The Charcot foot: a pictorial review
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Abstract
Charcot foot refers to an inflammatory pedal disease based on polyneuropathy; the detailed pathomechanism of the disease is still unclear. Since the most common cause of polyneuropathy in industrialized countries is diabetes mellitus, the prevalence in this risk group is very high, up to 35%. Patients with Charcot foot typically present in their fifties or sixties and most of them have had diabetes mellitus for at least 10 years. If left untreated, the disease leads to massive foot deformation. This review discusses the typical course of Charcot foot disease including radiographic and MR imaging findings for diagnosis, treatment, and detection of complications.

Keywords: Charcot foot, Imaging, Osteomyelitis, MRI, Radiographs

Key points
- X-rays may be normal during early stage of Charcot foot
- MRI should be done with large field of view covering the entire foot
- MRI can be used for early diagnosis, monitoring of disease activity and complications
- Acute MRI findings include bone marrow edema, soft tissue edema, and subchondral fractures
- Chronic MRI findings include subchondral cysts, joint destructions, joint effusion, and bony proliferations

Annotation regarding wording of planes of foot imaging in this review
Hindfoot: sagittal = parallel to long axis of metatarsal bones; coronal = perpendicular to long axis of metatarsal bones; axial = perpendicular to long axis of the tibia.
Forefoot: sagittal = parallel to long axis of metatarsal bones; axial = perpendicular to long axis of metatarsal bones; coronal = parallel to foot sole.

Introduction
The Charcot foot has been first described in 1868 by Jean-Martin Charcot, a French pathologist and neurologist, in patients with tabes dorsalis (myelopathy due to syphilis) [1]. The detailed pathomechanisms of this disease still remain unclear: there is consensus that the cause is multifactorial and that polyneuropathy (reduced pain sensation and proprioception) is the underlying basic condition of this disease. In industrialized countries, diabetes mellitus is the main cause of polyneuropathy in the lower limb [2]—much more common than other causes like alcohol abuse or malnutrition. The prevalence of Charcot foot in a general diabetic population is estimated between 0.1 and 7.5%, but regarding diabetic patients with apparent peripheral neuropathy, this prevalence is increasing up to 35% [3]. The risk of getting a Charcot foot is not related to the type (I or II) of diabetes mellitus. The incidence of bilateral involvement of the feet has been reported between 9 and 75% [2]. Patients with Charcot foot typically present within their fifties or sixties and most of them have had diabetes mellitus for at least 10 years [2].

Natural course of disease
Charcot foot is characterized by four different disease stages (Fig. 1) [7, 8], resembling active and inactive disease phases: inflammation, fragmentation, coalescence, and consolidation. The disease is normally limited to a single-run through these different disease stages. The active phase is characterized by a hot, red, and swollen foot (inflammation), often without pain, due to the polyneuropathy (Fig. 2) [1]. In the active phase, the bone gets...
fragile due to temporary osteopenia leading to fractures, joint destructions (often Lisfranc’s joint) and collapse of the longitudinal arch of the foot [2, 8, 9]. During the less active or inactive phase, the foot is not red any more, but some soft tissue and bone marrow edema may last. Prominent osteophytes and palpable loose bodies are the consequence of a substantial joint and bone destruction followed by bony proliferations [2, 9]. The typical end-stage appearance of a Charcot foot is the so-called rocker-bottom deformity (Fig. 3).

A recent study showed that there is a risk of re-activation of a “formerly in-active” Charcot foot in about 23% within a mean interval of 27 months [4] (Fig. 1).

Clinical stages and differential diagnoses
The (modified) Eichenholtz classification [5, 6], which relies on clinical and x-ray findings, is frequently used for clinical assessment of a suspected Charcot foot (stages 0, I, II, III, IV). Stage 0 is the ideal stage for early diagnose of a Charcot foot, but also the most difficult one for the clinician: the patients typically present with a red, swollen, warm foot, but no visible changes (yet) on radiographs. Typical differential diagnoses in this early stage include deep vein thrombosis, gout, osteoarthritis, and infection (cellulitis/osteomyelitis) [10].

