Ultrasound Monitoring of Fracture Healing: Is This the End of Radiography in Fracture Follow-ups?

Sourabh Chachan, MBBS, MS (Ortho), Barsha Tudu, MBBS, MS (Orth), and Biswajit Sahu, MBBS, MS (Orth), MCh (Orth)

Objective: To compare the efficacy of ultrasonography (US) versus radiography (XR) in monitoring fracture healing.

Design: Prospective diagnostic follow-up study.

Setting: Department of Orthopaedics, Level II trauma center.

Patients: Forty-eight acute closed tibial mid diaphysis fracture (OTA 42-A and B) treated by closed reduction and internal fixation with a reamed statically locked tibial interlocking nail between October 2011 and October 2012.

Intervention: Evaluation of fracture healing using both US and XR at 2 week intervals.

Main Outcome Measurements: Ultrasonographic criterion for fracture healing was set as progressive appearance of periosteal callus along with progressive decrease in visibility of nail. Radiographic criterion for fracture union was set as the appearance of bridging callus across all 4 cortices.

Results: Thirty-eight of 48 fractures achieved union, 6 developed a delayed union, whereas 4 went onto nonunion. It was observed that using the above-stated criteria, fracture union was diagnosed at an average of 2 weeks earlier with US as compared with XR. Four of the 6 delayed unions and all nonunions declared themselves much earlier on US versus XR.

Conclusions: Ultrasonography can provide valuable early information about union and predict delayed and nonunions at an earlier time interval than standard plain radiographs.

Key Words: ultrasonography, radiography, fracture healing, delayed union, nonunion, trauma

Level of Evidence: Diagnostic Level II. See Instructions for Authors for a complete description of levels of evidence.

(*J Orthop Trauma* 2015;29:e133–e138)

Accepted for publication July 14, 2014.

From the Department of Orthopaedics, Veer Surendra Sai Medical College, Sambalpur, India.

Presented in part at the Annual Meeting of the Orthopaedic Trauma Association, October 11, 2013, Phoenix, AZ.

The authors report no conflict of interest.

Reprints: Sourabh Chachan, MBBS, Room No. 208, PG hostel, Veer Surendra Sai Medical College, Burla, Sambalpur 768017, Orissa, India (e-mail: chachansourabh@gmail.com).

INTRODUCTION

Since its inception in 1895, radiography has been extensively used in the diagnosis, classification, treatment, and follow-up of fractures.[1,2] Despite the presence of various advanced modalities for imaging the skeletal system, radiography is still the primary imaging modality in fracture management.[2] Radiographs offer the convenience of easy availability, cost-effectiveness, and good visualization of bony structures.[1,2] Usefulness of radiography in fracture management is undoubted, but it is poor at visualizing soft tissues and also leads to radiation exposure, which can be quiet harmful in pregnant women and children.[1,2] Universally, a combination of clinical findings and radiographic examination has been used to monitor the fracture healing process and detect any adverse outcomes.[1,3–8] Various studies have reported high false-negative rates and delay in the diagnosis of nonunion with the use of radiography.[4,5,9–13]

Although ultrasound waves were discovered before x-rays, they were used for medical imaging much later.[14] This technology is based on the echogenicity of tissues.[14,15] Ultrasonography has mainly been used for imaging intraabdominal and pelvic structures.[16] In orthopaedics, its use is limited to imaging soft-tissue conditions such as joint effusions, tendon and ligament injuries, muscle trauma and tumors, nerve injuries, and for needle guidance during nerve blocks.[17–21] Ultrasonography has the advantages of being rapid, simple, economical, and radiation free and offers good visualization of soft tissues.[1]

This study was conducted to compare the efficacy of radiography versus ultrasonography in monitoring fracture healing.

PATIENTS AND METHODS

A prospective follow-up study was conducted from October 2011 to October 2012. All patients with acute closed fractures of the middle third of the tibial shaft treated with a statistically locked reamed intramedullary nail (IMN) were assessed for this study. The purpose of the study was explained to, and informed written consent was obtained from, every patient enrolled. The cases were included in the study on the second postoperative day. Each patient underwent both US and XR at 2-week intervals. An orthopaedic surgeon who was blinded to the ultrasonographic findings predicted fracture healing based solely on XR, and similarly, an ultrasonographer who was blinded to the radiographic findings predicted fracture healing based solely on US.

