REVIEW

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Radiological diagnosis of the constitutional disorders of bone. As easy as A, B, C?

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Abstract Although many constitutional disorders of bone are individually rare, collectively they make up a large group of disorders. They are broadly classified into osteochondrodysplasias and dysostoses. Because of the rarity of some of these conditions, they can be difficult to diagnose. Members of the International Dysplasia Group meet regularly to update and clarify the nomenclature. The last meeting was in Oxford in 2001. This article attempts to highlight the differences between the osteochondrodysplasias and the dysostoses, and provides a systematic approach to their radiological diagnosis.

Keywords Osteochondrodysplasia · Dysostosis · Nomenclature Radiological diagnosis

Introduction

During the course of their training programme, most radiology residents are taught systematic approaches to analysing plain radiographs of such conditions as bone tumours and arthritic diseases, but very little is taught (or written) on the *approach* to diagnosing skeletal dysplasias and other constitutional disorders of bone. Furthermore, most of this is centred on the characteristic features of a few common conditions such as achondroplasia. Even the nomenclature is overlooked – how many are taught the difference between the osteochondrodysplasias and the dysostoses? How many are still using the term "cleidocranial dysostosis" rather than "cleidocranial dysplasia"?

This article is a synopsis of part of a workshop held at the ESPR meeting in Bergen 2002 and, as then, the purpose is not to leave readers with the impression that a firm diagnosis can always be reached, but rather to provide them with a systematic approach to skeletal surveys performed for the diagnosis of the dysplasias, osteodystrophies and dysostoses.

It is hoped that this approach will be particularly useful to radiology trainees by eliminating some of the mystery associated with the diagnosis of these conditions.

Nomenclature

An understanding of the nomenclature and of the revised classification of the constitutional disorders of bone [1] is inherent to an appreciation of a systematic approach to diagnosing these conditions. In brief, the constitutional disorders of bone are divided into two broad groups: the osteochondrodysplasias and the dysostoses.

Osteochondrodysplasias

The osteochondrodysplasia group is further subdivided into two: *dysplasias* (abnormalities of bone and/or cartilage growth) and *osteodystrophies* (abnormalities of

bone and/or cartilage texture). The dysplasias form the largest group of bone disorders, hence the loose term "skeletal dysplasia" that is often incorrectly used when referring to a condition that is in reality an osteodystrophy or dysostosis. Osteochondrodysplasia abnormalities are intrinsic to bone and cartilage [2, 3, 4], and as a result of gene expression, the phenotypes in this group of conditions continue to evolve throughout life. In other words, previously apparently unaffected bones and joints may subsequently demonstrate abnormality. Multiple bones of the axial and appendicular skeleton are usually involved, as well as bones that form both from membranous and from enchondral ossification. The diagnosis of an osteochondrodysplasia may be made either at birth or later [1]. Occasionally, it is because of the changes that occur with increasing patient age that a confident diagnosis is made, e.g. metatropic dysplasia. The International Nomenclature Group has subdivided osteochondrodysplasias into 33 broad groups [1], examples of which are shown in Figs. 1, 2, 3.