Treatment
Current state-of-the art treatment is the off-loading of the affected foot—as soon as possible—so that the
It has been mentioned that the four disease stages run-through while the foot is protected from major shape changes (Fig. 4) [1]. One commonly used method is the treatment of patients with custom-made removable total contact casts (Fig. 5a) until the activity signs of the Charcot foot are significantly reduced or gone. This might take up to 18 months [4]. Establishing an early diagnosis and therefore an early off-loading treatment is crucial for the prognosis and outcome of an acute Charcot foot. The stabilization with the Ilizarov external fixator frame is considered an alternative treatment option for the off-loading [11] (Fig. 5b) in feet with complications (severe deformity or after the removal of osteomyelitic bone fragments) [12].

**Imaging findings**

This review is focused on typical findings of a Charcot foot on radiographs and MR imaging since these two modalities play the most important role for disease monitoring, classification, and treatment [13].

**Classifications**

The Charcot foot can be classified using various systems according to anatomical landmarks and clinical symptoms. The most common ones are the Sanders and Frykberg classification, the Brodsky classification, and the Eichenholtz-classification [5, 7, 14–17]. This review covers the Sanders and Frykberg classification in detail, because it can be used without additional clinical information.

**Sanders and Frykberg classification**

Sanders and Frykberg identified five zones of disease distribution according to their anatomical location, as demonstrated in Fig. 6. Most commonly involved are zone II in about 45% and zone III in about 35% of cases [2], Fig. 7 and Fig. 8.
Role of conventional radiographs

Conventional radiographs of the Charcot foot are traditionally the standard imaging technique to establish the diagnosis, to stage, and to monitor the disease. The main value of plain radiographs is to assess the position of the bones to each other in general, and in particular under load (Fig. 9) [13, 18, 19].

Typical measurements on radiographs [19] help to determine the severity of deformation in a Charcot foot (especially in follow up studies), Fig. 10:

1. Meary’s angle: angle between the line originating from the center of the body of the talus, bisecting the talar neck and head, and the line through the longitudinal axis of 1st metatarsal; normal value should be around 0°.
2. Cuboid height: perpendicular distance from the plantar aspect of the cuboid to a line drawn from the plantar surface of the calcaneal tuberosity to the plantar aspect of the 5th metatarsal head. Mean normal value is about 1.2 cm above that line.
3. Calcaneal pitch: angle between a line extending from the plantar aspect of the calcaneus to the plantar surface of the 5th metatarsal head and the line extending from the most plantar portion of the calcaneal tuberosity to the most plantar portion of the anterior calcaneus [18]. Normal value lies between 20 and 30°.
4. Hindfoot-forefoot angle: Dorsoplantar (dp) radiographs can reliably show the (sub-)luxation in the Lisfranc’s joint, especially the medial aspect of the joint (Fig. 11). Dorsoplantar radiographs in follow-up studies typically show the increase in forefoot abduction relative to the hindfoot over time, the so-called hindfoot-forefoot angle (Fig. 11). Oblique conventional radiographs are superior to
dp-radiographs in visualizing the lateral aspect of the Lisfranc’s joint (3rd to 5th tarsometatarsal joint).

Role of magnetic resonance imaging

MRI can be very helpful in order to establish an early diagnosis of Charcot foot. MRI also allows to determine the course of the healing process and the success of the off-loading treatment (monitoring: active or inactive disease). Another very significant role of MRI is its ability to further evaluate complications of a Charcot foot, in particular soft tissue infections and osteomyelitis (Fig. 12) [3, 13, 20]. In patients with contraindications for MR examination, nuclear medicine imaging can be performed (see section below: “CT and nuclear medicine imaging”).

MRI-protocol

For Charcot foot, it is essential to use a large field of view (FoV) since the disease can affect the entire foot. It is necessary to use a fluid sensitive sequence (e.g., STIR) for assessing edema in the bone marrow and soft tissue. A classic T1 TSE (turbo spin-echo) sequence is irreplaceable to demonstrate the anatomy and the fat signal of the bone marrow. T2-weighted sequences can demonstrate the presence of subchondral cysts and help to identify fluid collections and sinus tracts [2, 3]. Axial images are useful to assess the Lisfranc’s joint disease. An MRI protocol proposal for Charcot foot evaluation is demonstrated in Fig. 13. Nephrotoxic effects of gadolinium...
are still controversially discussed, and almost all patients with a Charcot foot are at risk for development of renal failure (due to diabetes) [21, 22]. Therefore, the application of contrast media should be limited to patients with suspected infections (abscess collections and osteomyelitis).

**MRI for Charcot foot diagnosis**
Charcot foot cannot be diagnosed based on imaging alone and should always be interpreted in context with the clinical parameters (known polyneuropathy, red foot, and so on) [2, 23]. However, there are some typical MR imaging features for the early- and late-stage of a Charcot foot.