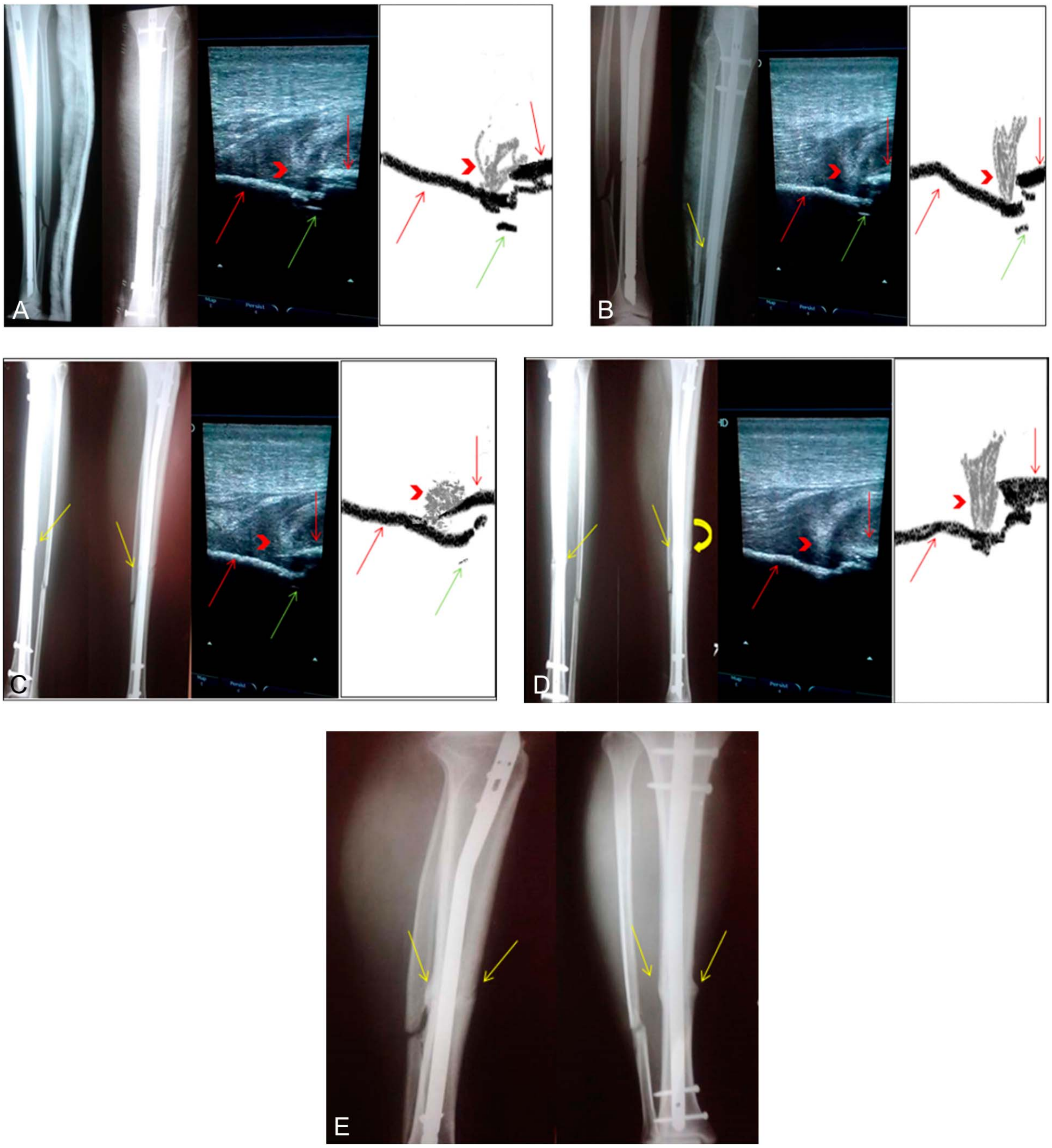

FIGURE 1. A, A 24-year-old patient at 2-week postoperative radiograph showing fracture line without any bridging callus; ultrasonography (original and illustration) showing bone cortex (red arrows), nail (green arrow), and periosteal soft callus (red arrow heads). B, The same patient at 4-week postoperative radiograph showing bridging callus (yellow arrow) across the posterior cortex; ultrasonography (original and illustration) showing bone cortex (red arrows), decreased nail visibility (green arrow), and increased periosteal soft callus (red arrow head) as compared with previous ultrasonography. C, The same patient at 6-week postoperative radiograph showing bridging callus (yellow arrows) across the lateral and posterior cortex; ultrasonography (original and illustration) showing bone cortex (red arrows), decreased nail visibility (green arrow), and increased periosteal soft callus (red arrow head) as compared with previous ultrasonography. D, The same patient at 8-week postoperative radiograph showing bridging callus (yellow arrows) across the lateral and posterior cortex with small increase in callus (curved yellow arrows) across the anterior cortex; ultrasonography (original and animation) showing bone cortex (red arrows), absence of nail, and increased periosteal soft callus (red arrow head) as compared with previous ultrasonography. Ultrasonographic diagnosis of fracture union was made. E, Radiograph of the same patient at 12 weeks postoperatively showing bridging callus (yellow arrows) across all the 4 cortices. Radiographic diagnosis of fracture union was made.

Radiographic findings were recorded as follows. Union was defined as bridging callus across 4 cortices, delayed union was defined as slow appearance of bridging callus and minimal change in fracture gap healing in 4 consecutive radiographs, each taken 2 weeks apart, whereas nonunion was defined as minimal bridging callus and no change in appearance of fracture gap in 4 consecutive radiographs, each taken 2 weeks apart (Fig. 1).

