Progression of Radiographic Healing Following First Ray Arthrodesis in the Foot Using a Biplanar Plating Technique Without Compression

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Introduction

The healing potential of bone has been shown to be similar in fracture and fusion models (1), contributing to similar internal fixation methods for each, including crossed wires, compressive screws, rigid plates and combinations of these. Studies aiming to determine the optimal quality and quantity of interfragmentary motion to achieve bone healing have found cyclic compression that avoids excessive shear force and torsion increases periosteal callus formation and increases the rate of osteosynthesis (2-6).

In 2016, Dayton et al. described a fixation construct for first tarsal-metatarsal joint (TMTJ) arthrodesis that balances multiplanar stability with the desired cyclic mechanical loading, allowing for adequate callus formation and increased healing strength (7). This construct utilizes two small dimension plates along the axis of bone at 90 degrees to each other without interfragmentary compression. This construct was found to provide greater stability with cyclic loading and with a single static load when compared to a single locked plate with a compression screw. Despite this increased stability of the biplanar construct, cyclic motion of the opposed segments was maintained.

The purpose of the present study is to assess the progression of osseous healing and clinical outcomes when biplanar fixation with early weight bearing is employed in first TMTJ and first metatarsophalangeal joint (MTPJ) arthrodesis procedures.

Literature Review

A mechanical environment of relative stability, as opposed to rigidity, allows controlled micromotion at the bone-to-bone interface and leads to secondary bone healing by callus formation. Secondary healing has been shown to increase the cross-sectional stability of the healing site and decrease time to healing (8, 9).

In 2004, Hente et al. demonstrated that micromotion in the form of cyclic compressive displacement allowed for significantly more callus formation and a stronger healing construct (3). In 2017, Bottlang et al. compared a compression plate to an active plate which allowed controlled micromotion, reporting a six times larger callus and 42% more strength in the active plate group at nine weeks (10). The use of compression screws to create static compression at a healing site does not permit cyclic compressive displacement to allow for the increased callus formation and strength of secondary bone healing.

Multiplane stability at the bone-to-bone interface can be obtained without static compression or rigidity through the use of biplanar plating. Studies of biplanar plating in humerus fractures have determined that parallel locking plates oriented 90° to 180° from each other are able to achieve multiplane stability while avoiding the excessive rigidity seen with compression fixation (11-13).

