The Inverted Z Bunionectomy: Quantitative Analysis of the Scarf and Inverted Scarf Bunionectomy Osteotomies in Fresh Cadaveric Matched Pair Specimens

Quantitative analyses of the Scarf/Z and inverted Scarf/Z bunionectomy osteotomy procedures utilizing two-screw fixation were performed in fresh cadaveric specimens. Eighteen trials (nine matched pair feet) were used for direct comparison. Ultimate strength and failure areas were examined. Trial results revealed a strong statistically significant positive effect. The inverted Z approach was found, on average, 1.6 times stronger in resisting simulated weightbearing forces on the capital fragment to failure than that of the traditional Z bunionectomy osteotomy.

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Hypothesis

Reversal of the traditional Scarf or Z bunionectomy osteotomy utilizing two-screw fixation is superior in resisting weightbearing forces on the capital fragment that cause osseous fatigue/fracture.

Many surgical procedures have been devised for correction of hallux valgus deformity. Various surgical approaches have been considered, and at least 130 different procedures have been described in the literature (1-3). At present, osteotomy of the first metatarsal with internal fixation is commonly used for correction of moderate to severe metatarsus primus varus associated with this deformity.

In 1983, Gudas *et al.* described the Z bunionectomy.[7] This, essentially, was a modification of the transverse plane osteotomy made through the shaft of the first metatarsal as described by Mau and Lauber (1, 4) (Fig. 1). The osteotomy is a horizontally directed displacement Z osteotomy that is performed at the diaphyseal junction level in an upper 2/3 and lower 1/3 manner. The distal apex is placed 1 cm. proximal to the articular surface with the distal limb coursing dorsally at an acute angle of 70 to 80 degrees to the horizontal limb (1). The proximal cut, also angled 70 to 80 degrees from the horizontal limb, is directed plantarly. The horizontal bone cut is approximately 2.5 to 3.0 cm. in length and is angled 5 to 10 degrees in relation to the transverse plane in a plantar lateral direction.

The capital fragment is then transposed laterally up to 1/2 of the metatarsal width for correction of metatarsus primus varus. It may also be rotated in the transverse plane to correct for mild to moderate proximal articular cartilage deviations, Fixation is achieved with two 2.7- or 3.5-mm cortical bone screws utilizing AO/ASIF technique.[8] Satisfactory results have been achieved using this procedure with minimal complications (1, 5). The presentation of a postoperative fracture of the osteotomy, at its most proximal segment, is considered rare[7] (1).

In 1992, Chang *et al.* formulated initial research to evaluate the inherent stability of commonly used first metatarsal osteotomies in bunionectomy procedures. In particular, they evaluated the traditional scarf versus the inverted scarf osteotomy procedure (6). This research, based upon plastic sawbone models, employed nondisplaced capital fragment procedures. A manual

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[8] AO, Association for Osteosynthesis; ASIF, Association for the Study of Internal Fixation.

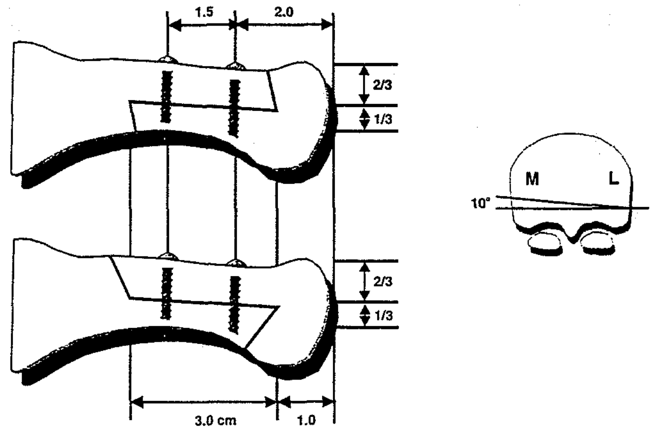

Figure 1. Above, The traditional Z bunionectomy osteotomy. Below, The inverted Z bunionectomy osteotomy.

stress/strain device quantified capital fragment force of these models. The data supported the initial premise that a consistent fracture pattern was produced with each osteotomy. In addition, the Scarf/Z bunionectomy failed with a significantly less quantitative force as compared with the inverted Scarf/Z bunionectomy (4 and 18 lb. dorsiflexory force, respectively).

