Another disorder finds its gene

Siintola et al. describe for the first time three patients with a deficiency of the lysosomal aspartyl proteinase cathepsin D (CTSD). In one of these patients, the authors found a mutational inactivation of the cathepsin D gene (CTSD) that encodes CTSD. All the patients described had severe neurological abnormalities at birth including intractable seizures, spasticity, apnoea and microcephaly. This deficiency is proposed as the underlying cause of congenital neuronal ceroid lipofuscinosis (CNCL) (Humphreys et al., 1985; Garborg et al., 1987; Barohn et al., 1992).

Originally described in a sheep model (Tyynela et al., 2000, 2001) and further corroborated by findings in a canine model (Awano et al., 2006), defects in CTSD were considered to be part of the neuronal ceroid lipofuscinoses (NCLs). The ovine model proved to be a feasible tool to study the disease. The affected sheep have a mutation in the active site of CTSD and newborn lambs suffer similar pathological and neurological consequences as seen in the human NCLs. The NCLs encompass a group of lysosomal storage diseases sharing similar clinical features (Goebel et al., 1999; Herva et al., 2000; Santavuori et al., 2000; Weimer et al., 2002; Mole, 2004). Described in the 19th and early 20th century as one disease with a variable age of onset, these diseases are now known to be caused by mutations in six different genes (CLN1–CLN3, CLN5, CLN6 and CLN8) located on different chromosomes (for a review see Mole, 2004). Adult NCL is expected to be caused by mutations in a gene not yet identified (CLN4). The worldwide incidence of the NCLs is 1 : 30 000 live births (Santavuori et al., 2000).

The NCLs present with progressive loss of vision and neurodevelopmental decline, seizures, myoclonic jerks and premature death. The classification of the four major clinical forms is based on the age of onset: infantile (INCL/CLN1), late infantile (LINCL/CLN2), juvenile (JNCL/CLN3) and adult (Kufs disease or ANCL/CLN4). In addition the NCLs also include three variants of the late infantile form (vLINCLs/CLN5, CLN6 and CLN8) and northern epilepsy (NE/CLN8) which is allelic with one of the vLINCLs (Ranta et al., 2004). Now with the addition of CNCL due to mutation of CTSD the human NCLs currently consist of nine diseases due to mutation in eight genes, seven of which have been identified (Table 1). Little is known about ANCL as it encompasses a more diverse clinical presentation and evolution, and some cases initially classified as ANCL have been later re-classified as variants of lipidosis (Berkovic et al., 1988; Goebel et al., 1999). Although presumed to be caused by mutations in CLN4, lack of the ability to perform accurate diagnosis has been a limiting factor for the identification of this gene.

Now with the addition of CNCL due to mutation of CTSD, the human NCLs currently consist of nine diseases caused by mutations in seven genes, six of which have been identified (Table 1). The common pathological finding is the primary deficiency of the lysosomal aspartyl proteinase cathepsin D (CTSD). The worldwide incidence of the NCLs is 1 : 30 000 live births (Santavuori et al., 2000).

Table 1 The Neuronal Cerebral Lipofuscinoses. Clinical classification, gene affected, and protein designation.