Methodology

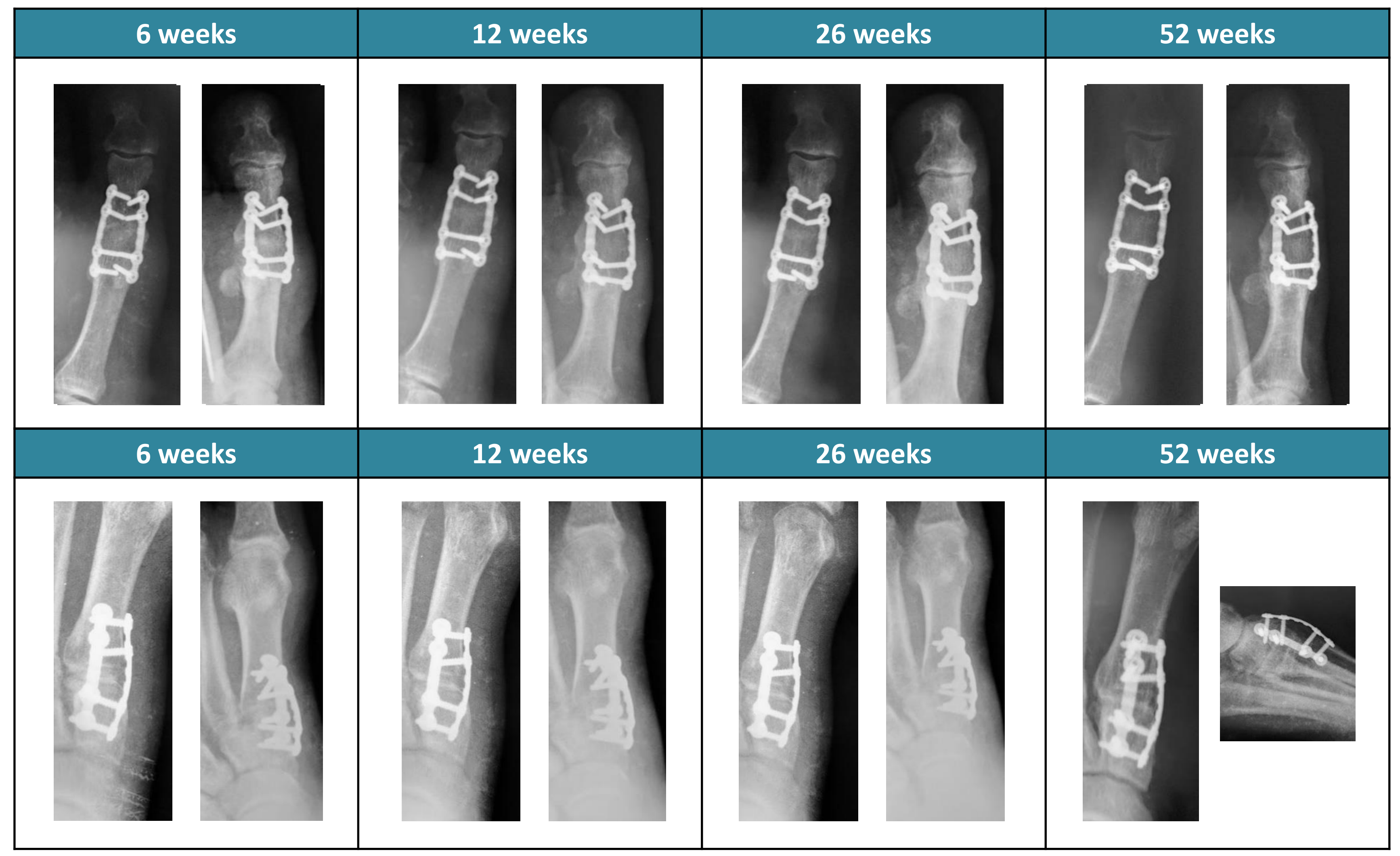
A retrospective review was performed on all patients undergoing first TMTJ or first MTPJ arthrodesis with a biplanar plating construct performed by the senior author (P.D.) from July 2011 to January 2017 to assess progression of radiographic healing. The inclusion and exclusion criteria are listed in Table 1. At least two separate weightbearing radiographs (dorsoplantar, medial oblique or lateral) were assessed by senior author (P.D.) and one other board certified foot and ankle surgeon not involved in the clinical care of the patients at each of the following intervals: 4-9 weeks, 10-12 week, 16-26 weeks and final follow-up (Fig. 1).

Table 1: Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
1. Utilization of ALPS Hand Biomet plates or Control 360 Treace Medical Concepts plates for fixation	1. Revision of arthrodesis
2. Plates placed in a 90° biplanar construct	2. Fusion for failed implant or osteotomy
3. At least two weightbearing radiographs from each healing interval	3. Clinically significant neuropathy with history of past ulceration or Charcot deformity
	4. Less than 12 week follow-up available

Methodology (cont.)

Figure 1: First MTPJ and First TMTJ Arthrodesis Healing Progression



Radiographic healing was assessed based on the following criteria: (1) Presence of lucency at arthrodesis site, (2) maintenance of position of arthrodesis segments, (3) evidence of hardware loosening or failure and (4) progressive increase in radiodensity and trabecular pattern at arthrodesis site. Presence of osseous union was assessed at final follow-up and was defined as osseous bone growth in >50% of arthrodesis site.