Our research evaluated these two osteotomies performed on fresh cadaveric specimens in a matched pairs design. As both procedures were performed on the same subject, alternating feet, this allowed for physiologic standardization of bone strength between osteotomies. A proximal cut modification was utilized in the inverted Z method (Fig. 1).

Methods and Materials

Specimens

Fresh frozen, unembalmed specimens were utilized for the scientific trials. Nine matched pairs were evaluated for a total of eighteen specimens and were stored at −20 degrees C until thawed for dissection of the first metatarsal and cuneiform segments *in toto.* Between trials, the specimens were kept in dampened towels with 0.9 normal saline solution to prevent desiccation. Specimen age ranged from 55 to 85 years with no evidence of previous foot surgery or trauma. Sawbone trials were initially performed in an attempt to reproduce the findings of Chang *et al.*

Equipment

A computer integrated Instron materials testing machine (Model 1122) was utilized to quantify force upon the capital fragment. A linear variable differential transducer (LVDT) (Model S5, Ultra Precision: Sensotic, Columbus, OH) was also used to measure gaping across the osteotomy site. This allowed for increased precision of the point of failure when integrated through the computer software. The resolution of the LVDT is approximately 1 micron. Computer software consisted of a data translation analog to digital board (Marlboro, MA).

The specimens were potted for trials with bone cement, crossed Kirschner wires traversed the metatarsal-cuneiform joint, and subsequently placed in the Instron holding device. Fifteen degrees of metatarsal declination was used. The design apparatus was constructed in a reciprocal manner, necessitated by convention of the Instron machine (Fig. 2).

Experiment

To validate the findings of Chang *et al.*, sawbone trials were performed using the previously described trial formation. Displaced and nondisplaced trials were performed with our findings being consistent with their original observations: 1) failure with the traditional Z with as little as 39.5 N (4.03 lb.) of force and 2) the nontraditional, or inverted Z, with 99.2 N (10.12 lb.) to 170.6 N (17.4 lb.) of force upon the capital fragment. Failure patterns were also reproduced as described by Chang (Fig. 3).

Before beginning the cadaveric trials, plain film radiographs were taken of all specimens. All subjects were noted to have similar cortical thickness of the first metatarsal between individual paired feet with no evidence of previous trauma, surgery, or osseous defects. Alternating left and right feet between subjects, a traditional Z and nontraditional (inverted) Z osteotomy was performed in a standardized manner (Fig. 1).

A power bone cutting saw was utilized for osteotomy cuts performed by the senior author. Since direct vis-

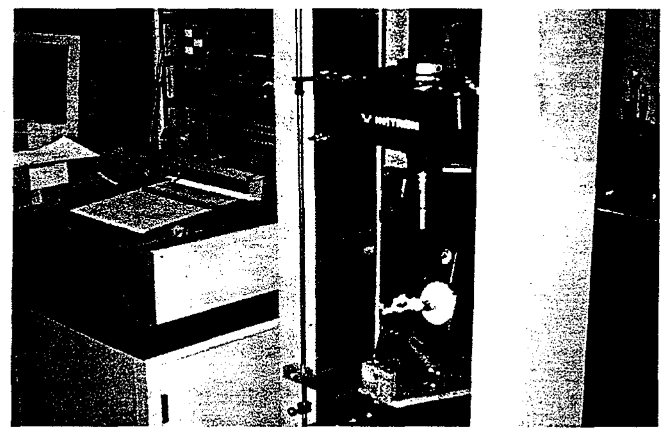

Figure 2. Instron materials testing machine with sawbone model in-holding device. Trials holding device is positioned with 15 degrees of inclination to accept force piston in an upside-down manner necessitated by the equipment.

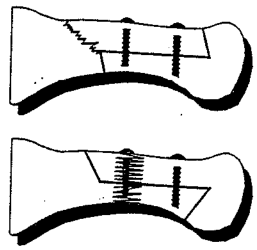

Figure 3. Failure areas of sawbone trials performed to reproduce original sawbone research by Chang *et al.* (6). Above, Traditional Z failure per stress riser formation. Below, inverted Z stress riser failure at site of the proximal screw.

ualization was available across the entire metatarsal segment, precise osteotomy cuts could be made easily. The osteotomy sites were inspected for accuracy and to ascertain that no over-cutting was performed, which could lead to stress riser formation. The capital fragment was then transposed 1/3 the metatarsal shaft width as described previously (1). This was performed to mimic the *in vivo* correction of metatarsus primus varus. Two 2.7-mm. cortical screws were placed in a standardized manner across the osteotomy utilizing AO/ASIF technique (7) (Fig. 1).