Dysostoses

Dysostoses comprise conditions that occur as a result of abnormalities of blastogenesis in the first 6 weeks of fetal life [1] resulting in defective bone formation. While changes in affected bones may progress, in contrast to the osteochondrodysplasias the malformations do not spread to involve previously normal bones and joints, i.e. the phenotype is static throughout life. Although they are
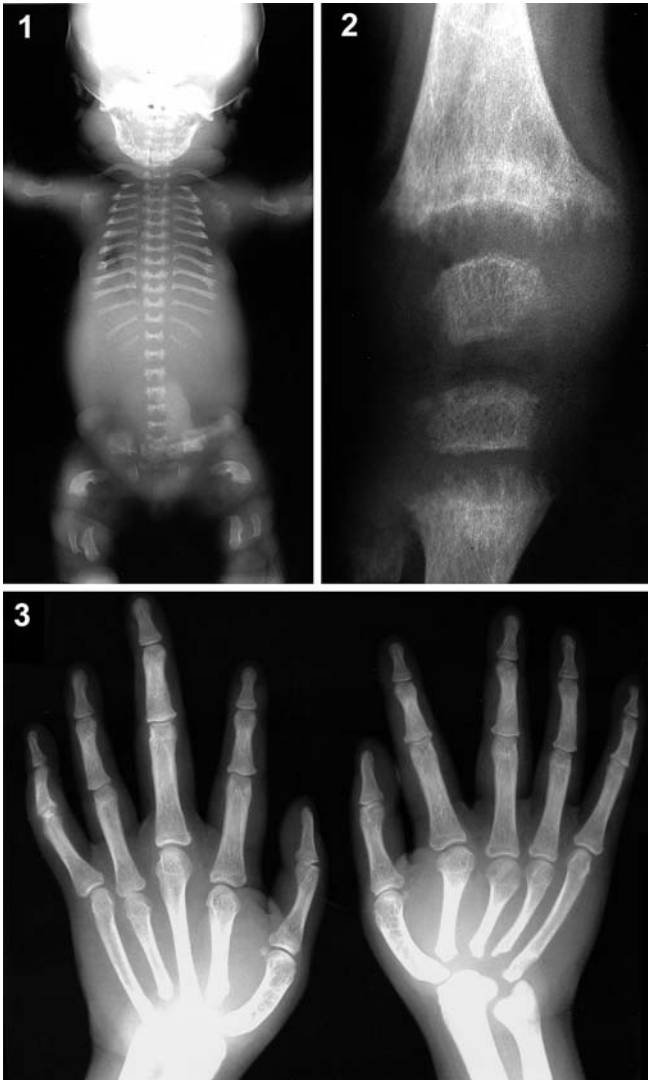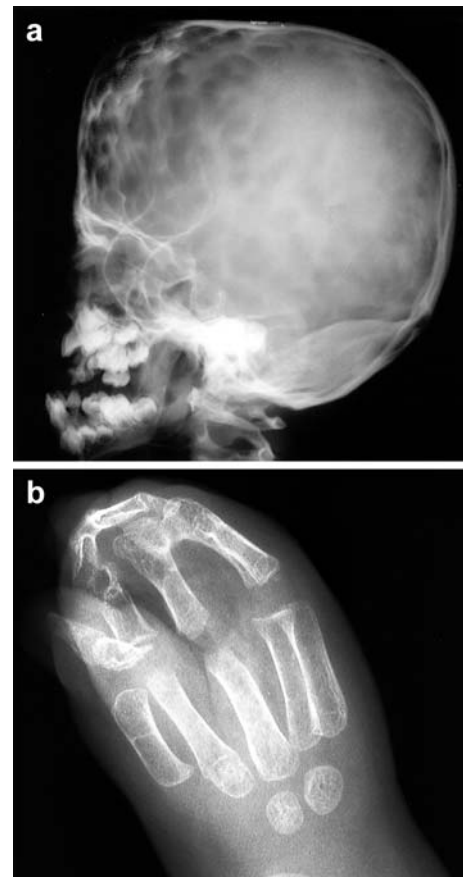

Fig. 1 Thanatophoric dysplasia (group 1 of the revised classification – achondroplasia group)

Fig. 2 AP radiograph of the knee demonstrates osteopaenia and the typical splayed and frayed metaphyses of hypophosphataemic rickets (group 25 – dysplasias with defective mineralisation)

Fig. 3 Complete resorption of the carpal bones and partial resorption of the metacarpal bases in carpo-tarsal osteolysis (group 32 – the osteolyses)

Fig. 4a, b Apert's syndrome (dysostosis group A – localised disorders with predominant cranial and facial involvement). a Turricephaly and a copper-beaten appearance secondary to premature fusion of the coronal suture. b Bony and soft tissue syndactyly with a mitten appearance of the hand

malformations of individual bones, several bones may be affected in combination. The International Nomenclature Group has subdivided dysostoses into three main groups: group A with predominantly craniofacial involvement, group B with predominant axial involvement, and group C with predominant involvement of the hands and feet [1]. Examples are illustrated in Figs. 4, 5.