ULTRASONOGRAPHY

Use of ultrasonography for monitoring of fracture healing has been based on its ability to delineate soft tissues with different densities.[1,5,22] When applied to a fracture site, it shows intact bone cortex as a dense white line because of complete reflection of waves from the bone surface.[15,23] However, the fracture gap, if present, allows the waves to pass through, which are now reflected from either the opposite cortex (in cases treated without nailing) or the IMN (in cases treated with nailing).[1,23] A fracture will appear as a break in the otherwise continuous white line (representing the intact bone cortex), and a second small white line, which is farther away from the first one, appears because of reflection of waves from the IMN.[1,15,23] As a fracture heals, the periosteal soft callus forms and grows in size and density with time and bridges the fracture gap.[24] This periosteal callus appears as various shades of gray depending on its density and can be delineated from the surrounding soft tissues because of differing densities of the two.[15,23] The bridging of a fracture gap by dense periosteal soft callus obscures the passages of waves through the fracture and hence the visibility of intramedullary nail decreases with time, until it completely disappears because of complete coverage of the fracture gap by soft callus.[15,22] During US therefore, a decrease in the visibility of the IMN as compared with previous ultrasonographs and an increase in the extent and density of periosteal soft callus across fracture site as compared with previous US indicates healing (Figs. 2 and 3).

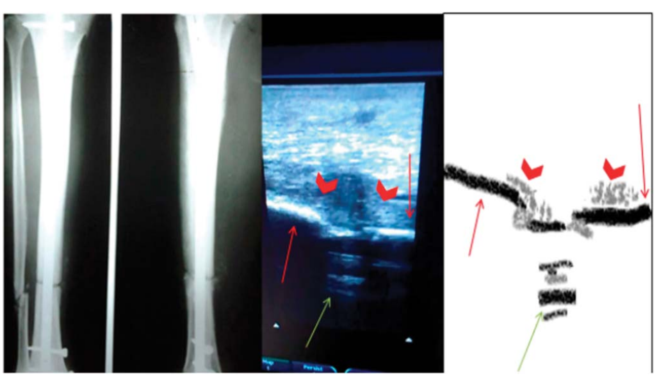

FIGURE 2. A 32-year-old patient with delayed union radiograph at 20-weeks postoperatively showing delayed union of tibia fracture; ultrasonography (original and animation) at 16 weeks postoperatively showing bone cortex (red arrows), nail (green arrow), and periosteal soft callus (red arrow heads), predicting delayed union of fracture.