The specimens were potted as described and mounted on the Instron to allow 15 degrees of metatarsal declination. The LVDT was placed about the osteotomy segment where gaping should occur with capital fragment loading. The target plate for the LVDT was placed parallel to the osteotomy on the stable (proximal) portion, and the LVDT piston was placed on the force-accepting portion of the construct. (Fig. 4).

The force arm of the Instron was aligned upon the plantar metatarsal head to apply graduated capital fragment forces. Force was applied at a speed/load rate of 2.0 mm./min./200 kg. until osseous failure was noted. Documentation of failure areas and ultimate strengths was performed.

Data Analysis

Instron force quantification and LVDT distraction data were directly fed into the computer software utilizing a data translation analog to digital board. Graphic analysis was also performed for all trials (Fig. 5). Due to the inherent variability of LVDT placement and perhaps slight rotational forces propagated from a displaced osteotomy, the gaping was used only to augment the exact point of osseous failure/fracture. This was appreciated by noting an acute increase in fragment separation at the point of failure.

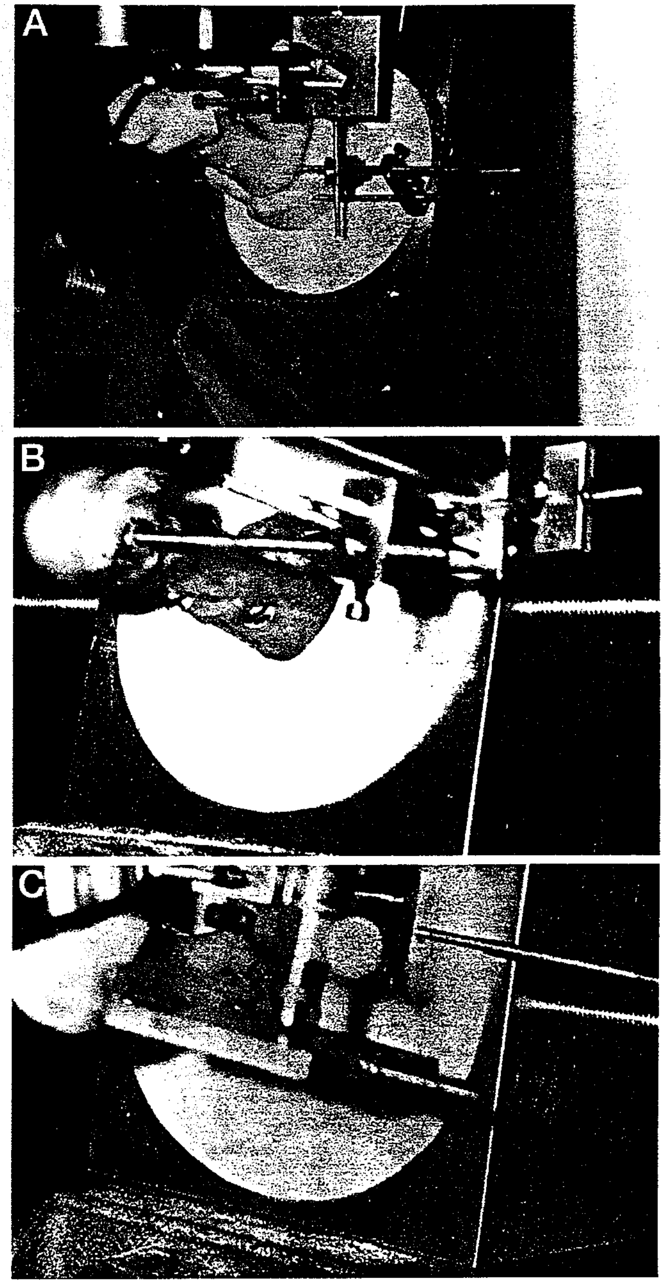

Figure 4. *A*, Traditional Z sawbone trial set up. Note Instron force arm upon capital fragment and LVDT, set up. *B*, Cadaveric trial of traditional Z set up. *C*, Cadaveric trial of inverted Z set up.