The term "cleidocranial dysostosis" was first recognised as a misnomer in 1978 [2]. It is an autosomal dominant condition in which there is abnormality in the *CBFA1* gene on chromosome 6p21 [1]. Although it manifests with predominant involvement of membranous bones, the spine, teeth and tubular bones are also affected. Furthermore, there may be evolution of the phenotype with age. For these reasons the correct term for this condition is not cleidocranial *dysostosis* but cleidocranial *dysplasia*. Table 1 summarises the differences between osteochondrodysplasias and dysostoses.

Fig. 5 Fused ribs, hemivertebrae and butterfly segments in spondylocostal dysostosis (dysostosis group B – predominant axial involvement)

Approach to a potential dysplasia

When faced with a request for the radiological investigation of a child with a suspected bone disorder, the radiology department responds by performing a series of radiographs known collectively as a skeletal survey. The exact radiographs that are performed may vary from institution to institution – the policy at the authors' institution is outlined in Table 2. This series of films is acquired for any child suspected of having a constitutional disorder of bone, regardless of the clinician's differential diagnosis, except in the following circumstances:

1. In cases with limb asymmetry or suspected epiphyseal stippling, views of *both* upper and lower limbs (rather than one side alone) should be obtained.
2. At sites of suspected abnormality (e.g. possible epiphyseal stippling, metaphyseal spurs, etc.), additional *coned views* of these sites are obtained for more detailed assessment by the radiologist.
3. In some instances imaging of other *family members* suspected of having the same condition as the proband may be helpful, as the radiological features at different ages can be ascertained, in addition to confirming possible modes of inheritance.
4. When a diagnosis remains uncertain, it is sometimes helpful to *repeat the survey* later. In our experience, there is no benefit to be had from repeating the survey within 12 months of the initial survey.
5. In preterm fetuses and stillbirths, a *babygram* [i.e. two anteroposterior (AP) and lateral films from head to foot] replaces the standard skeletal survey as summarised in Table 2.

Table 2 Routine skeletal survey as performed at the authors' institution

Skull (AP and lateral)
Thoracolumbar spine (AP and lateral)
Chest
Pelvis
One upper limb
One lower limb
Left hand (bone age)[a]

[a]Bone age may also be assessed from views of the foot and ankle, or from AP radiographs of the knee [7]

Table 1 Comparison of the constitutional disorders of bone

	Osteochondrodysplasia		Dysostosis
	Dysplasia	Osteodystrophy	
Abnormality of:	Growth	Structure	Structure
Site of abnormality:	Multiple bone/cartilage of axial and appendicular skeleton, membranous and/or enchondral bone		Individual bones, singly or in combination
Failure of:	Gene expression		Blastogenesis
Phenotype:	May evolve throughout life		Static

What to look for

Having obtained the radiographs, the radiologist then needs to analyse them in an orderly fashion [3, 4, 5]. The scheme listed here has been devised as an easy to remember mnemonic providing a systematic approach to the skeletal survey.

A − Anatomical localisation
B − Bones
C − Complications
D − Dead/alive

A − Anatomical localisation

Some conditions are broadly named according to the anatomical sites involved, as shown in Table 3, which is by no means exhaustive. While this broad classification may occasionally be sufficient (e.g. cleidocranial dysplasia, ischiopubicpatella syndrome), and certainly gives the radiologist a starting point if textbook or computer-aided diagnosis is required, it is usually necessary to further classify the condition (for genetic counselling, determination of prognosis, etc.), for example, spondyloepime-

taphyseal dysplasia (tarda or congenita), metaphyseal chondrodysplasia (types Schmid or McKusick) etc. In order to achieve a more precise diagnosis, it is necessary to analyse the bones and soft tissues more closely.

