Are Fassier-Duval Rods at Risk of Migration in Patients Undergoing Spine Magnetic Resonance Imaging?

Asim M. Makhdom, MD, MSc(c),† Waleed Kishta, MD, PhD, FRCSC,*
Neil Saran, MD, MHSc (Clin. Epi.) FRCSC,*
Michel Azouz, MD, FRCPC,‡ and François Fassier, MD, FRCSC**

Background: The Fassier-Duval (FD) rod is a stainless-steel device widely used to correct bone deformities and reduce the risk of fractures in patients with osteogenesis imperfecta (OI). Since these are telescopic expandable rods, there has been a reluctance to perform magnetic resonance imaging (MRI) in patients with OI secondary to a theoretical risk of migration during the MRI scans. The primary aim of this study was to assess the risk of migration of FD rods in patients who underwent MRI of the spine. The secondary aims are to assess the heating effects and artifact of these implants.

Methods: We retrospectively reviewed our database for all patients with OI who had undergone FD rodding and subsequent MRI evaluation for craniofacial and spinal disorders. Ten patients were eligible to be included in the study. The MRI examination was performed in all patients using a1.5 T magnet. The radiographic images pre-MRI and post-MRI were evaluated and compared to assess whether or not migration of implants had occurred. Patients' charts and MRI logbooks were reviewed to assess the heating effects based on patient-reported events during or immediately after the MRI. In addition, the scans were reviewed to evaluate peri-implant soft tissues to assess for changes that might indicate such effect. Artifact was judged to be present if it interfered with the evaluation of any portion of spinal anatomy of clinical interest.

Results: Ten patients underwent 19 FD roddings. The indications for MRI in these patients were basilar invagination, basilar impression, platybasia, and complex scoliosis. None of the implants have shown any migration, heating effect, or artifact.

Conclusions: FD rods are safe and pose no risk of migration, heating effects, or artifact when undergoing an MRI of the spine using a 1.5 T magnet. With the introduction of magnet strengths higher than 1.5 T, further testing should be performed.

Level of Evidence: Level IV.

From the *Division of Orthopaedic Surgery; ‡Department of Musculoskeletal Radiology, Shriners Hospital for Children, Montreal Children Hospital, McGill University, Montreal, QC, Canada; and †Department of Orthopaedic Surgery, King Abdulaziz University, Jeddah, Saudi Arabia.

The authors declare no conflicts of interest.

Reprints: Francois Fassier, MD, FRCSC, Division of Orthopaedic Surgery, Shriners Hospital for Children, Montreal Children Hospital, McGill University, Montreal, 1529 Cedar Avenue, Montreal, QC, Canada H3G 1A6. E-mail: ffassier@shrinenet.org.

Key Words: Fassier-Duval rod, telescopic rods, intramedullary rods, intramedullary nails, telescopic nails, osteogenesis imperfect, MRI, magnetic resonance imaging, bone fragility

(*J Pediatr Orthop* 2015;35:323–327)

The incidence of osteogenesis imperfecta (OI) is approximately 1 in 10,000 live births.[1] It is typically caused (in 70% of cases) by a mutation of 1 or 2 genes (COL1A1 and COL1A2), which encode type 1 collagen.[1–3] On the basis of the mode of inheritance, radiologic findings, and clinical features, Sillence et al[2] classified OI into 4 types (I to IV). Glorieux and colleagues expanded this classification to include types V to VII for those who have clinical features of OI but do not have a mutation of type 1 collagen.[1,4,5] The major clinical features of OI are bone fragility with or without multiple fractures, osteopenia, and skeletal deformities of long bones and the spine. In 39% to 80% of OI patients, spine deformity in the form of scoliosis might be encountered.[6] In addition, wide entities of craniocervical abnormalities are also associated with OI.[7] Of these, basilar invagination, basilar impression, and platybasia can be coexpressed or occur as isolated entities.

The advancement of medical treatment of OI, particularly pamidronate, has shown its efficacy in reducing fracture rates and pain, enhancing bone density parameters, and improving the quality of life in these children.[8] However, pamidronate has no effect on preexisting bone deformities on the more severely involved children[9] and, therefore, surgical intervention using an intramedullary nail is indicated in such cases.

