reconstruction. Retrieved May 15, 2019, from https://www.nsosmc.com.au/resources/AW/Tibialis-posterion-tendon-reconstruction.pdf

184 Backus JD, McCormick JJ. Tendon transfers in the treatment of the adult flatfoot. *Foot Ankle Clin.* 2014 Mar; 19(1):29-48.

185 P Mitchell, G & M. C. Gibson, J. (1967). Excision of calcaneo-navicular bar for painful spasmodic flat foot. *The Journal of bone and joint surgery. British volume.* 49. 281-7.

186 DeVries, J.G. and B. Scharer, Hindfoot Deformity Corrected With Double Versus Triple Arthrodesis: Radiographic Comparison. *J Foot Ankle Surg, 2015.* 54(3): p. 424-7.

187 *Tenenbaum S, Coleman SC, Brodsky JW. J* Improvement in gait following combined ankle and subtalar arthrodesis. *Bone Joint Surg Am.* 2014 Nov 19; 96(22):1863-9*.*

188 Singer S, Klejman S, Pinsker E, Houck J, Daniels T*.* Ankle arthroplasty and ankle arthrodesis: gait analysis compared with normal controls. *J Bone Joint Surg Am. 2013 Dec 18; 95(24):e191(1-10).*

189 Beischer, Andrew & W. Brodsky, James & E Pollo, F & Peereboom, Jeffery. (1999). Functional Outcome and Gait Analysis After Triple or Double Arthrodesis. *Foot & ankle international / American Orthopaedic Foot and Ankle Society [and] Swiss Foot and Ankle Society.* 20. 545-53.

190 Ankle Fusion (Arthrodesis). (n.d.). Retrieved May 15, 2019, from https://www.ouh.nhs.uk/footandankle/information/ankle/ankle-fusion.aspx

191 Martone J, Poel LV and Levy N. Complications of arthrodesis and nonunion. Clin Podiatr Med Surg 29: 11-18, 2012

192 Burrus MT, Werner BC, Carr JB, Perumal V, Park JS. Increased failure rate of modified double arthrodesis compared with triple arthrodesis for rigid pes planovalgus. *J Foot Ankle Surg*. 2016; 55(6):1169-1174

193 J. Klassen, Lindsey & M. Weinraub, Glenn & Shi, Eric & Liu, Jennifer. (2018). Comparative Nonunion Rates in Triple Arthrodesis. The Journal of Foot and Ankle Surgery. 57.

194 Arthroereisis. (n.d.). Retrieved May 15, 2019, from https://medical-dictionary.thefreedictionary.com/arthroereisis

195 Bernasconi, A., Lintz, F., & Sadile, F. (2017). The role of arthro-ereisis of the subtalar joint for flatfoot in children and adults. *EFORT open reviews*, *2*(11), 438-446.

196 Graham, M. E., DPM, FACFAS. (2010, April 20). Dispelling The Misconceptions About Subtalar Arthroereisis. Retrieved May 15, 2019, from https://www.podiatrytoday.com/dispelling-the-misconceptions-about-subtalar-arthroereisis

197 Subtalar Joint Arthroereisis Procedure. (n.d.). Retrieved May 15, 2019, from
http://www.cocoo.on.ca/pdf/guidelines/subtalar_joint_arthroereisis.pdf

198 Idem with 192

199 Metcalfe, S. A., Bowling, F. L., & Reeves, N. D. (2011). Subtalar Joint Arthroereisis in the Management of Pediatric Flexible Flatfoot: A Critical Review of the Literature. *Foot & Ankle International*, *32*(12), 1127–1139.

200 Flatfoot Surgical Correction. (n.d.). Retrieved May 15, 2019, from http://legacy.aofas.org/footcaremd/treatments/Pages/Flatfoot-Surgical-Correction.aspx

201 Metcalfe, S. A., Bowling, F. L., & Reeves, N. D. (2011). Subtalar Joint Arthroereisis in the Management of Pediatric Flexible Flatfoot: A Critical Review of the Literature. *Foot & Ankle International*, *32*(12), 1127–1139.

202 Saxena, Amol & Giai Via, Alessio & Maffulli, Nicola & Chiu, Haywan. (2016). Subtalar Arthroereisis Implant Removal in Adults: A Prospective Study of 100 Patients. The Journal of Foot and Ankle Surgery. 55.

203 Baker, J. R., Klein, E. E., Weil, L., Weil, L. S., & Knight, J. M. (2013). Retrospective Analysis of the Survivability of Absorbable Versus Nonabsorbable Subtalar Joint Arthroereisis Implants. *Foot & Ankle Specialist*, *6*(1), 36–44.

204 Fernández de Retana, Pablo & Alvarez, Fernando & Bacca Insuasty, Gustavo. (2012). Is There a Role for Subtalar Arthroereisis in the Management of Adult Acquired Flatfoot?. *Foot and ankle clinics*. 17. 271-81.

205 Crawford, AH; Kucharzyk, DO; Roy, DR; Bilbo, J: Subtalar stabilization of the planovalgus foot by staple arthroereisis in young children who have neuromuscular problems. *J. Bone Joint Surg*. 72A:840–845, 1990.

206 Needleman, R. L. (2005). Current Topic Review: Subtalar Arthroereisis for the Correction of Flexible Flatfoot. *Foot & Ankle International*, *26*(4), 336–346.