STABILIZATION OF TARSOMETATARSAL JOINT ARTHRODESIS: A BIOMECHANICAL STUDY

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SUMMARY

Introduction: Tarsometatarsal arthrodeses are an effective therapeutic alternative for treating symptomatic osteoarthroses of the Lisfranc joint. Stabilization methods available include: Kirschner's wires, cortical screws, plates and screws and staples. The stability provided and the surgical technique employed with each material is discussed in literature. Purpose: To compare compression forces and biomechanical stability of tarsometatarsal joint fixation with cortical screws and staples. Case series and method: Ten fresh male cadavers with ages ranging from 35 to 49 years were selected and submitted to bilateral dissection of the cuboidal and 4th metatarsal bones, with joint surfaces decortification and fixation with cortical screw – Cortical Screw 3.5mm Impol, and Uni-clip® Staple 2.0 NewDeal. Results: All the 20 biomechanical assays were completed. The statistical analysis of the methods using staples vs. cortical screw concerning accrued energy until reaching the assay's peak force p= 0.047, and the accrued energy until the completion of the assay p= 0.047 showed a significant difference. Conclusion: Load peaks supported by staples and cortical screws are significantly reduced with age. Superior force values are found for staples in osteoporotic bones. The accrued energy on graphs' work areas in assays with staples is shown to be statistically superior to cortical screws' values.

Keywords: *Foot joints. Arthrodesis. Internal fixators. Biomechanics*

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INTRODUCTION

Injuries of the tarsometatarsal joint - Lisfranc – affect about 55,000 people each year in the United States[1]. At the initial X-ray evaluation, only 40% of the injuries are diagnosed due to subdislocations, spontaneous reductions and non-compromised isolated ligament injuries[2,3].

Treatment fundamentals are as follows: early diagnosis, anatomic joint reduction and stable bone fixation, thus minimizing additional damages to soft tissues and to joint cartilage[4].

These are complex injuries presenting a high prevalence of evolution to a symptomatic osteoarthrosis, pain and functional deficit picture, representing an important cause of morbidity at the midfoot[5,6]. The therapeutic manipulation of these complications includes changing the kind of shoe worn, orthosis use, and surgical procedures, especially in tarsometatarsal arthrodeses[7-9].

Several fixation methods are available for providing tarsometatarsal arthrodesis, such as Kirschner's wires, Cortical Screws, Plates and screws, and staples.

Kirschner's wires present an easy implantation technique and do not require much manipulation of soft tissues; however, they present high failure rates[10].

Cortical Screws provide a stable fixation with significant compression, from the joint, but require a difficult implantation technique, which enables a small error margin[10,11].

Dorsal plates and screws are stable, rigid fixation devices that provide compression, require a considerable manipulation of soft tissues to be implanted and frequently require the removal of the synthesis material at postoperative follow-up period[11].

Staples are a stable and rigid fixation material, lending important compression. The implantation technique requires previous training, but with surgical access and intraoperative positioning quite reproducible.

The objective of the study was to compare the compression force and the biomechanical stability of the tarsometatarsal joint with Cortical Screws and Staples.

CASE SERIES AND METHOD

Fresh male cadavers supplied by the Death Examination Service of the Hospital das Clínicas – FMUSP were used in this study, with ages ranging from 35 to 49 years, no previous history of injuries or pathologies of the feet and ankles. They were submitted to a surgical procedure on the midfoot by a longitudinal incision

Study conducted at the Orthopaedics and Traumatology Institute, HC/FMUSP.
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at the dorsal surface on the 4th and 5th radios. Subsequently, the anatomic inventory of the ligamentar and bone status of the cuboidal, 4th and 5th metatarsals and the whole ligament complex stabilizing these three bones was carried out.
Ten cadavers were selected, in which the cuboidal and the 4th metatarsus of the right and left feet were surgically dissected, and all capsular and ligamentar structures were dried. These pieces were kept in refrigerator (Continental brand) to provide a controlled environment at –10° C for 30 days.

Technique

The 10 pairs of pieces were submitted to decortication of the proximal joint surface of the 4th metatarsus and of the distal surface of the cuboidal with the aid of a chisel and a hammer. Then, joints were reduced and juxtaposing of remaining surfaces with appropriate congruence was noted. (Figures 1 and 2).
The fixation material employed was a 3.5 mm Impol Cortical Screw and Uni-clip® Staple 2.0 NewDeal.
Fixation with Staple was provided with the aim of a specific instrument on the dorsal surface of the joint.
Fixation with Cortical Screw was provided with a specific instrument inserted from the dorsal cortical of the 4th metatarsal base at a 30° angle at plantar orientation towards the cuboidal – similar to a conventional surgical procedure.
All surgical procedures were carried out by only one surgeon; the anatomic inventory and reduction, surfaces juxtaposing, and proper congruence were intraoperatively checked out and assessed by three different surgeons.
After fixation, the pieces were prepared for biomechanical assay, with cuboidal's proximal end and 4th metatarsal's distal end being cemented to attach them to the test machine (Figure 3).
The machine used in this study was an universal assay machine Kratos® 5002 featuring a load cell – dynamometer – of 100 Kgf (9.810N), measured on a 50 Kgf (4.905N) scale. The tests were initiated using the following parameters: 0N at a speed of 20 mm/min, until either the synthesis or bone material failed, and measuring the force resistance peak as Newtons (Figures 4 and 5).