The raw data was reviewed and one set of difference scores calculated. It was hypothesized that if the intervention was ineffective, the average change in scores would be 0. An alpha coefficient was set at 0.05. The data were summed and standard deviation scores calculated. All equations were converted to obtain the final test statistic, which was then compared with a critical value of T_{cv} 0.051; 1.895, df 8.

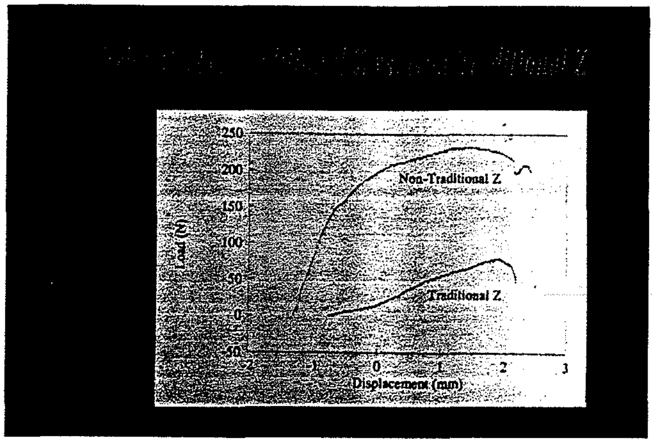

Figure 5. Force versus displacement of traditional and non-traditional (inverted) Z cadaveric trial #30821.

Results

A consistent failure pattern was reproduced with the traditional Z osteotomy in all trials. This fracture pattern is noted well in the literature, and seems to be caused by the stress riser produced from the proximal plantar cut (1, 6) (Fig. 6).

The inverted Z produced a relatively consistent failure pattern (six of nine cases). This failure area was located on the tension side of the bone with an explosion/fragmentation type pattern (Figs. 6, 7). The other three trials showed fixation failure prior to bone failure; this being distal screw pullout. The primary failure area in cadaveric bone was not consistent with failure patterns found in sawbone trials (proximal screw stress riser formation). This was not surprising because the anisotropic nature of bone creates a more complex model as compared with sawbone units. Trabecular patterns, cortical dynamics, and elastic properties of bone, in particular, create such a complex structure.

Quantitative analysis of ultimate strength to failure of the Z *versus* inverted Z bunionectomy yielded a mean of 101.92 N (10.40 lb.) *versus* 162.24 N (16.56 lb.), respectively. That is, the inverted Z osteotomy was shown to be approximately 1.6 times stronger than the traditional Z osteotomy in resisting simulated weight-bearing forces on average. The largest difference between ultimate strengths of the paired osteotomies was found to be about 15.7 lb. (Trial 30821). Six of the trials showed this consistent difference in strengths, however, three of the trials showed slight reversal of these findings (Fig. 8). A strong statistically significant positive finding was obtained in the comparison of the two methods ($T = 2.68$, $p = 0.0275$, 95% CL 8.6422, 154.234).

Average Failure Areas of Cadaveric Trials

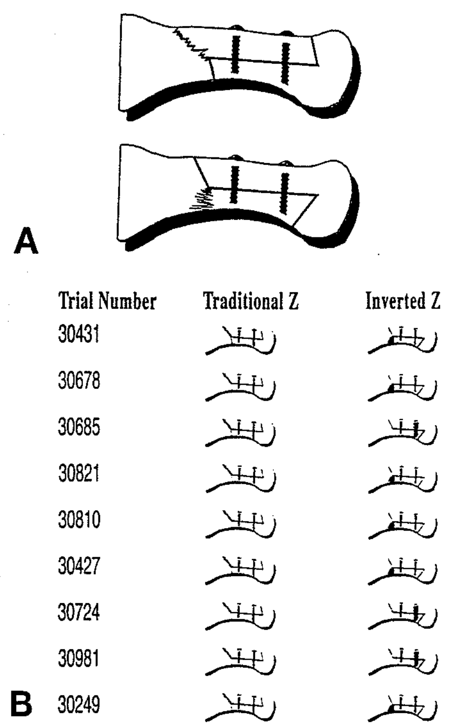

Figure 6. *A*, Failure areas in cadaveric trials of traditional and inverted Z bunionectomy osteotomies. *B*, Failure areas in all cadaveric trials.