B − Bones

The following is an aid memoir to the radiological analysis of bones (the five "S's"):

− Structure
− Shape
− Size
− Sum
− Soft tissues

Fig. 7 Vertical striations around the knee in osteopathia striata (group 26 – increased bone density without modification of bone shape)

Fig. 6 Note the multiple bony islands in this example of osteopoikilosis (group 26 – increased bone density without modification of bone shape)

Table 3 Classification according to anatomical localisation

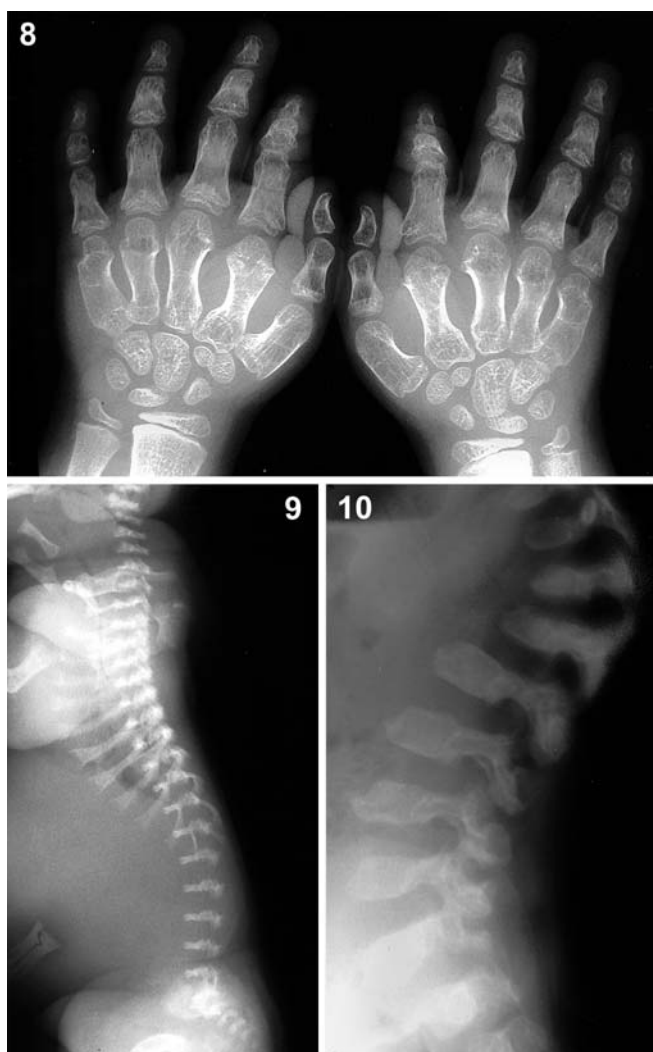| Axial skeleton		Appendicular skeleton	
Skull	Cranio/cranial	Location	Epiphyseal
Face	Facio/facial		Metaphyseal
Mandible	Mandibulo		Diaphyseal
Clavicle	Cleido		
Ribs	Costo	Shortening	Rhizomelic (proximal, e.g. femur)
Spine	Spondylo/vertebral		Mesomelic (middle, e.g. radius/ulna)
Pelvis	Ischio/ilio/pubic		Acromelic (distal – hands/feet)

Fig. 8 Note the significant shortening of all bones and cone-shaped epiphyses in acrodysostosis (group 17 – acromelic dysplasias)

Fig. 9 "Wafer-thin" is the term applied to the severe platyspondyly of thanatophoric dysplasia (group 1 – achondroplasia group)

Fig. 10 Hooked vertebral bodies are seen in the various mucopolysaccharidoses (group 22 – dysostosis multiplex group)