<table>
<thead>
<tr>
<th>Disease</th>
<th>Chromosome location</th>
<th>Gene affected</th>
<th>Protein designation/function</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNCL</td>
<td>1p15.5</td>
<td>CTSD</td>
<td>Cathepsin D</td>
</tr>
<tr>
<td>INCL</td>
<td>1p32</td>
<td>CLN1</td>
<td>Palmitoyl protein thioesterase I</td>
</tr>
<tr>
<td>LINCL</td>
<td>1p15</td>
<td>CLN2</td>
<td>Tripeptidyl peptidase protein I</td>
</tr>
<tr>
<td>JNCL</td>
<td>16p12</td>
<td>CLN3</td>
<td>Unknown</td>
</tr>
<tr>
<td>ANCL</td>
<td>Unknown</td>
<td>CLN4</td>
<td>Unknown</td>
</tr>
<tr>
<td>vfnLINCL</td>
<td>13q31–32</td>
<td>CLN5</td>
<td>Unknown</td>
</tr>
<tr>
<td>vLINCL</td>
<td>15q21–23</td>
<td>CLN6</td>
<td>Unknown</td>
</tr>
<tr>
<td>vturkLINCL</td>
<td>8p23</td>
<td>CLN8</td>
<td>Unknown</td>
</tr>
<tr>
<td>NE</td>
<td>8p23</td>
<td>CLN8</td>
<td>Unknown</td>
</tr>
</tbody>
</table>
presence of autofluorescent storage material in the lysosome, which varies in composition amongst the different NCLs (Palmer et al., 1997; Tyynela et al., 1997). Although not completely characterized, it is known that the deposits contained in INCL, LINCL and JNCL include saposins A and D (SAPs), various lipids and other proteins. However, in INCL there is no accumulation of the subunit c of mitochondrial ATP synthase, which has been found in LINCL and JNCL to be a predominant component of the storage material (Palmer et al., 1992). In JNCL, accumulations also show variable amounts of amyloid beta peptide, dolichyl compounds and oligosaccharides. The mechanism(s) responsible for the accumulation of these materials is (are) not completely understood, and their heterogeneity suggests that more than one degradation pathway in the lysosome may be affected. Ultrastructural analyses of the storage material also reveal a different appearance depending on the disease (Palmer et al., 1997; Tyynela et al., 1997; Goebel et al., 1999). Granular osmiophilic deposits (GRODs) are the hallmark for INCL. These aggregates are localized in neurons forming packed structures of nearly 5 μm in size, but can be found in other cell types as well. Curvilinear profiles (CP) are membrane bound bodies present in almost any cell, and are a hallmark of LINCL. Rectilinear complex and fingerprint bodies are present in lesser extent in JNCL and vLINCLs. However, the role that the storage material plays in the pathophysiology of the NCLs has been the focus of debate, and remains elusive.

To date, the only NCL genes whose encoded proteins have a known function are CLN1 and CLN2. CLN1 encodes palmitoyl protein thioesterase 1 (PPT1) and CLN2 encodes the serine protease, tripeptidyl peptidase protein I (TPP1), both of which are soluble lysosomal enzymes (for a review see Lin et al., 2001; Hofmann et al., 2002).

The protein mutated in JNCL, denoted CLN3, is most likely a lysosomal transmembrane protein (for a review see Phillips et al., 2005), which has been associated with different cellular pathways such as arginine transport into the lysosome (Kim et al., 2003; Ramirez-Montalegre and Pearce, 2005), lysosomal vATPase activity and vacuolar pH regulation (Pierce et al., 1999a,b; Ramirez-Montalegre and Pearce, 2005; Padilla-Lopez and Pearce, 2006), and apoptosis (Puranam et al., 1999; Persaud-Sawin et al., 2002). The Finnish variant for the late infantile form is caused by mutations in CLN5. It is likely a transmembrane protein, and localizes to the lysosome (Iosomppi et al., 2002). The gene responsible for the vLINCL described in small populations of patients of Spanish, Romany or Portuguese origin was mapped to chromosome 15, and corresponds to CLN6 (Sharp et al., 1999). Naturally occurring animal models of this disease include the nclf mouse model (Bronson et al., 1998) and the South Hampshire sheep model (Broom and Zhou, 2001). Interestingly, as opposed to most of the other CLN-proteins, CLN6 has been localized to the endoplasmic reticulum (Heine et al., 2004; Mole et al., 2004). The Turkish variant of LINCL (vturkLINCL) has been recently identified as being caused by a mutation in CLN8 (Ranta et al., 2004), although it was originally classified as being due to mutation in a gene designated as CLN7. Northern epilepsy (NE) is caused by mutations in CLN8 (Tahvanainen et al., 1994). The function of CLN8 is not known; however, it has been localized to the endoplasmic reticulum (Lonka et al., 2000).