The surgical techniques for first TMTJ arthrodesis and first MTPJ arthrodesis began with of an incision over the joint to be fused. Intra capsular and subperiosteal dissection without subcutaneous separation maintained full thickness soft tissue flaps. All cartilage and subchondral bone was resected using a rongeur, bur or saw down to healthy metaphyseal bone. The fusion site was contoured to provide complete correction of the deformity in the transverse, sagittal and frontal planes. Temporary fixation was carried out with a smooth Kirschner wire followed by permanent fixation with two small locking plates placed at 90° with (4) 2.5x12 mm and (4) 2.5x14 mm screws applied unicortically through the locking plates. Temporary fixation was then removed and the capsule and skin were closed.

At the first post-operative visit within 5 days, patients were allowed to ambulate in a cast boot or post-operative shoe, but were advised to avoid excessive activity or high impact.

Results

249 potential patients were identified through electronic CPT code review and manual search of surgery schedules for senior author (P.D.). After inclusion and exclusion criteria were applied, 195 feet were included in the clinical and radiographic review. The results of the radiographic assessment can be found in Table 2. Table 3 includes the results of a chi-squared test to determine which of the radiographic assessments changed during the post-operative period. Table 4 includes a specific analysis of the change in lucency during the post-operative period.

Our results demonstrate osseous bone growth of >50% of the arthrodesis site at final follow-up in 98.24% of MTPJ patients and 96.82% of TMTJ patients. Combining TMTJ and MTPJ patients, 97.44% had osseous bone growth of >50% of the arthrodesis site at final follow-up.

Table 3 demonstrates the percentage range for each radiographic assessment. This table demonstrates no statistically significant change in position over time, no increase in hardware failure or loosening and continued increase in radiodensity and trabecular pattern over time.

Table 4 demonstrates a statistically significant decreases in lucency over the course of the study as well as between weeks 6 and 12 and weeks 12 and 26 in patients who had MTPJ or TMTJ arthrodesis.

Table 2: Radiographic Assessment Data Reported in Percentage

Weeks	Assessment	MTPJ		TMTJ		Total	
		% Yes	% No	% Yes	% No	% Yes	% No
6 weeks	Presence of lucency at arthrodesis site	62.96	37.04	50.48	49.52	55.95	44.05
	Presence of hardware failure or loosening	0.62	99.38	0.96	99.04	0.81	99.19
12 weeks	Presence of lucency at arthrodesis site	30	70	30.61	69.39	30.36	69.64
	Maintenance of stable position of arthrodesis site	100	0	98.98	1.02	99.40	0.60
	Presence of hardware failure or loosening	1.43	98.57	0.51	99.49	0.89	99.11
	Progressive increase in radiodensity/trabecular pattern	97.14	2.86	97.96	2.04	97.62	2.38
26 weeks	Presence of lucency at arthrodesis site	11.54	88.46	10.42	89.58	10.95	89.05
	Maintenance of stable position of arthrodesis site	100	0	98.61	1.39	99.27	0.73
	Presence of hardware failure or loosening	2.31	97.69	1.39	98.61	1.82	98.18
	Progressive increase in radiodensity/trabecular pattern	97.69	2.31	97.92	2.08	97.81	2.19
52 weeks	Presence of lucency at arthrodesis site	7.69	92.31	3.77	96.23	5.43	94.56
	Maintenance of stable position of arthrodesis site	100	0	98.11	1.89	98.91	1.09
	Presence of hardware failure or loosening	1.28	98.72	1.89	98.11	1.63	98.37
	Progressive increase in radiodensity/trabecular pattern	97.44	2.56	98.11	1.89	97.83	2.17
Final Follow-up	Osseous bone growth in >50% of arthrodesis site	98.24	1.76	96.82	3.18	97.44	2.56

Table 3: Change in Radiographic Assessments Over Time

Assessment	MTPJ percent	TMTJ percent	Total percent
Maintenance of stable position	100%	98.11%-98.98%	98.91%-99.40%
Hardware failure or loosening	0.62%-2.31%	0.51%-1.89%	0.81%-1.82%
Increasing radiodensity/trabecular pattern	97.14%-97.69%	97.92%-98.11%	97.62%-97.83%