Structure

This applies to the general appearance of the bones, including abnormalities of *bone density*, and the presence of tumorous lesions such as *exostoses* and *enchondromas*. The distribution of abnormality is also important; thus axial osteosclerosis is seen in conjunction with appendicular osteoporosis in trichothiodystrophy. Osteosclerosis may affect all bones, be limited to certain bones, or appear as bone islands, e.g. osteopoikilosis (Fig. 6), or metaphyseal striations, e.g. sponastrime dysplasia or osteopathia striata (Fig. 7).
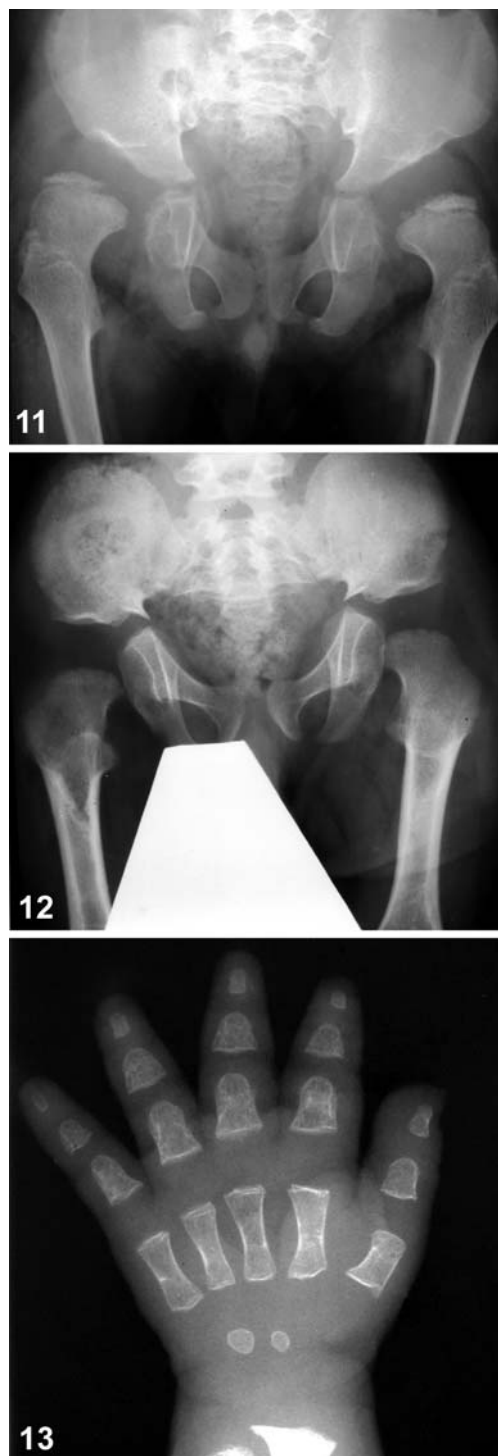

Fig. 11 Sloping acetabular roofs and flared iliac wings are a feature of the mucopolysaccharidoses. Note also the flattened irregular femoral heads (group 22 – dysostosis multiplex group)

Fig. 12 Horizontal, trident acetabular roofs and squared iliac wings are characteristic of achondroplasia (group 1 – achondroplasia group)

Fig. 13 The trident hand of achondroplasia (group 1 – achondroplasia group)
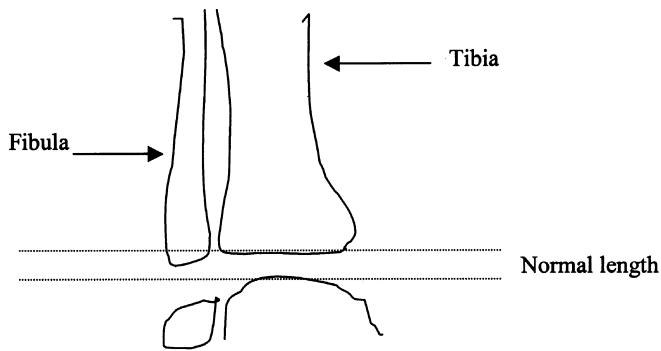
Fig. 14 Line diagram demonstrating the expected position of the normal-length distal fibula. The distal fibular physis lies above the *first line* when too short, and below the *second line* when too long