Discussion

The Z bunionectomy, as described by Gudas, has been utilized by numerous podiatric surgeons over the past 10 years with good results. A rare but significant complication of this procedure has been postoperative fracture of the metatarsal at its proximal segment. The

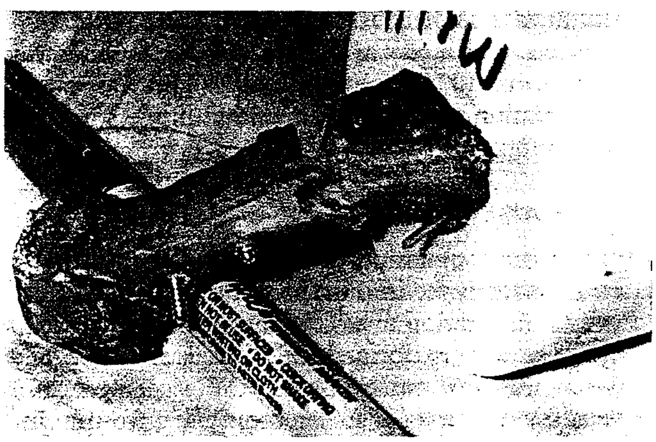

Figure 7. Failure area noted with the inverted Z in cadaveric trial #30821. Note the gross fragmentation and explosion type pattern consistent with complete ultimate osseous failure.

A

Traditional Z	Ult. Strength (N) Trad.	lbs	Non-Traditional Z (inverted Z)	Ult. Strength (N) Non-Trad.	lbs
30431 L	47.90	4.84	30431 R	100.59	10.26
30678 R	45.98	4.69	30678 L	188.73	19.26
* 30685 L	35.45	3.62	30685 R	140.83	14.37
30821 R	79.51	8.11	30821 L	233.75	23.85
30810 L	124.18	12.67	30810 R	189.69	19.36
30427 R	141.79	14.47	30427 L	128.37	13.10
* 30724 L	72.48	7.40	30724 R	55.47	5.66
* 30981 R	156.06	15.92	30981 L	231.12	23.58
30249 L	213.96	21.83	30249 R	191.60	19.55

* *Fixation failure (distal screw pull-out)*

B

	Traditional "Z"	*Inverted "Z"*
Variable Count	9	9
Mean	101.92 N	162.24 N
Standard Deviation	+/- 60.63	+/- 60.19
Minimum	35.45 N	55.47 N
Maximum	213.96 N	233.76 N
Trial Max. Difference	79.52 N (8.11 lbs)	233.76 N (23.85 lbs)

* mean difference: 1.6 x stronger (*p* = 0.0275)

Figure 8. *A*, Quantitative data in all cadaveric trials. Trials 30427, 30724, and 30249 show slight reversal of expected results. *B*, Mean, standard deviation, and range calculations.

ramifications of such a complication include metatarsus elevatus, malunion and possible need for further operative intervention. The occurrence rate for this complication is not well documented in the literature. In the original study of the Z bunionectomy, fracture of the first metatarsal was noted in two cases (two occurrences in 66 feet, or 3% occurrence) (1). In discussion with Dr. Gudas, he relates observing a few of these postoperative fracture complications over the years; however, he believes most are a result from technical errors, poor patient selection (>55 years of age), and postoperative trauma rather than from normal postoperative protected ambulation.[9] He also added that this type of complication was greatly reduced when the osteotomy was revised to a 2/3 and 1/3 horizontal cut as described in the original manuscript (1). The authors have had one occurrence of this particular complication with the Z osteotomy.

With critical analysis of the osteotomy cuts utilized in the traditional Z bunionectomy osteotomy, it is clear that the proximal cut creates a significant stress riser with weightbearing forces (Fig. 9). The strength of this osteotomy relies directly in the strength of the proximal dorsal shelf, hence the original author's valid recommendation for creating the longitudinal osteotomy in

Traditional Z Stress Riser

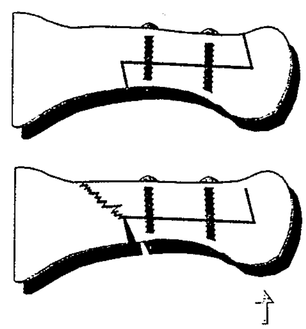

Figure 9. The proximal osteotomy cut in the traditional Z creates a significant stress riser with weightbearing.

the lower 1/3 of the shaft to create a more stable construct in resisting capital fragment forces (1, 6).