Since its introduction by the senior author (F.F.) Fassier-Duval (FD) rods have been used worldwide to treat OI patients to correct bone deformities and reduce the risk of fractures.[10–13] The FD rod is a stainless-steel (SS) expandable telescopic nail system that includes a female hollow nail anchored in the proximal epiphysis of the long bone, and a male solid nail anchored to the distal epiphysis. The anchorage of the FD rod system is achieved through screw type fixation by threaded portions at the proximal and distal ends (Fig. 1).

Since the incidence of neurological pathology in patients with OI is not uncommon secondary to the craniocervical disorders and spinal deformities, a diagnostic

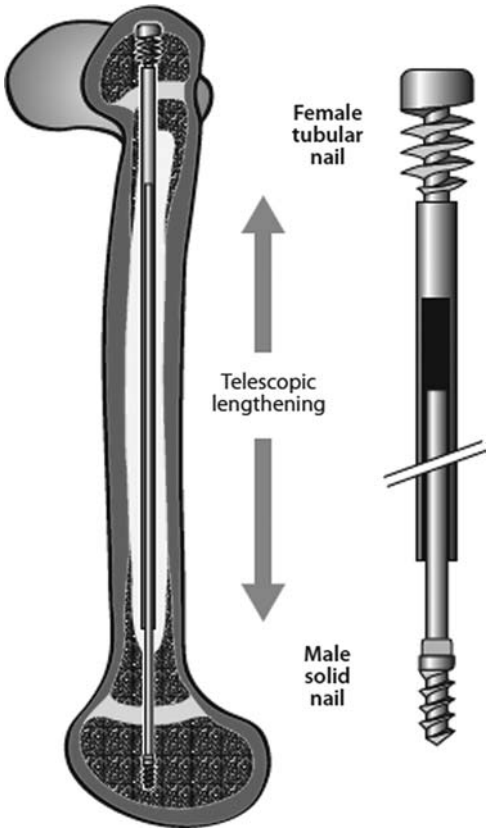

FIGURE 1. Diagram showing the design of Fassier-Duval rod.

magnetic resonance imaging (MRI) is often indicated in this patient population. However, the migration risk of the rod because of the magnetic field remains undetermined. In addition, the clinical safety of MRI in terms of heating effects and artifact in patients with such implants remains unclear. The primary aim of this study was to assess the risk of migration of FD rods in patients who underwent MRI evaluation of the spine. The secondary aims are to assess the heating effects and artifact of these implants.

METHODS

After approval from our institutional review board, we performed a retrospective chart review for all patients with OI who had undergone FD rodding (Pega Medical, Laval, QC, Canada) and subsequent MRI evaluation for craniofacial and spinal disorders at the Montreal Children Hospital in Montreal from January 2008 to July 2013. Patients' demographic and medical information were collected from the electronic medical record system including the radiographic and MRI results. Our initial search identified 17 patients. Of these, 7 patients were excluded from the study because of insufficient data and difficulty of retrieving radiographs/MRI that were performed elsewhere. Ten patients were included in this study. There were 3 male and 7 female patients and their mean age was 16.7 years (range, 13 to 19 y). These patients underwent 19 FD roddings [humerus (n = 1), tibia (n = 5), and femur (n = 13)]. In addition, 8 SS Kirschner wires (K-wires) [humerus (n = 2), tibia (n = 4), radius (n = 1), ulna (n = 1)] and 1 SS Sheffield rodding [tibia (n = 1)] were performed. The details of implant locations and types are summarized in Table 1. The MRI examination was performed in all patients at the Montreal Children's Hospital using a 1.5 T magnet. The MRI examination was performed for the entire spine in 7 cases and the skull in 10. The indications for the MRI examination were basilar invagination (n = 8), basilar impression (n = 1), and platybasia (n = 1). These were combined with severe scoliosis in 7 patients.