Shape

Although there are numerous descriptive terms used for the abnormalities of bone shape seen in dysplasias, there are certain terms in use that depict a specific dysplasia. Alterations in shape may affect the whole bone or be restricted to part of a bone, such as the metaphyses, which may be *flared*, or the epiphyses, which may, for example, be *stippled* or *cone-shaped* (Fig. 8). *Wafer-thin* vertebral bodies are suggestive of severe platyspondyly seen in the thanatophoric dysplasias (Fig. 9), *hooked* vertebral bodies occur in the mucopolysaccharidoses (Fig. 10) and *posterior scalloping* of the vertebral bodies in neurofibromatosis and achondroplasia. Compare the *sloping* acetabular roofs of the mucopolysaccharidoses (Fig. 11) with the *horizontal trident* roofs seen in achondroplasia (Fig. 12). *Trident* may also apply to the hands in achondroplasia (a result of all the fingers being roughly equal in length and an inability to appose the fingers; Fig. 13).
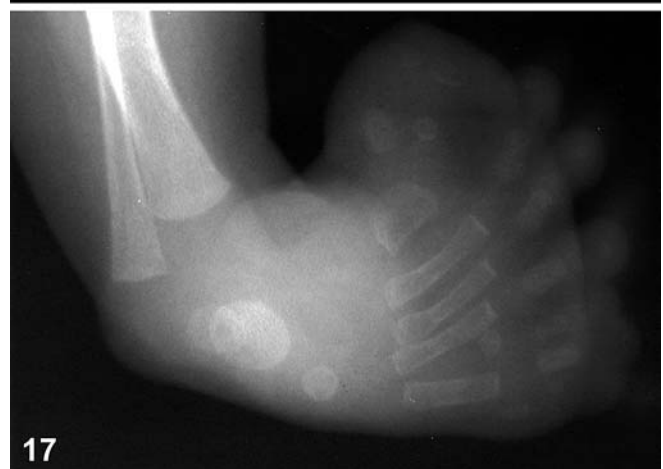
Size

Abnormalities of size are self-explanatory, and terms used include *tall* (in relation to vertebral bodies), *short*, *long*, *large*, *broad* or *hypoplastic*. Abnormalities of size may be absolute or relative to the size of other bones in that individual, e.g. the fibula is relatively long in comparison to the tibia in hypochondroplasia, but relatively short in campomelic dysplasia (the normal distal fibula

▶

Fig. 15 Lateral knee radiograph demonstrating multiple epiphyseal centres of the patella in multiple epiphyseal dysplasia autosomal recessive type (group 6 – diastrophic dysplasia)

Fig. 16 Lateral radiograph of the foot showing multiple calcaneal centres in Larsen's syndrome (group 21 – multiple dislocations with dysplasias)

Fig. 17 Pre- and post-axial polydactyly demonstrated on this foot radiograph of a patient with oral-facial-digital syndrome (dysostoses group A – predominant cranial and facial involvement)

physis should be at the level of the tibio-talar joint; Fig. 14). Note that if a child has constitutional short stature, then while his fingers may be short compared with another child of the same age, they are normal for him (given his height), and therefore not hypoplastic. When considering size, it is also relevant to consider bone age, which may be assessed from views of the wrist, foot and ankle, or knee depending on local practice.