**MRI for diagnosis of early-stage Charcot foot** MRI is the best imaging modality to confirm diagnosis of suspected early active Charcot disease [24]. This may be crucial, since conventional radiographs can appear normal during very early stage of Charcot disease (Eichenholtz stage 0, Fig. 14). Early signs of a Charcot foot in MRI are bone marrow edema and soft tissue edema, joint effusion, and eventually microfractures (subchondral) [2, 25]. During early stage of Charcot foot, there are no cortical fractures and no gross deformity seen [26].
MRI of middle- to late-stage Charcot foot (fragmentation to consolidation) Joint destruction, cortical fractures, and joint dislocations are present (Figs. 15 and 16). Bone marrow edema can be present (very common in middle-stage Charcot foot) or absent, depending on disease activity. Especially the involvement of Lisfranc’s joint leads to a typically superior and lateral dislocation of the metatarsal bones leading to a complete collapse of the longitudinal arch [2, 24, 25]. The talus head is typically tilted toward the sole of the foot (Fig. 17a), the navicular bone typically dislocates into a medial and superior position, often with fractures and fragmentation. Prominent well-marginated subchondral cysts are a typical feature of the chronic Charcot foot (Fig. 17b). Bone proliferation and sclerosis, debris, and intraarticular...
bodies can occur (Fig. 17c) [2, 26]. Fluid collections surrounding destructed joints may be huge (Fig. 18).

**Monitoring of disease activity with MRI**

MRI is the best imaging modality to monitor the disease activity. As long as a significant amount of bone marrow edema is seen on MRI, consequent off-loading therapy with removable total contact casts has to be continued [27]. After a significant decrease or complete disappearance of bone marrow edema, the cast can be removed, and an orthopedic shoe adapted (Fig. 19).

**MR-imaging of complications: infection/osteomyelitis**

In Charcot foot, the cuboid bone typically becomes the most inferior bone in the foot [3] (Fig. 20). Due to the resulting changes in pedal shape, the foot is prone to extensive callus formation, blisters, and ulcerations, especially plantar to the cuboid bone (Fig. 20c). This may lead to soft tissue infections and osteomyelitis (Fig. 20a, b) [2].

MRI has a high diagnostic accuracy in diagnosing osteomyelitis of the foot, with a high sensitivity (77–100%) and a high specificity (80–100%) [24]. MRI has a very high negative predictive value (98%); if there are no signs of osteomyelitis on MRI, osteomyelitis can practically be excluded [28].
However, discriminating an active Charcot foot from acute osteomyelitis remains challenging [25]. Both entities have similar image characteristics like bone marrow edema, soft tissue edema, joint effusions, fluid collections, and contrast enhancement in bone marrow and soft tissues. Even the degree of signal drop in T1 sequences might be quite similar in both conditions (Figs. 15 and 20). However, there are some imaging features (listed in Table 1, Fig. 21) that may help to find the correct diagnosis.

Fig. 17 Three sagittal images of different patients showing classic features of late-stage Charcot foot. a (Sagittal STIR) inferior dislocation of the talar head (white arrow), effusion in the tibiotalar joint (white arrow head). b (Sagittal STIR) prominent subchondral cysts at the Lisfranc's joint (white arrows). c (Sagittal T1) bone proliferation and debris in the midfoot (white arrows) and fragmentation of navicular bone.

Fig. 18 A 45-year old patient with Charcot foot and sudden shortening of the leg due to a collapse in Sanders/Frykberg zone IV (a). Note the huge amount of fluid (black asterisk) and debris within the impacted zone of the hindfoot (white arrows) on sagittal STIR image (b). Corresponding coronal CT slice in standing position (d) shows medial dislocation of the hindfoot (red arrow) under weight-bearing (d) compared to non-weight-bearing CT (c). The white asterisk marks the calcaneus.
**Advanced MR-imaging techniques**

Diffusion-weighted imaging may contribute in the detection and extension of osteomyelitis: pure edema does not show diffusion restriction, whereas the presence of pus and inflammatory cells in infection leads to restricted diffusion with lower ADC-values than in pure edema [31]. Dynamic contrast enhancement (DCE)-perfusion may help in the discrimination between viable tissue and necrosis. Furthermore, the enhancement pattern in DCE-perfusion seems to be different between osteomyelitis and osteoarthropathic changes, increasing the potential of differing lesions with bone marrow edema [30].