Radiographic images pre-MRI and post-MRI were evaluated and compared to assess whether or not migration of implants had occurred. In both lower and upper extremity images, an anatomic landmark was selected as a reference point in the pre-MRI films. Then, we measured the distance between the end point of the implant and the reference point. This was repeated in the post-MRI images and the measured values were compared. Migration of the implant was considered positive if there was any discrepancy between the measured distances in the pre-MRI and post-MRI images.

To assess for heating effects, we reviewed the MRI logbooks in which the radiology technicians systemically record any event (eg, pain or burning sensation) that occur during or immediately after the scan. In addition, the results of MRI scans were reviewed to evaluate periimplant soft tissues to assess for signals that might indicate heating effect. We were able to assess adjacent soft tissues in 4 patients (4 K-wires and 1 FD rod) of 10 as the implants in the remaining 6 patients were not completely visible on the scans. Artifact was judged to be present if it interfered with the evaluation of any portion of spinal anatomy of clinical interest.

RESULTS

A total of 10 patients with metallic FD rods and K-wires underwent an MRI examination (Table 1). None of these implants have shown any displacement or change in the implant level fixation after the MRI examination (Figs. 2A–C). The average time interval between the pre-MRI and post-MRI films was 8 months (range, 3 to 18 mo). There was no report of pain, heating, or burning sensation during or following the MRI in all patients. In addition, the MRI evaluation of the adjacent soft tissues of implants in all 4 patients showed no evidence of thermal injury. None of the MRI results have shown any artifact that interfered with the spinal anatomy of clinical interest.

DISCUSSION

In the last 3 decades, the evolution of MRI as an imaging tool has been unparalleled in diagnostic imaging. One of the major advantages is its ability to utilize the subtle magnetic properties of atomic nuclei without the need for ionizing radiation.[14] MRI has an excellent soft tissue contrast and has the ability to provide a sectional representation of the human body at any plane or angle. As such, MRI is ideally suited to evaluate the spinal cord

TABLE 1. Patients' Demographics and Results

Patients	Age (y)	Sex	Indication of MRI	Type of Implant and Location	Migration	Heating Effect	Artifact
1	19	Male	BI and scoliosis	FD rod: right tibia, right humerus, and right femur	No	No	Absent
2	18	Female	BI and scoliosis	FD rod: left femur	No	No	Absent
3	18	Male	BI, basilar impression and scoliosis	FD rod: right tibia and left femur K-wire: right humerus	No	No	Absent
4	15	Female	Platybasia and scoliosis	FD rod: bilateral femur	No	No	Absent
5	13	Female	BI	FD rod: bilateral femurs and bilateral tibia	No	No	Absent
6	16	Female	Scoliosis	FD rod: right femur	No	No	Absent
7	17	Female	BI	FD rod: right tibia K-wires: right radius and ulna	No	No	Absent
8	17	Male	BI	FD rod: bilateral femurs K-wires: bilateral tibia	No	No	Absent
9	17	Female	BI and scoliosis	FD rod: left femur Sheffield rod: right femur K-wires: right humerus	No	No	Absent
10	18	Female	BI and scoliosis	FD rod: bilateral femurs K-wires: bilateral tibia	No	No	Absent

BI indicates basilar invagination; FD rod, Fassier-Duval rod.

in patients with suspected spinal compression or other pathologies. However, several risks are posed with this technology in association with implanted metallic devices. The strong static magnetic fields can create a torque of magnetic materials that results in a rotational movement of the implanted devices.[15] Moreover, a translational movement can occur when a spatial magnetic field gradient is present. Another potential risk is excessive heating and thermal injury resulting from ferromagnetism of the implant.[16–18]