Sum

Bones may be *too many*, *too few*, *or fused*. Supernumerary teeth are seen in chondroectodermal dysplasia, multiple epiphyseal centres occur in the patella in some forms of diastrophic dysplasia and autosomal recessive multiple epiphyseal dysplasia (MED), i.e. MED with the diastrophic gene (Fig. 15), while multiple centres in the calcaneum are almost pathognomonic of Larsen's syndrome (Fig. 16). An absent patella occurs in the nail-patella syndrome. An absent radius forms part of TAR (thrombocytopaenia absent radius) syndrome, but may also be seen in Holt–Oram syndrome, as may fusion of the forearm bones, while fused carpal bones may be seen in Ellis–van Creveld syndrome. Polydactyly is associated with numerous dysplasias; it is described as being pre-axial if it occurs on the side of the thumb or big toe, and post-axial on the side of the little finger or toe (Fig. 17).

Soft tissues

Abnormalities of the soft tissues that should be looked for include *wasting*, *excessive soft tissues*, *contractures* and *calcification*.

Fig. 18 Note the characteristic lace-like appearance of the sclerotic borders of the iliac wings in Dygvve–Melchior–Clausen syndrome [group 10 – other spondyloepi(meta)physeal dysplasias, (SE(M)D)

Soft tissue involvement may change not only the diagnosis, but also the patient's prognosis. Thus the co-existence of multiple enchondromas and phleboliths changes the diagnosis from Ollier's disease to Maffucci's syndrome, and although these are now thought of as a continuum of the same disorder, there is a greater risk of malignancy of up to about 30% in the latter [6]. Patients with Bruck's syndrome (soft tissue contractures and osteogenesis imperfecta) have reduced mobility when compared to those with osteogenesis imperfecta alone.

C – Complications

Although recognition of complications does not usually help in reaching a diagnosis, from the point of view of patient management it is important to exclude known complications of a condition once a diagnosis has been reached. Common complications include *fractures* in both osteoporotic (e.g. osteogenesis imperfecta) and osteosclerotic (e.g. osteopetrosis) conditions. *Atlanto-axial subluxation* can occur in mucopolysaccharidosis. *Progressive scoliosis* may be a feature in neurofibromatosis and in survivors of campomelic dysplasia. *Limb length discrepancies* may be seen in conditions associated with epiphyseal stippling, dysplasia epiphysealis

Fig. 19 Medial extension of the iliac wings leads to a characteristic snail-like appearance in the appropriately named schneckenbecken (*snail pelvis*) dysplasia (group 3 – metatropic dysplasia group)

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hemimelica, Ollier's disease, multiple cartilaginous exostoses, etc. *Malignancy* may be a consideration in the latter condition and in Maffucci' s syndrome.