The proximal plantar cut interrupts the tension side of the first metatarsal, which is anatomically the strongest portion of this bone in resisting weightbearing forces. With interruption of this plantar cortex, primary trabecular patterns are invaded allowing propagation of force superiorly often known as a stress riser. Preservation of the proximal plantar cortex is the primary principle at which inversion of the traditional Z bunionectomy osteotomy produces inherent stability.

Figure 10 depicts weightbearing forces across the first metatarsal with the inverted Z. As force is applied across the capital fragment (metatarsal head), pressure is transmitted against the interlocking segments of the distal plantar cut. Because the fragments are held securely per the screw fixation, this prohibits distal propagation of the capital fragment and allows the interlocking construct distally to transmit the capital forces back to the

Inverted Z Weightbearing Force Vectors

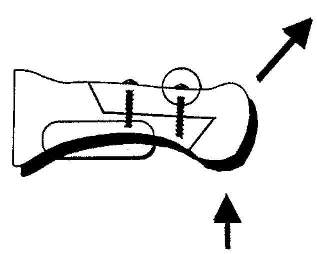

Figure 10. With loading of the capital fragment in the inverted Z (inferior arrow), the capital fragment transmits pressure upon the distal interlocking osteotomy. This changes the force vector (superior arrow) to a resultant distal superior propagating force. With screw fixation prohibiting this distal propagation and the inherent interlocking segment stability from the distal cut, the weightbearing forces are accepted back to the strength of the intact plantar cortex.

[9] Personal communication Charles Gudas, DPM, Chicago, IL.

intact plantar segment. This, in theory, should be capable of accepting weightbearing forces to the same point at which the bone would fail physiologically. This is supported by the complete explosion/fragmentation pattern seen with failure of this construct on the tension side of this bone (Fig. 7).

This experimentation provides basic scientific data of the inherent stability of the Z bunionectomy and inverted Z bunionectomy with a proximal cut modification to substantiate our hypothesis. The proximal cut modification does not factor in the stability of the construct. It merely adds more dorsal area for screw placement and provides less binding when the capital fragment is rotated for proximal articular correction, if required.

Fresh cadaveric matched pair specimens were used to provide physiologic standardization between procedures in a direct comparison study. The capital fragments were also displaced to try to mimic the *in vivo* situation for first metatarsal reconstruction in hallux valgus surgery.

The authors report a statistically positive difference between the stability of the traditional versus nontraditional approach. On average, the inverted Z bunionectomy is inherently 1.6 times more stable in resisting simulated weightbearing forces than the traditional Z.

The traditional Z bunionectomy produced a consistent failure pattern originating from the stress riser produced from the proximal plantar cut. This occurred in 100% of the trials (nine out of nine specimens). This is consistent with the postoperative fracture complication described earlier (Fig. 11).

The nontraditional, or inverted Z osteotomy also revealed a relatively consistent fracture pattern when forced to failure. This fracture pattern occurred in six of the nine trials, or 65% of the time. The three trials where this did not occur represented fixation failure (distal screw pullout), presumably resultant from poor bone quality secondary to osteopenia.

The average pressure to failure in the trials was 162.23 N (approximately 16.6 lb.). With review of the current literature, the average peak pressures of the first metatarsal head in normal asymptomatic patients has been quantitated approximately 8 lb. (Bennett 1993: 3.1 ± 0.9 kg./cm.^{2} or approximately 8 lb.; Duckworth 1988: 3.5 kg./cm.^{2} or approximately 7.7 lb.) (8, 9). However, recent unpublished studies utilizing the F-scan are now predicting these peak pressures to be upwards of approximately 20 lb.