As the FD rod is an expandable telescopic device, migration risk would be theoretically higher than those implants used in fracture fixation, which are rigidly fixed to bone. Our data suggests that this theoretical concern is not clinically important and has shown that the use of MRI at 1.5 T is safe with the FD rod without any risk of migration. Interestingly, we also found that all K-wires (8 K-wires in 5 patients) appeared stable. Although one explanation for lack of migration in the FD nails is that the threaded portions of the nail provides sufficient fixation proximally and distally to prevent migration, it is possible that the magnetic strength of a 1.5 T MRI is not sufficient to cause significant deflection forces of such implants. In the current body of literature, it appears that orthopaedic implants are generally safe during MRI scanning.[14,19–22] Kumar et al[14] performed an experimental study questioning the safety of orthopaedic implants in terms of motion and thermal effects during MRI scanning. The authors examined various implants including femoral prostheses [titanium (Ti), SS, and cobalt alloy], condylar blade plates (12 holes/SS), tibial buttress plates (6 holes/Ti), universal femoral nails (SS), interlocking tibial nails (Ti), external fixator clamps (SS), external fixator rods (Carbon fiber), and shoulder hemiprostheses (Ti). The degree of ferromagnetism was estimated by deflection analysis at the portals of a 0.25 T permanent magnet and 1.0 T clinical MRI machine. None of the aforementioned implants were found to be ferromagnetic except the external fixator clamps, which showed significant attraction toward the 1.0 T magnetic field. In a cadaveric study, Mansour et al[20] assessed the safety of a distal traction pin (SS) as well as a Bohler-style Steinmann Pin Tractor Bow (tractor bow) and a K- wire bow subjected to a 1.5 T clinical MRI. Although the authors did not observe significant migration to any pin, some degree of deflection forces to all pins was noted. These findings postulate that the clinical safety of MRI in orthopaedic implants should consider the magnet strength as higher values (>1.5 T) might show some hazardous effects. It is reasonable to conclude that the FD rod is safe to undergo MRI at a magnetic field strength of 1.5 T or below.

None of our patients have experienced pain or burning sensation during the MRI examination. In addition, we did not detect any soft tissue changes adjacent to the implants that indicate heating effects when reviewing the MRI scans. These findings are in keeping with the previously reported studies in the literature. Shellock has examined the heating effects of several external cervical fixation devices including SS, Ti, and aluminum. These devices were applied on volunteer subjects and

