# Weight-Bearing Computed Tomography Scan Evaluation of Weil Osteotomy

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## INTRODUCTION

When evaluating the patient with metatarsalgia, there are many anatomic and biomechanic factors to consider: first ray hypermobility, metatarsal length, metatarsal elevation and metatarsophalangeal joint (MPJ) stability (plantar plate). One may use traditional weight-bearing radiographs to evaluate metatarsal length but they cannot assess metatarsal sagittal plane position (1). Sesamoid axial views can evaluate the metatarsal head sagittal plane position but such radiographs are not reliable. Weight-bearing computed tomography (CT) can accurately measure the relative position of the metatarsal heads to one another and to the weight-bearing surface (2-5).

The transverse slices of the weight-bearing CT scan allow for the precise evaluation of metatarsal length. Depending on the technique for determining metatarsal parabola and the ideal postoperative position, the surgeon can accurately measure metatarsal length. The sagittal weight-bearing slices can identify the position of the metatarsal heads in relation to the ground and in relation to one another (5). The surgical goal is to even out the metatarsal weight-bearing pattern to reduce the submetatarsal pressure, pain, and callus formation under any individual or collective metatarsals.

One option that has gained popularity among surgeons is the Weil osteotomy, which shortens the metatarsal in hopes of taking pressure off that metatarsal. The biggest problems surgeons run into with this procedure are the floating toe syndrome and the dredged transfer lesion (6, 7). Presurgical planning with a weight-bearing CT scan provide surgeons with a tool to help asses exactly how much to shorten the metatarsal and determine the angle in which to make the osteotomy in order to prevent transfer lesions. The weight-bearing CT scan allows the surgeon to create a patient- and pathology-specific surgical plan. We hypothesize that using weight-bearing CT imaging of the Weil osteotomy can effectively show us where the shortened metatarsal is positioned and provide surgeons with a valuable preoperative template to work with.

## METHODS

Weight-bearing CT scans obtained at the principal surgeon's office were reviewed from March 2014 to January 2015 and were retrospectively analyzed by a single investigator. Seven patients (4 female and 3 male) who were diagnosed with metatarsalgia or plantar plate rupture, had 9 Weil osteotomies performed (age range was 38-67 years). Weil osteotomies were performed unilaterally on the second metatarsal (n = 7) and third metatarsal (n = 2). Other procedures performed were proximal interphalangeal joint fusions and bunionectomies. The average follow-up time was 5 weeks (range 4-6 weeks).

Using the CubeVue 2011-2012 program software, and the CurveBeam, LLC Version 2.2.0.2 scanner, preoperative and postoperative weight-bearing CT images were taken of the affected foot with the patient in relaxed calcaneal stance position. Images were taken in less than one minute (approximately 9 seconds of radiation exposure to the patient), with slices of 0.3 mm, and a relatively small radiation dose (~2μSv). Slices are then combined via, CubeVue software, into a 3-dimensional image to be viewed.

We assessed the position of the metatarsal preoperatively and postoperatively surgically in the frontal plane for all the metatarsals and sync to the sagittal plane image to precisely determine the level of the metatarsal head compared to adjacent metatarsals. Other preoperative and postoperative measurements taken were the length of the metatarsal, metatarsal declination angle, frontal plane rotation of the metatarsal head, metatarsal to toe angle and angle of osteotomy cut postoperatively to determine if there is any change in these measurements after the Weil osteotomy. All measurements were then analyzed using SPSS software and student's *t*-test to determine if there is any statistical significance between the angle of osteotomy, amount of shortening, and weight-bearing position of the metatarsal head.

## RESULTS

SPSS software was used for all statistical analysis. The paired sample *t*-test, Pearson R correlation coefficient for determining association between variables, 1-way ANOVA, and 2-way ANOVA were all used to analyze the data. *P* values less than or equal to 0.05, or (5%), were considered significant. All data were within ± 2 standard deviations, and followed a normal bell curve, indicating an appropriate sample population. Table 1 shows the mean change in all the measurements and their statistical significance. All measurements changed significantly except the toe angle measurements due to the small sample size (n = 7), 2 patients were omitted because they had Kirschner wires (K-wires) in place at the final follow-up appointment and did not have any further imaging.

The average metatarsal length decreased from 75.23 mm to 71.86 mm, the average metatarsal declination angle preoperatively was 23.32 degrees (range 20.3-30.4 degrees), which the average increased significantly to 24.4 degrees. The average metatarsal frontal plane rotation changed from 109.84 degrees to 115.51 degrees. The average toe angle did not change significantly, 2 of the patient's measurements for toe angle were excluded due to the presence of K-wires when the last postoperative CT images were taken, making the sample size for analysis smaller. The metatarsal declination angle averaged 23.32 degrees. The metatarsal head was on average elevated 2 mm postoperatively with the average osteotomy angle of 19 degrees. Our results show that as metatarsal head is translated proximally, it elevates in the sagittal plane.

## DISCUSSION

The weight-bearing CT study provides the surgeon with the critical anatomic information to allow for more precise surgical planning. The Weil osteotomy was first introduced as a procedure to correct the long metatarsal pathology by shortening the metatarsal in the transverse plane without a sagittal plane change when the osteotomy is made parallel to the weight-bearing surface (6, 8). Our results show that as we shorten the metatarsal, we also elevate the head due to the metatarsal declination angle and angle of the osteotomy. According to many published articles, the Weil osteotomy is always associated with a relative depression of the metatarsal head and that greater proximal shift increases plantar displacement. This seems to oppose the idea that in stance the metatarsal head bears a smaller load after a Weil osteotomy (6-9). When we consider the dynamic nature of foot function, perhaps an explanation can be found.