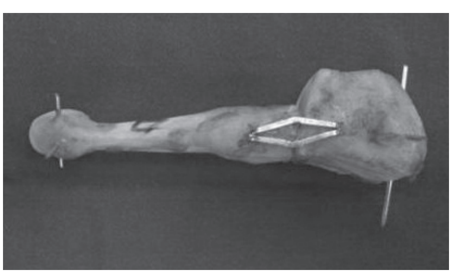

Figure 1 *– Fixation with staple.*

Figure 2 *– Fixation with cortical screw.*

Figure 3 *– Pieces prepared for biomechanical test*

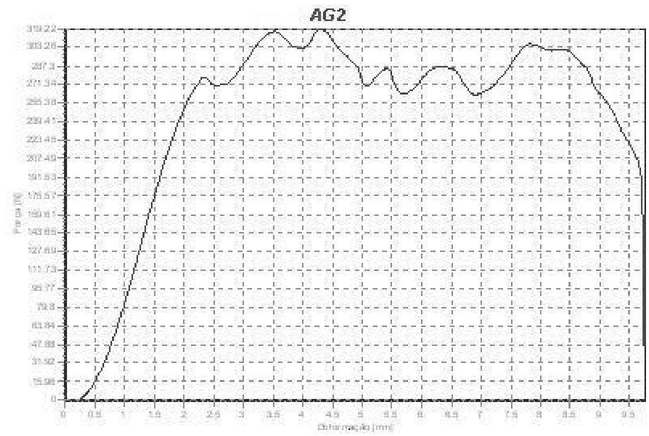

Figure 4 *– Assay 2 staple*

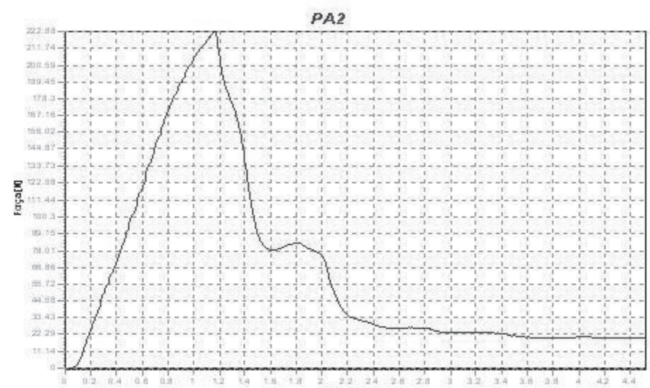

Figure 5 *– Assay 2 cortical screw*

Statistical analysis of results:

The results analysis was provided by means of "Prism test" and "Wilcoxon's matched pairs test", Linear Regression and "Mann-Whitney's Paired test" for fixation's biomechanical resistance strength at a significance level of $p < 0.05$.

RESULTS

Donator cadavers' mean age was 41.1 years, ranging from 35 to 49 years. All of them were males. The 20 biomechanical assays were completed.
The resistance peaks were measured as N force for Staples and Cortical Screws (Table 1).
The Staple's mean maximum force was found to be greater than that measured with the Cortical Screw –and the minimum force measured for Cortical screw is lower than that of the staple (Table 2).

The charts comparing synthesis methods vs age of the piece showed a clear correlation of the synthesis material's resistance strength with the age group. Superior force values are found for Staples in osteoporotic bones (Tables 3 and 4).

Assay	Staple	Screw
1	333N	323N
2	320N	223N
3	152N	311N
4	313N	342N
5	278N	253N
6	164N	169N
7	145N	168N
8	123N	116N
9	146N	21N
10	164N	22N

Table 1 *– Distribution of the maximum resistance peak paired on biomechanical assays for fixation with Staples and Cortical Screws.*

	Staple	Cortical Screw
Mean	213.8N	196.8N
Standard Deviation	27.03981	37.84994
Median	164	196
Mode	164	#N/D
Standard Deviation	85.50737	119.692
Sample Variance	7311.511	14326.18
Kurtosis	–1.96596	–1.13356
Asymmetry	0.502795	–0.28155
Interval	210	322
Minimum	123	21
Maximum	333	343
Sum	2138	1968
Counting	10	10
Cvp	39.99409	60.81911

p= 0.3848

Table 2 *– Comparative statistical parameters of the fixation methods as assessed by the single-tail Wilcoxon's paired non-parametric test.*

Staple Assay	Age	Load Peak
1	35	333
2	35	320
3	37	152
4	37	313
5	38	278
6	45	164
7	44	145
8	43	123
9	49	146
10	48	164