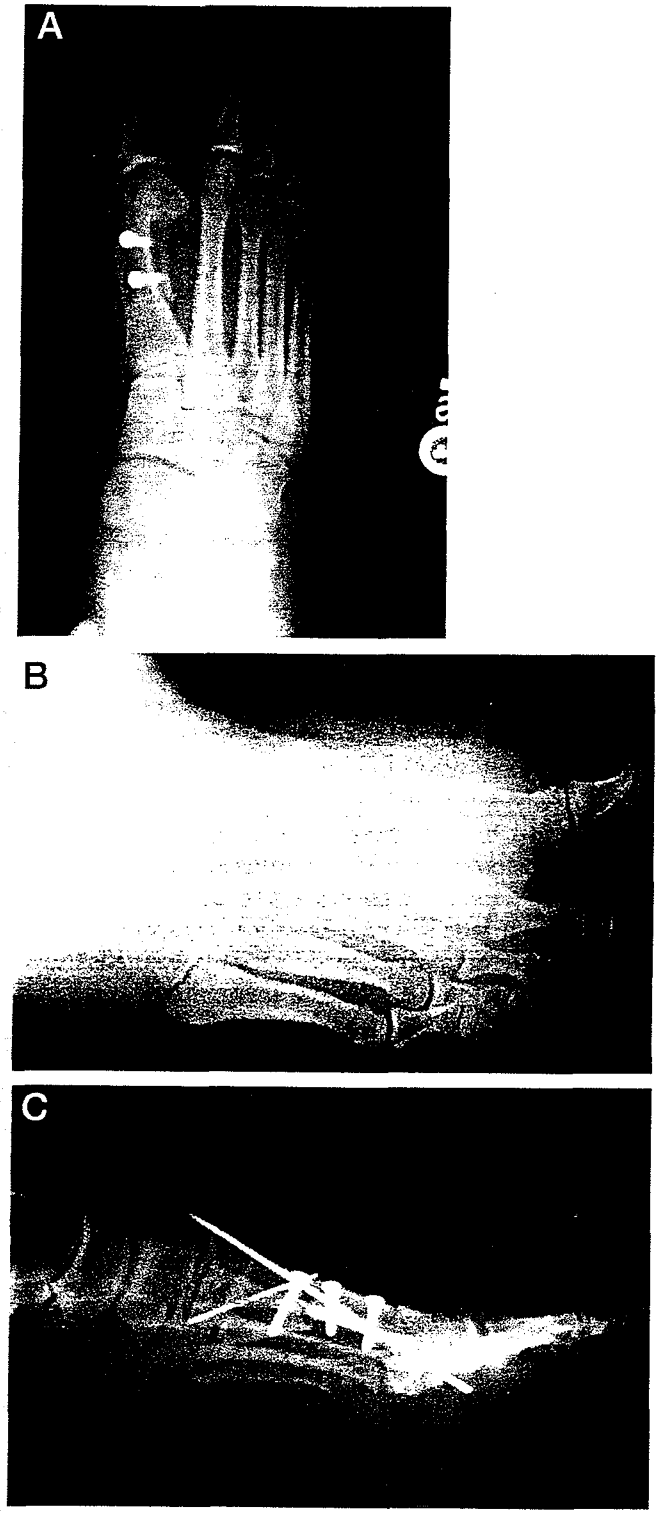

Figure 11. *A*, Postoperative radiograph of a traditional Z bunionectomy with satisfactory result. *B*, Oblique radiograph of the same patient showing fracture of the osteotomy 2 days postoperatively after mild trauma to the affected foot. The patient had been walking without surgical shoe protection (unadvised) and subsequently tripped and fell, injuring the surgical area. Fracture locale is at the proximal dorsal aspect of the osteotomy. *C*, Postoperative radiographs after open reduction with internal fixation of the fracture. (Above radiographs compliments of Charles Reilly, DPM).

In theory, with the inverted Z maintaining the plantar proximal cortex intact (the tension side of bone), and the failure noted being complete explosion/fragmentation, this represents physiologically peak pressure to failure of the first metatarsal itself, not only of the osteotomy. Chang *et al.*'s sawbone models also reflect this theory, noting failure of the Inverted Z and non-osteotomized model at 18 lb. of force (6, 10). Considering the age of the cadaveric subjects (55 to 85 years of age), this ultimate strength is probably exceedingly larger in the age group that most commonly undergo an osteotomy procedure of this type.

An additional advantage of the inverted Z approach, besides its inherent stability and ultimate strength, concerns channeling or troughing of the capital fragment. If such an event occurs, it will actually lead to plantarflexion of the metatarsal head. This, as opposed to dorsiflexion observed with the traditional Z, is biomechanically more advantageous. The inverted Z also appears to be technically easier to perform due to the proximal cut being dorsal, allowing better visualization of the osteotomy junctures and decreased intraoperative over-cutting. This new procedure also requires less plantar dissection than the traditional Z (Fig. 12).

The indications and correction potential for the inverted Z appear identical with the traditional Z bunionectomy approach. This procedure is currently being utilized at Loyola University Medical Center in patients where traditional Z bunionectomies were performed in the past. Thus far, we have not observed a difference in outcomes, and intraoperative findings allowed us to cite some of the above advantages.