CNCL is defined as a rare congenital condition characterized by severe microcephaly, spasticity, neonatal status epilepticus and death within the first days or weeks of life (Humphreys et al., 1985; Garborg et al., 1987; Barohn et al., 1992). Based on clinical findings from reports of affected patients, CNCL was tentatively included as a variant NCL without genetic assignment (Goebel et al., 1999), because evaluation of post-mortem tissue showed the presence of autofluorescent material with similar components to those found in INCL. Owing to the possibility of other severe neonatal conditions that could explain similar clinical signs, differential diagnosis is difficult and includes a large number of fatal metabolic diseases.

Using blood samples from a reported still-alive case of CNCL in a newborn of Pakistani origin, and based on their previous findings in the ovine model, Siintola et al. screened CTSD using samples obtained from the father and the affected newborn. This family had a previous history of two affected newborns clinically classified as CNCL. These two newborn boys died within the first days of life. Paraffin embedded samples from the two diseased newborns, and samples obtained from a fourth non-related case of British origin, were used for non-genetic analyses.

A search for mutations in the nine exons and adjacent intron/exon boundaries of CTSD revealed that the affected newborn had a homozygous single nucleotide duplication in exon 6 that alters the reading frame and causes a premature stop codon at position 255. Similar analysis of the father showed that he is a heterozygous carrier of the same mutation. Although not available for analysis, it is predicted that the mother carries a similar mutation due to consanguinity, as the parents are first cousins. As a consequence of the mutation, the CTSD mRNA is probably degraded by the nonsense-mediated mRNA decay system (Maquat, 2004). This likely accounts for the lack of detectable CTSD in the patient’s tissues studied by immunohistochemistry. It is also possible that if the mRNA survives the normal decay controls, the truncated protein is degraded. The authors were able to express the truncated protein in model systems and found that it had no CTSD activity. Thus, it is almost certain that the CTSD mutation, and consequent lack of CTSD enzyme activity, accounts for the severe disease seen in the Pakistani patient. Further work will reveal if all cases of CNCL are due to mutations in CTSD. It is also possible that less damaging mutations in CTSD, that allow some residual enzyme activity, may cause CNCL with a later onset and milder presentation.

Neuropathological findings using paraffin embedded samples from the two Pakistani newborns and the British
patient showed absence of CTSD immunostaining, microglial activation, severe neuronal and white matter loss, and presence of storage deposits including SAPs, which were previously described in other CNCL patients. In the samples analysed, Siintola et al. report the absence of accumulation of the subunit c of mitochondrial ATP synthase. This finding was also reported in previous cases. The pathological reports presented in the article also resemble results previously obtained from the ovine model.

The findings of Siintola et al. strongly support the notion that CNCL is in fact another form of NCL. Their results also show that CNCL is caused by mutations in the gene encoding the lysosomal enzyme CTSD. Their approach nicely demonstrates the value of naturally occurring animal models for investigation of the NCLs. In this particular instance, the animal models pointed towards a likely candidate gene, which seems to be correct for the cases studied. In the absence of the animal models it would have taken much longer to identify the gene responsible for such a rare and hard to diagnose disease. The animal models will also very likely prove to be important in the elucidation of the normal functions of the proteins that are defective in other types of NCL. Furthermore, similar to INCL and LINCL in which lysosomal enzymes are lacking or defective, their findings suggest that common cellular pathways involving the proper lysosomal degradation of proteins and lipids are affected in the different NCLs. This could explain common features present in a set of diseases that are quite diverse with respect to the causative gene, composition of the storage material and severity (Table 1).

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References

Kim Y, Ramirez-Montealegre D, Pearce DA. A role in vacuolar arginine transport for yeast Btn1p and for human CLN3, the protein defective in Batten disease. Proc Natl Acad Sci USA 2003; 100: 15458–62.