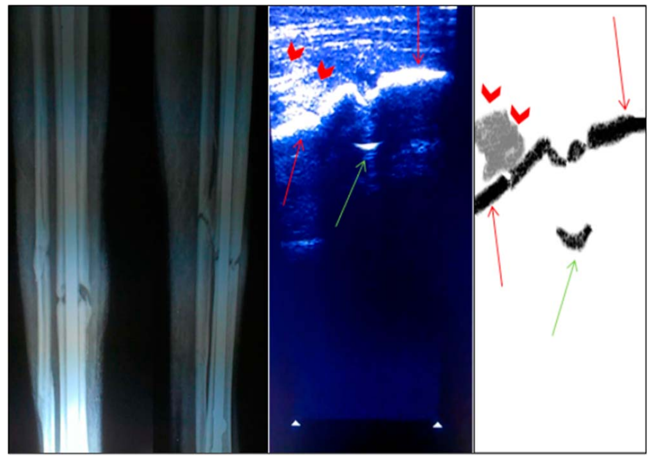

FIGURE 3. A 37-year-old patient with nonunion radiograph at 24 weeks postoperatively showing nonunion of tibia fracture; ultrasonography (original and animation) at 16 weeks postoperatively showing bone cortex (red arrows), nail (green arrow), and minimal periosteal soft callus predicting nonunion of fracture.

Union was therefore defined as a progressive increase in periosteal soft callus and decrease in visibility of the IMN followed by dense periosteal reaction and complete disappearance of nail at union. Delayed union was defined as lack of good periosteal soft callus along with slow rate of disappearance of nail in 4 consecutive ultrasonographs, each taken 2 weeks apart, whereas a nonunion was defined as no or minimal periosteal soft callus and no change in appearance of nail in 4 consecutive ultrasonographs, each taken 2 weeks apart.

For the purpose of this study, as functional outcomes were not evaluated, fractures were only followed until obvious healing or established nonunion. Data were analyzed statistically using Student *t* test, and $P < 0.01$ was considered significant.

RESULTS

There were 48 nonconsecutive fractures in 48 patients (32 male patients and 16 female patients) available to analyze, with an average injury to surgery time of 1.6 days (range, 1–4 days). Follow-up based on healing or lack thereof ranged from 14 to 52 weeks. Thirty-eight of 48 (79%) achieved union, 6 developed a delayed union, and 4 went onto nonunion.

Using US, all 38 fracture unions were diagnosed at an average of 9.74 weeks (range, 8–12 weeks). XR diagnosis of these 38 unions was made at an average of 12.11 weeks (range, 10–14 weeks). Sensitivity and specificity of ultrasonography to diagnose fracture union was 100% and 80%, respectively using the Student *t* test, $P < 0.01$, which was significant. Ultrasonography diagnosed 4 of 6 delayed unions at an average of 17.5 weeks (range, 16–20 weeks), whereas it took an average of 23 weeks (range, 22–24 weeks) to diagnose these delayed unions radiographically. Two cases of delayed union were falsely predicted by ultrasonography as union, which were later diagnosed by radiography as a delayed union at 18 and 22 weeks. There were a total 4 nonunions, and all 4 nonunions were diagnosed at an average of 18 weeks (range, 16–20 weeks) with US and at 26.5 weeks (range, 24–28 weeks) using XR.

Overall, in this study, US required an average of 11.13 weeks (range, 8–22 weeks) for the diagnosis of fracture healing outcomes, whereas XR required an average of 14.54 weeks (range, 10–28 weeks). Using the Student *t* test, $P = 0.0001$, this was significant (Fig. 4, Table 1).

DISCUSSION

Successful monitoring of fracture healing process using ultrasonography has been described in only a few studies.[1,3–9,15,22,23] In 1995, Maffulli and Thornton[23] reported good results with the use of ultrasonography for monitoring the fracture healing process in 24 patients with long bone fractures and 3 cases of humerus nonunions. In 1998, Moed et al[22] reported a 97% success rate in predicting the status of union in a study involving 47 patients with a tibial fracture. In 2009, Dudkiewicz et al[5] reported successful use of ultrasonography for monitoring fracture healing in fibula and metatarsal fractures, which were treated conservatively. In 2012, Chen et al[1] used a rabbit model and concluded good feasibility of ultrasonography in monitoring fracture healing.