Limitations

Our research results should be tempered with the following considerations: 1) small sample size of trials (18 specimens); and 2) age of cadaveric specimens (55 to 85 years of age). Although the sample size was small. statistical analysis of experimental data yielded significant findings ($p = 0.0275$). With an aged specimen group, ultimate strength of osteopenic bone may be considerably lower than expected in the population that traditionally undergo an osteotomy procedure (11). However, because trials were performed in a matched pair fashion, the inherent stability ratio still proves valid.

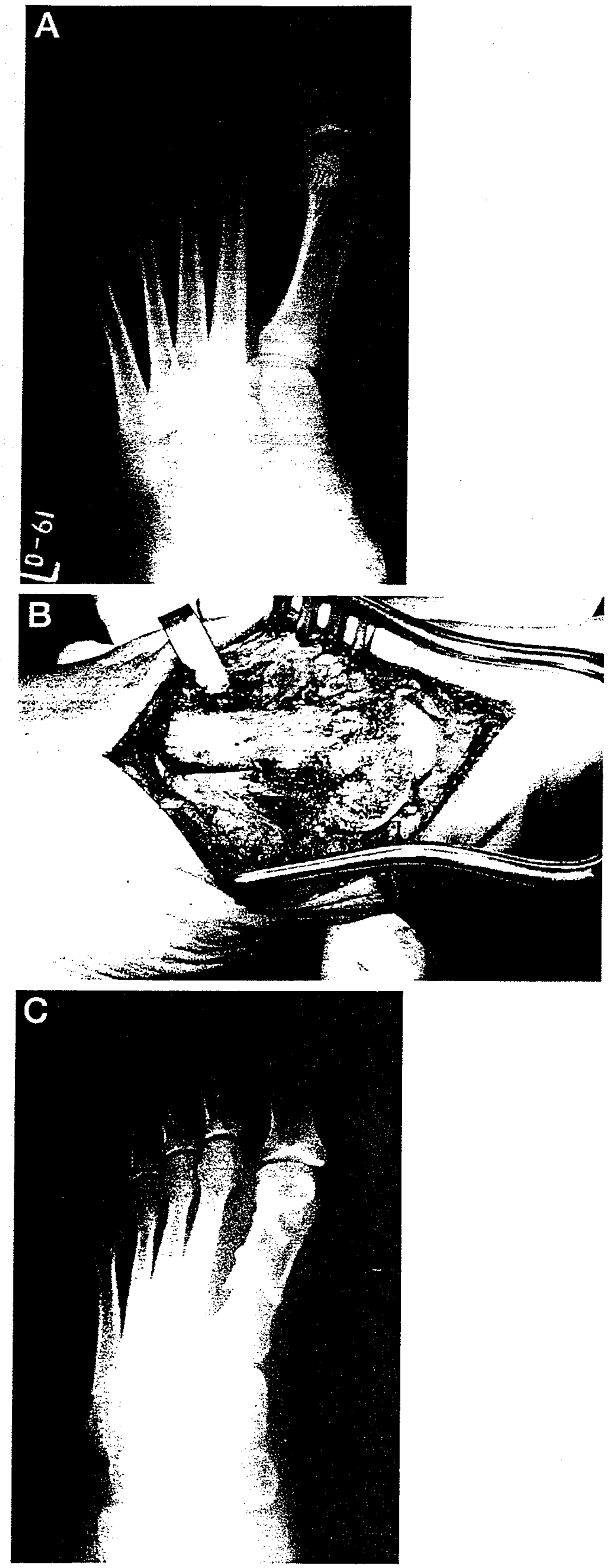

Figure 12. *A*, Preoperative radiograph of a patient with hallux valgus deformity. *B*, Intraoperative picture showing an inverted Z bunionectomy osteotomy. Note the distal interlocking segment, slight rotation of the capital fragment in the transverse plane to correct for proximal articular cartilage deviation, and two 2.7-mm. screw fixation. *C*, Postoperative radiograph of the inverted Z bunionectomy procedure in the same patient.

Conclusion

This research project provides basic scientific data that supports strength of the described procedure *versus* the other, and also points out other advantages over the traditional procedure. In our research trials the authors were able to show with statistical significance that the inverted Z bunionectomy osteotomy is inherently more stable than the traditional Z osteotomy in resisting weightbearing forces, on average 1.6 times stronger.

Acknowledgements

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