Table 4: Reduction of Lucency at Fusion

Comparison by weeks	MTPJ p value	TMTJ p value	Total p value
6 vs 12 weeks	**<0.00001***	**0.000049***	**<0.00001***
12 vs 26 weeks	**0.000204***	**<0.00001***	**<0.00001***
26 vs 52 weeks	0.372743	0.050136	**0.040447***

Table 2: Results of radiographic assessment reported in percentage with MTPJ and TMTJ arthrodesis reported separately and combined. **Table 3:** Results of radiographic assessment reported in ranges of percentage over time for the specific assessments listed, reported separately and combined for MTPJ and TMTJ arthrodesis. **Table 4:** Results of chi-squared test for change in lucency at specified times during post-operative period. (*) indicates significant result.

Discussion

Our review demonstrates the ability of a biplanar plating construct without a compression screw to provide the appropriate mechanical environment to allow bone healing following first MTPJ or TMTJ arthrodesis.

Many studies on bone healing evaluate the surgical site a one specific time point during recovery. This common practice may not fully define the actual healing of the site, especially when tightly compressed surfaces are evaluated using standard radiographs. The most consistently used measure of union in arthrodesis procedures is continuity of trabecular pattern across the arthrodesis segments observed on radiographs, which is subjective and not always accurate. In 2006, Coughlin et al. called into question the accuracy of radiographic evaluation of osseous union, showing that reliance on radiographs to determine the extent of healing in rearfoot arthrodesis shows poor agreement when compared to CT findings (14). While radiographs are unable to evaluate the extent of healing that has taken place at an individual time point, progressive healing with increasing radiodense bridging and decreasing radiolucency is observable with serial radiographs.

Progressive callus formation was observed in the present study, indicated by lucency at the fusion interface early on, which progressively filled in over time. Lucency was present in 55.95% of all feet at 6 weeks, 30.36% at 12 weeks, 10.95% at 26 weeks, and 5.43% at final follow-up. These results were statistically significant for progressive decrease in lucency throughout the post-operative period (p<0.00001), allowing for the conclusion that osseous bridging occurred over time. Gap filling, indicated by a progressive increase in radiodensity and trabecular pattern at the arthrodesis site, was present was present in >97.6% of all radiographs at 12, 26 and 52 weeks, demonstrating that the mechanical environment produced by a biplanar plating construct does enable callus formation throughout healing. Further, osseus bone growth in >50% of the arthrodesis site was present in 97.44% of feet at final follow-up. Along with the low failure rate of <2.31%, this allows for the conclusion that this construct possesses the strength to uphold the mechanical demands needed to facilitate healing and fusion following first MTPJ or first TMTJ arthrodesis with early weightbearing.

Limitations of this study include the retrospective nature of the review and the use of plain film radiographs. Although CT imaging has been shown to be superior (14), radiographs were utilized as they are a more realistic imagining modality for the majority of patients due to cost, frequency and timing. Further, the use of non-digital radiographs is a limitation due to the importance of image quality for radiographic assessment.

Conclusion

Our results demonstrate the ability of a biplanar plating construct to provide reliable stability resulting in progressive bone healing and ultimately fusion for first MTPJ and first TMTJ procedures. The overall union rate at final follow-up was 98.24% for MTPJ arthrodesis and 96.82% for TMTJ arthrodesis. Lucency at the arthrodesis site progressively decreased during the post-operative period for both MTPJ and TMTJ arthrodesis indicating progression of callus healing. The rate of hardware failure or loosening was <2.31%.

Multiplane stability at the bone-to-bone interface can be obtained without static compression or rigidity through the use of a biplanar plating construct for first MTPJ and first TMTJ arthrodesis procedures. Future research is needed to determine if bone healing is stronger when biplanar plating is performed with or without a compression screw.

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