Mean	41.1	213.8
SD	5.322	85.507
Standard error	1.683	27.040
Quartile 1	37	146
Median	40.5	164
Quartile 3	45	313
Minimum	35	123
Maximum	49	333
Counting	10	10

p= 0.008502 *

Table 3 *– Distribution of load peak for fixation with Staple vs. age as assessed by Linear Regression test.*

Assay Cortical Screw	age	Load Peak
1	35	323
2	35	223
3	37	311
4	37	342
5	38	253
6	45	169
7	44	168
8	43	116
9	49	21
10	48	22

Mean	41.1	196.8
SD	5.322	119.692
Standard error	1.683	37.850
Quartile 1	37	116
Median	40.5	196
Quartile 3	45	311
Minimum	35	21
Maximum	49	343
Counting	10	10

p= 0.000233 *

Table 4 *– Distribution of load peak for fixation with Cortical screw vs. age as assessed by Linear Regression test.*

In the statistical analysis of the values found on the work area of assays' charts (Table 5), the Staple is shown to be superior in all measured parameters, namely: maximum force, maximum deformation, accrued energy until force peak is reached, and assay's overall energy, showing statistically significant difference on the last two measurements.

DISCUSSION

The optimal method for fixating arthrodeses of the Lisfranc's joint complex should ideally provide stability, with high compression ability and minimal surgical aggression[2,5].

Stabilization with Kirshner's wires, despite being easier, does not provide proper compression, and the use of plates and screws has as a disadvantage a high degree of surgical aggression, and, in some patients, postoperative discomfort, sometimes requiring removal of the synthesis material after procedure consolidation[8,11].

Today, the method of choice for most authors is the cortical screw, which, when percutaneously introduced, assure an excellent stability and compression, with restricted surgical aggression. This method, however, has as a disadvantage a challenging screw positioning requiring a too acute insertion angle with the resultant potential of fracture and mechanical stress concentration on bone cortical on which the screw head is supported. The consequence of this complication is the loss of correction, stabilization and a difficult secondary correction[10].

The alternative use of compression staples allows for compression exactly on the arthrodesis core, providing excellent stability and restricted surgical aggression. In addition, the introduction of staple nails perpendicularly to the bone yields a larger support area compared to screws.

The objective of this study was to compare the stability provided by fixation with cortical screws to compression staples in fixating Lisfranc's complex arthrodeses by means of traction mechanical assays.

		FMAX	DMAX	ENERGY TO FMAX	OVERALL ENERGY
	Mean	213.8	6.319	577.421	1058.853
	Standard Deviation	85.25867	2.27696	335.92779	626.93909
	Median	164.35	6.205	509.45	843.765
ST	Q1	147.6	4.32	297.75	641.325
	Q3	304.075	8.275	835.9525	1307.875
	Minimum	123.1	3.38	162.5	488.3
	Maximum	332.9	9.73	1118.5	2379.9
		FMAX	DMAX	ENERGY TO FMAX	OVERALL ENERGY
	Mean	195.81	3.656	253.598	546.432
	Standard Deviation	121.36263	3.1539	315.79243	578.28205
	Median	195.85	2.29	144.75	395.01
CS	Q1	128.95	1.6275	132.125	229.325
	Q3	296.325	4.66	262.59	435.125
	Minimum	11.9	1.16	39.1	47.4
	Maximum	343.7	11.39	1114	1723.1
	p value	0.721	0.074	0.047	0.047

***Table 5 –** Statistical representation of Force vs Deformation graphs with Staples and Cortical Screws, by means of analysis of ST vs CS averages with the Mann-Whitney's Paired test.*

Recommendations against this kind of assay include the use of non-physiological loads applied to the assembly and the potential deformation of the staple during mechanical tests.

Our results show that the assembly resistance with the staple was greater than with the screw in all assays, despite the absence of statistically significant differences.

In two tests, the load peak withstood by the assembly was quit inferior to all other tests. This fact was interpreted as a condition of reduced bone resistance to the employed material, probably associated to osteoporosis or to the presence of systemic disease.

On these samples, the result of the staple assembly was quite superior to the one withstood by the assembly with cortical screw, thus indicating that, in patients with low bone stock or with poor quality bones, the use of staples is much more advantageous than the fixation with screws.

Still, the need to conduct further comparative clinical studies is warranted to confirm these experimental findings.

CONCLUSION

Load peaks supported by staples and cortical screws are significantly reduced with age. superior force values are found for staples in osteoporotic bones. the accrued energy on graphs' work areas in assays with staples is shown to be statistically superior to cortical screws' values

Average load peaks supported with fixation with staples are superior to those shown with fixation with cortical screws, although they did not reach statistical significance.

Load peaks supported by fixation with Staples and cortical screws are significantly reduced with age. However, superior force values are found with Staples on osteoporotic bones.

The accrued energy until maximum force is reached, as well as the overall accrued energy in assays with staples are shown to be statistically superior to Cortical Screws' values.

The staple is shown to be stable and technically reproducible as a method for Lisfranc arthrodeses fixation.

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