**CT and nuclear medicine imaging**

During early-stage Charcot foot, CT does not play an important role for imaging since bone marrow and soft tissue...
| Location of bone marrow abnormality (edema shown in fluid sensitive sequences, and reduction of fatty bone marrow shown in T1 sequences) | Active Charcot foot | Osteomyelitis |
| --- | --- | --- |
| ○ Pattern tends to be periarticular | ○ Tendency to involve a single bone with diffuse marrow involvement | |
| ○ Usually involves several joints and bones (mostly tarsometatarsal joints and metatarsophalangeal joints) | ○ Usually affects weight-bearing surfaces of the toes, metatarsal heads, calcaneus, malleolus, and a special area in Charcot: cuboid (in rocker-bottom deformity) | |
| Sinus tracts | ○ Usually not present | ○ Often present |
| Skin ulceration (technician should mark the exact ulcer location) | ○ Can be present | ○ Often present |
| ○ Present | ○ Often present | ○ Often relationship to sinus tract |
| Fluid collections | ○ Usually smaller than in case of infection, unless sinus tract is present | ○ Present | |
| ○ Dorsal often with edema, plantar often normal | ○ Usually larger than in active Charcot foot, unless a sinus tract exists over which the collection is drained (paradoxical decrease of size of fluid collection) | |
| Subcutaneous fat | ○ Typical image feature in chronic Charcot foot | ○ Tendency to disappear in case of infection/osteomyelitis |
| ○ The presence of subchondral cysts indicates the absence of infection | ○ Best recognized if regular previous follow-up studies are present, which demonstrate the disappearance of the cysts | |
| Intraarticular bodies | ○ The presence of intraarticular bodies indicates the absence of infection | ○ Often disappear in the setting of infection due to dissolution or obscuresness by surrounding inflammation | |
| “The ghost sign” | ○ Negative: a neuropathic joint without infection will not demonstrate the “ghost sign” because the bones are definitely destroyed and will look destroyed on all sequences | ○ Positive: bones that “disappear” on T1-weighted images and “reappear” (outline of the bone becomes visible again) after contrast administration (or on T2-weighted images)—suspicious of osteomyelitis—Fig. 21 |
changes can be better visualized using MRI [2]. However, CT may be used in later-stage Charcot foot for better visualization of bony proliferations and consolidation, or for surgery planning and treatment monitoring in patients with Ilizarov fixation [2]. Furthermore, CT and PET-CT may be used as an alternative cross-section imaging tool in patients with contraindications for MR examination (pace-maker, severe claustrophobia, etc.). PET-CT allows the quantification of the inflammatory process in all stages of Charcot foot and allows to follow-up its evolution over time: recent research showed that PET-CT may be of additional help for evaluation of treatment duration in addition to MR imaging [32].

Furthermore, nuclear medicine imaging may be of important value in non-conclusive cases with suspected infection of a Charcot foot: a recent meta-analysis compared MRI, FDG–PET-CT, and white blood cell scintigraphy [33]. The authors concluded that despite all of these modalities having a similar sensitivity for detection of osteomyelitis in Charcot foot, the nuclear imaging methods show a higher specificity [33]. However, all nuclear medicine imaging methods are more expensive than MRI and result in radiation exposure to the patient.

**Conclusion**

The Charcot foot is a rare disease, associated with polyneuropathy, in industrialized countries most commonly seen in the long-term diabetic population. The radiologist plays an important role in the management of this disease. Therefore, it is important to be familiar with the typical imaging characteristics of the Charcot foot and to consider this diagnosis in a proper clinical setting. Recognizing this disease in early stages prevents a delayed onset of an appropriate therapy and helps minimizing the disability of these patients.

Although radiographs are important to assess the position of the bones to each other in general, and in particular under load, MRI is the method of choice not only in establishing an early diagnosis but also in monitoring the course of the disease activity and in diagnosing infectious complications.
Abbreviations
ADC: Apparent diffusion coefficient; CT: Computed tomography; Dp: Dorsoplantar; FDG: Fluorodesoxyglucose; FoV: Field of view; MR: Magnetic resonance; MRI: Magnetic resonance imaging; PET: Positron emission tomography; STIR: Short tau inversion recovery

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Ethics approval and consent to participate
All patients have signed consent forms agreeing that their images and data were used for educational purposes.

Competing interests
The authors declare that they have no competing interests.

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