One should always consider *complications of therapy*, such as increasing angular deformity, excessive rate of distraction of a leg length osteotomy site or infection, which may be local or distant (e.g. following bone marrow transplantation for osteopetrosis).
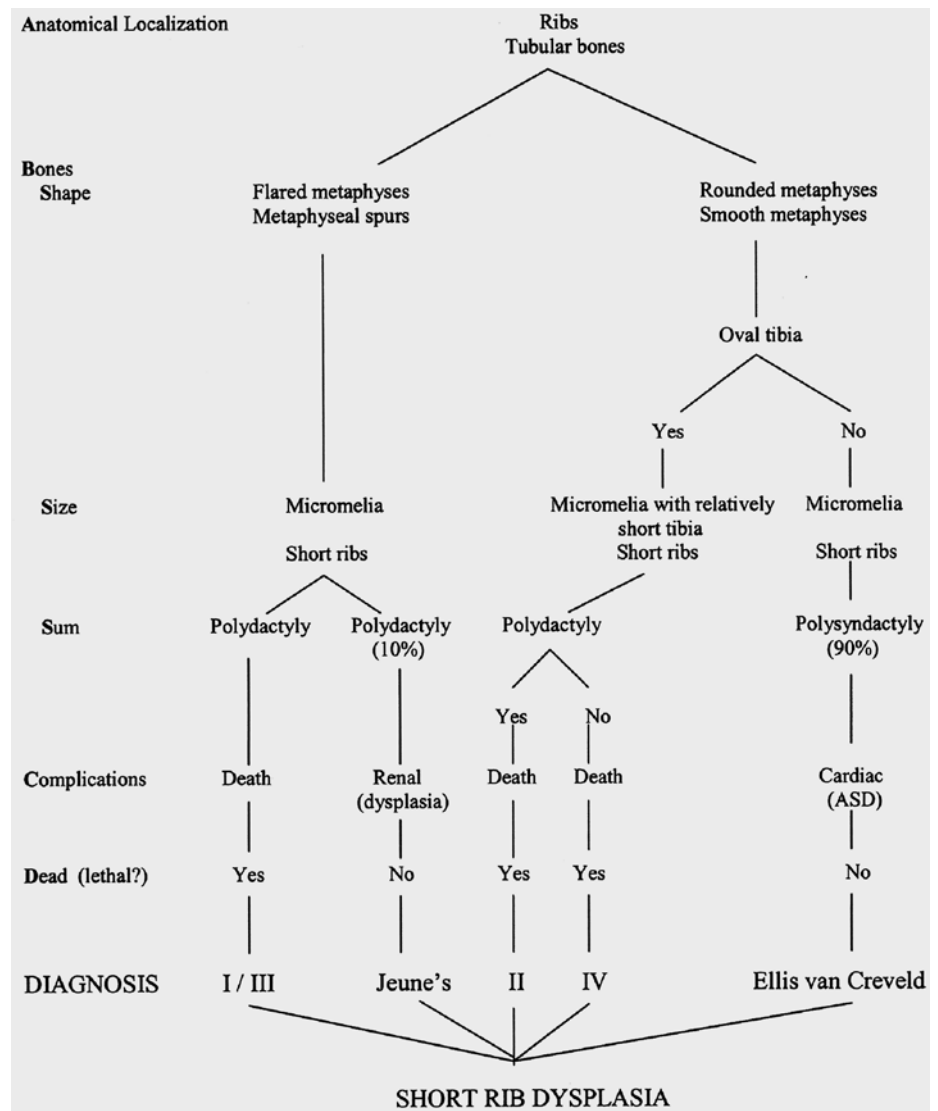
D – Dead or alive

On occasion, the fact that a dysplasia is lethal helps to exclude or confirm a given diagnosis, or affects the subtype of the condition, which may change the mode of inheritance and therefore the genetic counselling given to the parents.

Making the diagnosis

Orthopaedic management of a dysplasia does not necessarily require a firm diagnosis. However, if a diagnosis can be made, it allows the geneticist to give a prognosis in terms of expected complications, final adult height and intelligence, and also to give genetic counselling both for the parents and the patient. In addition, it can be beneficial in terms of psychological support, enabling the family to join relevant societies and meet other families with a similarly affected child.

The diagnosis of some conditions is based on the recognition of certain characteristic or pathognomonic features, e.g. of *structure*: the wavy, lace-like sclerotic pattern seen in the iliac wings of patients with Dygvve–Melchior–Clausen syndrome (Fig. 18), or of *shape*: the medial extension of the iliac wings giving them a

Fig. 20 A schematic illustration of the systematic approach. The short rib dysplasias (with or without polydactyly) belong to group 4 of the revised nomenclature

snail-like appearance in schneckenbecken dysplasia (Fig. 19). Usually the diagnosis is reached by putting together all the abnormal findings, a process which may be facilitated by consultation with colleagues, textbooks or computer aids, such as the Radiological Electronic Atlas of Malformation Syndromes and Skeletal Dysplasias (REAMS) [8] or the London Dysmorphology Database [9]. Figure 20 summarises how the scheme may be used to reach a diagnosis, using the conditions that occur in group 4 of the International Classification as an example.

A word of warning: it is not always possible, even in the best of hands, to reach a diagnosis, and once the patient has been given a diagnosis it is often difficult to reverse. Remember–no label is better than the wrong label!

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