In this study, US imaging was able to predict fracture union at an average of 2 weeks earlier than XR. Furthermore, US was able to predict all 4 nonunions at an average of 8.5 weeks earlier than conventional XR. While evaluating the 6 delayed unions, US only predicted 4 cases accurately but did so at an average of 5.5 weeks earlier than XR. It falsely predicted union in 2 cases. Overall, US diagnosis of fracture healing was 3 weeks sooner than XR on average. These data indicate that US may be equivalent to XR and therefore be used in place of XR for routine fracture follow-up, with XR reserved for those cases that require further evaluation of healing. Large multicenter RCT studies should be performed in future to determine whether these early results bear out. The cost implications and the decrease in radiation would be of significant interest to payors and patients alike.

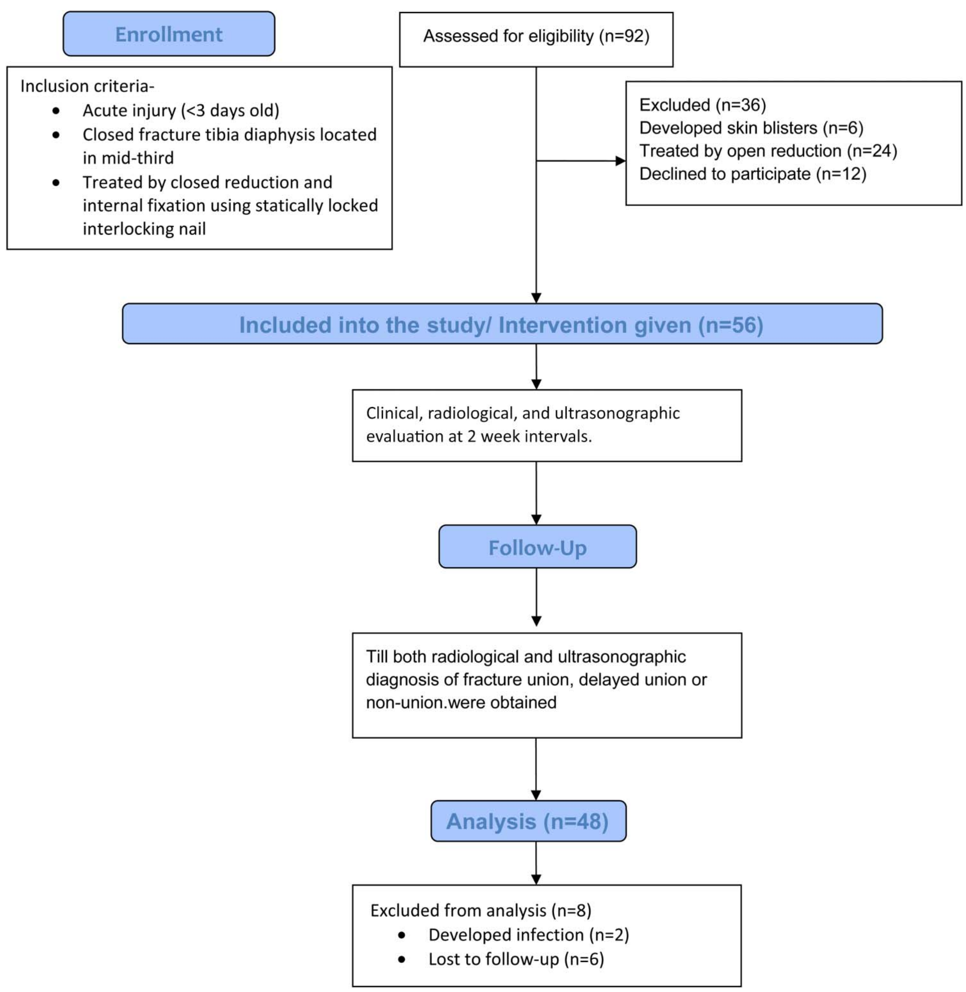

FIGURE 4. CONSORT diagram of the study analysis.