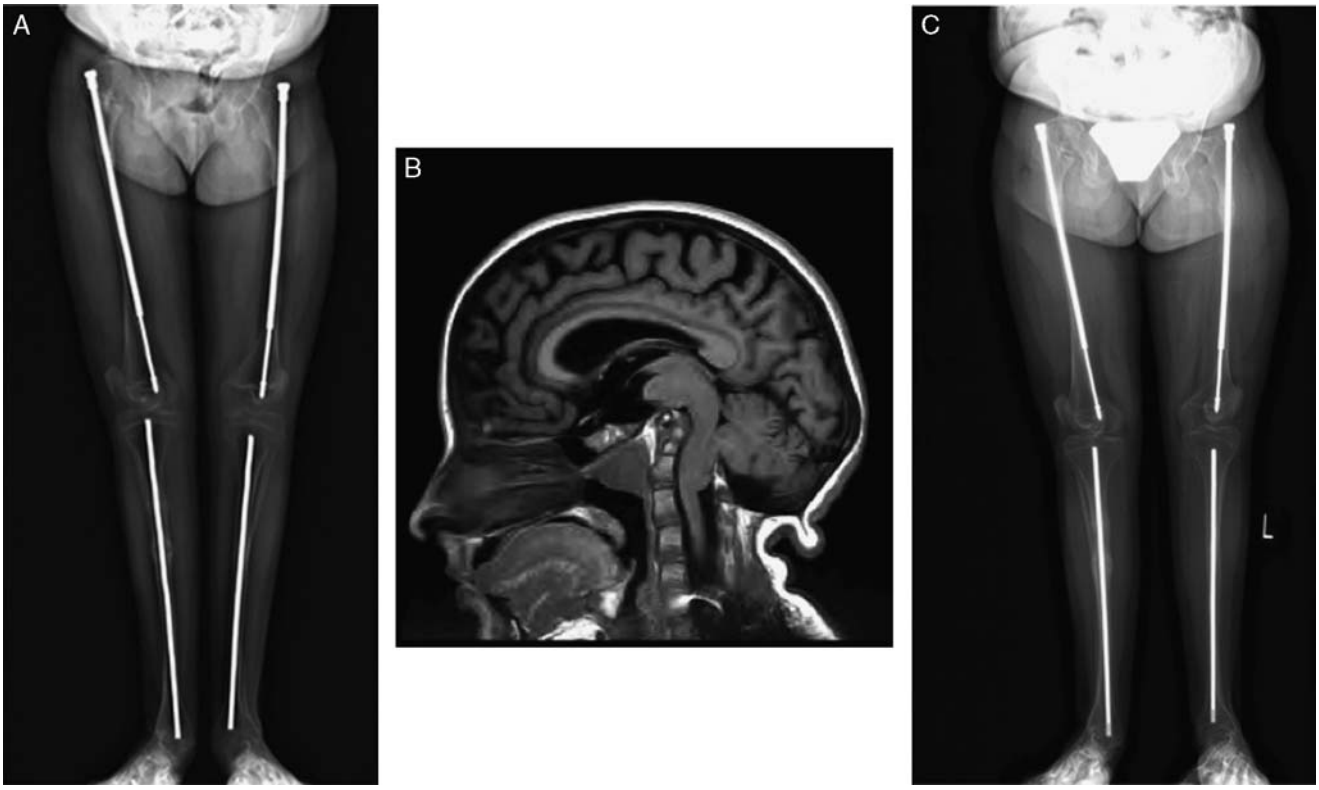

FIGURE 2. A, Anteroposterior radiographs of lower extremities showing bilateral femur Fassier-Duval rods and bilateral tibial K-wires in an 18-year-old male patient with osteogenesis imperfecta before the magnetic resonance imaging (MRI) evaluation. B, MRI of the cervical spine in the same patient shows basilar invagination without artifact. C, Anteroposterior radiographs of lower extremities of the same patient after the MRI evaluation showing no migration of implants.

underwent MRI examination. The maximum increase of temperature was 1.5 °C and no relation between the implant composition and temperature was noted.[23] Kumar and colleagues in their experimental study have also reported that the maximum rise of temperature from the implants after "worst-case" imaging sequence for 60 minutes was only 1.5 °C. The authors found both SS and Ti implants have equivalent degree of heating.[14] Furthermore, Mansour et al[20] also reported no significant thermal effects in their experiment. These results indicate that the heating effects of SS implants are negligible in both clinical and experimental models.

The presence of artifact on MRI scans may lead to diagnostic misinterpretations. It has been shown that implant composition has a direct correlation with the degree of image distortion by artifacts.[24] For example, SS implants produce more significant artifact when compared with Ti and its alloys.[21] Rupp and colleagues have evaluated 15 patients who underwent postoperative spine MRIs at magnetic strength of 1.5 T. These patients were treated with SS and Ti implants. Although the authors found no migration or heating effects from either material, SS implants created significant image distortion when compared with Ti implants. In our study, none of the spinal MRIs had artifacts originating from the SS implants that were located in either the upper or lower extremities. This is likely because the implant axis is not perpendicular to the principal direction of the magnetic field[24] and because the desired field of imaging (eg, spine or skull) is away from the FD rods and K-wires.

The primary limitation of our study is the small sample size. OI is a very rare disorder and the number of OI patients that require spinal or cranial MR imaging is quite low. Although our small study of 10 patients has shown initial safety of using MR in patients with implanted FD rods and K-wires, patients undergoing MR imaging should be counseled about the potential risk of implant migration.

In conclusion, our study has shown that the use of spinal MRI with a1.5 T magnet is safe in patients with implanted FD rods. There was no implant migration, heating effect, or artifact. However, because of the small study size, patients and their parents must be counseled about the theoretical risk of migration. Further testing of orthopaedic implants will be required as the strength of the MRI magnets increase.

REFERENCES

1. Glorieux FH. Osteogenesis imperfecta. *Best Pract Res Clin Rheumatol*. 2008;22:85–100.
2. Sillence DO, Senn A, Danks DM. Genetic heterogeneity in osteogenesis imperfecta. *J Med Genet*. 1979;16:101–116.
3. Rauch F, Glorieux FH. Osteogenesis imperfecta. *Lancet*. 2004;363:1377–1385.