Grimes et al found that if your osteotomy angle is bigger than the metatarsal declination angle, then you can get depression of the capital fragment, and if the osteotomy angle is smaller you get elevation of the capital fragment. This explains how some studies saw depression of the metatarsal head, and others did not (10). In our study, we found as we shorten the metatarsal, we get elevation. With an average metatarsal declination of 23.32 degrees and an average osteotomy angle of 19 degrees elevation is created as you shorten, which correlates with the findings from Grimes study.

Trynka et al found it difficult to create an osteotomy with an angle of less than 25 degrees relative to the longitudinal axis of the metatarsal. Therefore, if the angle of inclination of the metatarsal is smaller than 25 degrees you get depression of the metatarsal head. As the angle of inclination becomes smaller, the difference between the attainable osteotomy angle and parallel widens, producing greater plantar displacement (10, 11). Studies have shown that increased plantar translation of the metatarsal head with a more oblique Weil osteotomy did not significantly increase plantar pressure, and the 4-mm slice resection did not significantly unload the metatarsal head. This is most likely due to plantar displacement of the metatarsal head and the dynamic function of the metatarsals in gait (8, 9).

As we attempt to correct the metatarsal parabola with the Weil osteotomy, we have to take into account the sagittal plane changes and how they can affect the weight-bearing surface through gait. Because the foot is a 3-dimensional structure, we need to determine where we would like to place the metatarsal head in the transverse and sagittal plane and how it can affect the patient clinically. Diaz et al examined the relative metatarsal head distances from the ground and their heights relative to each other using weight-bearing CT. The researchers found the mean distance from ground to the sesamoids and fourth and fifth metatarsal to be the closest to each other. They found a

**Table 1. Average preoperative and postoperative weight-bearing computed tomography measurements.**

| N=9 | Mean Pre | SD Pre | Mean Post | SD Post | *t* test (*P* = 0.05) |
|---|---|---|---|---|---|
| Met length | 75.23 | 6.51 | 71.86 | 5.70 | 0.001 |
| Met dec angle | 23.32 | 3.34 | 24.74 | 3.81 | 0.006 |
| Met front angle | 109.84 | 6.34 | 115.51 | 6.04 | 0.041 |
| Toe angle (N=7) | 114.45 | 39.87 | 122.15 | 34.95 | 0.402 |
| Met head pos | 8.22 | 2.10 | 10.22 | 2.31 | 0.000 |

Figure 1A. Preoperative weight-bearing computed tomography sagittal slice.

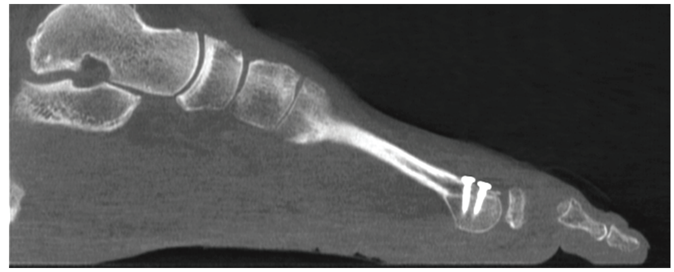

Figure 1B. Postoperative weight-bearing computed tomography sagittal slice.

high correlation between the distance from the ground to each of the metatarsals and sesamoids, concluding that if 1 metatarsal was found to be elevated, all of the metatarsals and sesamoids were found to be elevated (5). We found the same correlation in our study showing that the metatarsal parabola works as a unit in stance to accept our weight as we go through gait.

Our study and many other studies looking at the weight-bearing parabola of the foot are statistically analyzing the static parabola even though the foot is a dynamic structure. Most of our research for dynamic function and weight-bearing surface of the metatarsal parabola comes from 3-D finite computer studies. This is due to the difficulty in analyzing the dynamic function and the 3-D structure of the foot in the past (12, 13). We believe weight-bearing CT of the foot has opened up the door for future research on 3-D analysis of the foot. Being able to combine the images with force plate analysis can give us a better understanding of the dynamic weight-bearing parabola of the foot. Obtaining a toe off image of the metatarsal parabola preoperatively and postoperatively would give us more information about the dynamic function of the metatarsals, which can be something to look at in future research.

The biggest limitation to our study was the small sample size; even though we obtained statistically significant results, we had no power to our study. We believe our pilot study would encourage future research using the weight-bearing CT to study a larger sample of patients who have had a Weil osteotomy. Another limitation to the study was the short follow-up. The senior author has recently switched to using weight-bearing CT for his preoperative imaging and postoperative imaging. In the future, the technology can be used to evaluate patients undergoing a Weil osteotomy for a longer follow-up period of time to see if there are any changes in the measurements.

In conclusion, weight-bearing CT scanners are a safe, effective imaging tool to evaluate for preoperative planning and postoperative changes in foot surgery. It provides a 3-dimensional image, which is far more accurate than traditional radiographs. As the technology becomes more widely used, we as researchers can use it to better study the 3-dimensional structure of the foot before and after many different procedures as we did with the Weil osteotomy.

Our study provided a framework for future research on the analysis of the weight-bearing parabola of the foot. Many studies in the past had shown that the Weil osteotomy provides shortening of the metatarsal in the transverse plane and plantar declination of the metatarsal head in the sagittal plane, our study showed actually as the metatarsal shortens it elevates in the sagittal plane. However, this is a purely static image and we must also consider the dynamic forces during gait. Combining our findings with pressure plates will give us more information on the structure and clinical dynamic function after Weil osteotomies. We need to see how the pressure distribution changes as the metatarsal elevates or plantar declinates. This study and many others have shown that the metatarsal head changes position in both the transverse and sagittal plane structurally following a Weil osteotomy. But we still need to ask at what position in the 3-dimensional realm should we place the metatarsal head to function most optimally.

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