TABLE 1. Observations of the Study

S. No.	Age	Sex	Age Group	Mode of Injury	OTA	Injury Surgery Interval, d	Outcome	Follow-up, wk	USG Diagnosis, wk	Radiographic Diagnosis, wk
1	27	F	22–33	RTA	42-B2	2	Nonunion	52	18	28
2	32	M	22–33	RTA	42-A3	1	Union	20	10	12
3	23	M	22–33	SPORTS	42-A1	2	Union	22	12	14
4	24	M	22–33	RTA	42-A2	1	Union	18	8	10
5	38	M	33–44	RTA	42-B1	2	Delayed Union	36	16	24
6	26	F	22–33	FALL FH	42-A3	3	Union	20	10	12
7	31	M	22–33	RTA	42-A2	2	Union	18	10	10
8	29	M	22–33	RTA	42-A1	1	Union	18	8	12
9	38	M	33–44	RTA	42-A2	2	Delayed union	42	Nil	22
10	43	M	33–44	RTA	42-B1	1	Union	14	8	10
11	30	F	22–33	RTA	42-A3	1	Union	16	10	12
12	32	M	22–33	SPORTS	42-A2	1	Union	22	12	14
13	27	M	22–33	RTA	42-A1	2	Union	20	10	14
14	35	M	33–44	RTA	42-A2	1	Union	18	12	14
15	23	F	22–33	RTA	42-A3	1	Union	24	10	12
16	38	M	33–44	RTA	42-A3	1	Union	20	8	10
17	32	F	22–33	RTA	42-A2	2	Delayed union	32	16	20
18	29	M	22–33	FALL FH	42-A1	1	Union	16	10	12
19	28	M	22–33	RTA	42-A1	2	Nonunion	46	20	28
20	34	F	33–44	RTA	42-A2	1	Union	14	10	12
21	27	M	22–33	RTA	42-A3	2	Union	22	12	12
22	32	M	22–33	RTA	42-B1	2	Delayed union	28	Nil	18
23	28	M	22–33	RTA	42-A2	2	Union	20	10	14
24	31	F	22–33	RTA	42-A1	2	Union	22	8	12
25	39	M	33–44	FALL FH	42-A2	2	Union	24	10	12
26	23	M	22–33	RTA	42-B2	1	Delayed union	30	18	24
27	25	F	22–33	RTA	42-A2	1	Union	18	12	14
28	41	M	33–44	RTA	42-A3	2	Union	16	8	10
29	25	F	22–33	RTA	42-A1	1	Union	20	10	12
30	32	M	22–33	FALL FH	42-A2	2	Union	24	10	12
31	36	M	33–44	FALL FH	42-A2	1	Union	22	10	14
32	42	F	33–44	RTA	42-A3	3	Union	20	8	12
33	26	F	22–33	RTA	42-A2	1	Union	24	10	14
34	37	M	33–44	RTA	42-B1	1	Nonunion	44	16	24
35	40	M	33–44	SPORTS	42-A2	4	Union	20	10	12
36	31	F	22–33	RTA	42-A3	1	Union	22	8	10
37	41	M	33–44	RTA	42-B2	1	Nonunion	40	18	26
38	31	M	22–33	RTA	42-A2	1	Union	22	12	14
39	29	F	22–33	RTA	42-A3	1	Union	18	10	12
40	25	M	22–33	RTA	42-A2	2	Union	26	8	12
41	38	M	33–44	RTA	42-A2	1	Union	22	10	12
42	24	F	22–33	SPORTS	42-A1	2	Union	20	8	10
43	36	M	33–44	RTA	42-B2	1	Union	24	8	12
44	32	M	22–33	RTA	42-A3	3	Union	16	10	12
45	28	F	22–33	RTA	42-B1	2	Delayed Union	36	20	24
46	27	F	22–33	FALL FH	42-A2	1	Union	24	12	14
47	30	M	22–33	RTA	42-A2	2	Union	22	10	12
48	29	M	22–33	RTA	42-B2	1	Union	18	8	10

F, female; M, male; FALL FH, fall from height; RTA, road traffic accident; SPORTS, sports-related injuries.