4. Glorieux FH, Rauch F, Plotkin H, et al. Type V osteogenesis imperfecta: a new form of brittle bone disease. *J Bone Mineral Res*. 2000;15:1650–1658.
5. Glorieux FH, Ward LM, Rauch F, et al. Osteogenesis imperfecta type VI: a form of brittle bone disease with a mineralization defect. *J Bone Mineral Res*. 2002;17:30–38.
6. Burnei G, Vlad C, Georgescu I, et al. Osteogenesis imperfecta: diagnosis and treatment. *J Am Acad Orthop Surg*. 2008;16: 356–366.
7. Khandanpour N, Connolly DJ, Raghavan A, et al. Craniospinal abnormalities and neurologic complications of osteogenesis imperfecta: imaging overview. *Radiographics*. 2012;32:2101–2112.
8. Rauch F, Travers R, Glorieux FH. Pamidronate in children with osteogenesis imperfecta: histomorphometric effects of long-term therapy. *J Clin Endocrinol Metabol*. 2006;91:511–516.
9. Enright WJ, Noonan KJ. Bone plating in patients with type III osteogenesis imperfecta: results and complications. *Iowa Orthopaed J*. 2006;26:37–40.
10. Ruck J, Dahan-Oliel N, Montpetit K, et al. Fassier-Duval femoral rodding in children with osteogenesis imperfecta receiving bisphosphonates: functional outcomes at one year. *J Child Orthopaed*. 2011;5:217–224.
11. Birke O, Davies N, Latimer M, et al. Experience with the Fassier-Duval telescopic rod: first 24 consecutive cases with a minimum of 1-year follow-up. *J Pediatr Orthop*. 2011;31:458–464.
12. Balanescu R, Ulici A, Rosca D, et al. Use of minimally invasive (percutaneous) Fassier-Duval telescopic rod on an 8 year old patient with Lobstein disease. *Chirurgia (Bucur)*. 2013;108:120–125.
13. Fassier F, Esposito P, Sponseller PD, et al. *Multicenter Radiological Assessment of the Fassier-Duval Femoral Rodding*. San Diego, CA: Proceedings of the Annual Meeting of the Pediatric Orthopaedic Society of North America (POSNA); 2006.
14. Kumar R, Lerski RA, Gandy S, et al. Safety of orthopedic implants in magnetic resonance imaging: an experimental verification. *J Orthopaed Res*. 2006;24:1799–1802.
15. Dempsey MF, Condon B, Hadley DM. MRI safety review. *Semin Ultrasound CT MR*. 2002;23:392–401.
16. Kanal E, Shellock FG, Talagala L. Safety considerations in MR imaging. *Radiology*. 1990;176:593–606.
17. Davison BL, Cantu RV, Van Woerkom S. The magnetic attraction of lower extremity external fixators in an MRI suite. *J Orthop Trauma*. 2004;18:24–27.
18. Chung SM. Safety issues in magnetic resonance imaging. *J Neuroophthalmol*. 2002;22:35–39.
19. Shellock FG. MR imaging of metallic implants and materials: a compilation of the literature. *Am J Roentgenol*. 1988;151:811–814.
20. Mansour A, Block J, Obremskey W. A cadaveric simulation of distal femoral traction shows safety in magnetic resonance imaging. *J Orthopaed Trauma*. 2009;23:658–662.
21. Hayes JS, Richards RG. The use of titanium and stainless steel in fracture fixation. *Expert Rev Med Devices*. 2010;7:843–853.
22. Rupp R, Ebraheim NA, Savolaine ER, et al. Magnetic resonance imaging evaluation of the spine with metal implants. General safety and superior imaging with titanium. *Spine*. 1993;18:379–385.
23. Shellock FG. MR imaging and cervical fixation devices: evaluation of ferromagnetism, heating, and artifacts at 1.5 Tesla. *Magn Reson Imag*. 1996;14:1093–1098.
24. Suh JS, Jeong EK, Shin KH, et al. Minimizing artifacts caused by metallic implants at MR imaging: experimental and clinical studies. *Am J Roentgenol*. 1998;171:1207–1213.