REFERENCES

1. Chen T, Lai RF, Zhou ZY, et al. Application of ultrasonic inspection in monitoring dynamic healing of mandibular fracture in rabbit model. *Asian Pac J Trop Med.* 2012;5:406–409.
2. Novelline R. *Squire's Fundamentals of Radiology*. 5th ed. Harvard University Press; 1997:1.
3. Njeh CF, Kearton JR, Hans D, et al. The use of quantitative ultrasound to monitor fracture healing: a feasibility study using phantoms. *Med Eng Phys.* 1998;20:781–786.
4. Blokhuis TJ, de Bruine JH, Bramer JA, et al. The reliability of plain radiography in experimental fracture healing. *Skeletal Radiol.* 2001;30: 151–156.
5. Dudkiewicz I, Heim M, Salai M, et al. Ultrasonographic evaluation of union in long bones fractures. *J Musculoskelet Res.* 2009;12. doi:10. 1142/S0218957709002225.
6. Atkinson P, Lennon R. Use of emergency department ultrasound in the diagnosis and early management of femoral fractures. *Emerg Med J.* 2003;20:395.
7. Legome E, Pancu D. Future applications for emergency ultrasound. *Emerg Med Clin North Am.* 2004;22:817–827.
8. McManus JG, Morton MJ, Crystal CS, et al. Use of ultrasound to assess acute fracture reduction in emergency care settings. *Am J Disaster Med.* 2008;3:241–247.
9. Hammer RR, Hammerby S, Lindholm B. Accuracy of radiologic assessment of tibial shaft fracture union in humans. *Clin Orthop Relat Res.* 1985:233–238.
10. Panjabi MM, Walter SD, Karuda M, et al. Correlations of radiographic analysis of healing fractures with strength: a statistical analysis of experimental osteotomies. *J Orthop Res.* 1985;3:212–218.
11. Ebraheim NA, Savolaine ER, Patel A, et al. Assessment of tibial fracture union by 35 to 45 degrees internal oblique radiographs. *J Orthop Trauma.* 1991;5:349–350.
12. Panjabi MM, Lindsey RW, Walter SD, et al. The clinician's ability to evaluate the strength of healing fractures from plain radiographs. *J Orthop Trauma.* 1989;3:29–32.
13. Whelan DB, Bhandari M, McKee MD, et al. Interobserver and intraobserver variation in the assessment of the healing of tibial fractures after intramedullary fixation. *J Bone Joint Surg Br.* 2002;84:15–18.
14. Newman PG, Rozycki GS. The history of ultrasound. *Surg Clin North Am.* 1998;78:179–195.
15. Ricciardi L, Perissinotto A, Dabala M. Mechanical monitoring of fracture healing using ultrasound imaging. *Clin Orthop Relat Res.* 1993:71–76.
16. Carovac A, Smajlovic F, Junuzovic D. Application of ultrasound in medicine. *Acta Inform Med.* 2011;19:168–171.
17. Punzi L, Oliviero F. Arthrocentesis and synovial fluid analysis in clinical practice: value of sonography in difficult cases. *Ann N Y Acad Sci.* 2009; 1154:152–158.
18. Chen MJ, Lew HL, Hsu TC, et al. Ultrasound-guided shoulder injections in the treatment of subacromial bursitis. *Am J Phys Med Rehabil.* 2006; 85:31–35.
19. Thiele RG, Schlesinger N. Diagnosis of gout by ultrasound. *Rheumatology (Oxford).* 2007;46:1116–1121.
20. Giovagnorio F, Andreoli C, De Cicco ML. Ultrasonographic evaluation of de Quervain disease. *J Ultrasound Med.* 1997;16:685–689.
21. Liu SS, Ngeow JE, Yadeau JT. Ultrasound-guided regional anesthesia and analgesia: a qualitative systematic review. *Reg Anesth Pain Med.* 2009;34:47–59.
22. Moed BR, Subramanian S, van Holsbeeck M, et al. Ultrasound for the early diagnosis of tibial fracture healing after static interlocked nailing without reaming: clinical results. *J Orthop Trauma.* 1998;12:206–213.
23. Maffulli N, Thornton N. Ultrasonographic appearance of external callus in long-bone fractures. *Injury.* 1995;26:5–12.
24. Cleveland KB. Delayed union and nonunion of fractures. In: Canale ST, Beaty JH, eds. *Campbell's Operative Orthopedics*. Philadelphia, PA: Mosby; 2007:3529–3574.