Original articles

Angelman syndrome phenotype associated with mutations in MECP2, a gene encoding a methyl CpG binding protein

Pamela Watson, Graeme Black, Simon Ramsden, Margaret Barrow, Maurice Super, Bronwyn Kerr, Jill Clayton-Smith

Abstract
Angelman syndrome (AS) is a neurodevelopmental disorder characterised by severe mental retardation, absent speech, ataxia, sociable affect, and dysmorphic facial features. Eighty-five percent of patients with AS have an identifiable genetic abnormality of chromosome 15q11-13. Mutations within the X linked MECP2 gene have been identified in patients with Rett syndrome (RTT), a neurodevelopmental disorder which affects females almost exclusively and which shares phenotypic overlap with AS. RTT is usually associated with normal development in infancy followed by loss of acquired skills and evolution of characteristic hand wringing movements and episodes of hyperventilation.

A panel of 25 female and 22 male patients with a clinical diagnosis of AS and no molecular abnormality of 15q11-13 were screened for MECP2 mutations and these were identified in four females and one male. Following the diagnosis, it was possible to elicit a history of regression in three of these patients, who by then were showing features suggestive of Rett syndrome. In the remaining two subjects the clinical phenotype was still considered to be Angelman-like.

These findings illustrate the phenotypic overlap between the two conditions and suggest that screening for MECP2 mutations should be considered in AS patients without a demonstrable molecular or cytogenetic abnormality of 15q11-13. Since MECP2 mutations almost always occur de novo, their identification will substantially affect genetic counselling for the families concerned.

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Keywords: Angelman syndrome; Rett syndrome; MECP2 mutations

Angelman syndrome (AS) is a neurodevelopmental disorder characterised by severe mental retardation, inability to speak, ataxia, dysmorphic facial features, and a seizure disorder associated with a characteristic EEG appearance.2 Aﬀected subjects have a speciﬁc behavioural phenotype; they are happy and sociable with a tendency to outbursts of laughter caused by minimal provocation. The subtle dysmorphic features associated with AS include deep set eyes, wide, smiling mouth, and a prominent chin. Head circumference is usually normal at birth but head growth decelerates during the early years of life and 30% of subjects become microcephalic.3,4 Most cases of AS are sporadic, although many familial cases have been reported. A variety of different genetic mechanisms involving chromosome 15q11-13, a known imprinted region, have been described in association with AS.5 Approximately 70% of patients have a de novo maternal deletion of chromosome 15q11-13, while 3% have uniparental paternal disomy for chromosome 15. In a further 5% of cases there is biparental inheritance of chromosome 15, but both chromosomes have a paternal expression pattern owing to defective imprinting of 15q11-13. Finally, around 5% of patients have loss of function mutations in the UBE3A gene, a gene encoding E6-AP, a ubiquitin protein ligase. All result in a deficiency of the E6-AP protein, which is involved in the process of ubiquitination.6 There remain a group of around 15% of AS patients, both sporadic and familial, in whom no cytogenetic or molecular abnormality involving chromosome 15q11-13 can be identiﬁed. There are few data documenting the clinical characteristics of this group of patients.7 Our own observations suggest that patients diagnosed with AS on clinical grounds alone have greater motor delay, are more likely to have some speech, and are less likely to have seizures and the characteristic Angelman syndrome EEG changes. While this group may have mutations affecting UBE3A expression which cannot be deﬁned, there remains the possibility that AS is heterogeneous with other, as yet unidentified causes.

Rett syndrome (RTT) is a disorder which is seen almost exclusively in females.8 Classically, it is characterised by normal development for the first 12-18 months followed by developmental regression and loss of acquired skills, especially...
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Embryonic cellular differentiation appears to be of importance for the X-linked gene MECP2.12 This encodes methyl CpG binding protein 2, which binds to single CpG dinucleotides throughout the genome and interacts with a histone deacetylase complex to mediate transcriptional repression. In the mouse, mecp2 is highly expressed in the brain and appears to be of importance for embryonic cellular differentiation.12

AS and RTT show phenotypic overlap, as was pointed out by Scheffer et al13 in 1990. Both are associated with severe mental retardation, acquired microcephaly, ataxia, seizures, and stereotypic hand movements. The main distinguishing feature is the clinical history as AS patients do not have an initial normal period of development or a distinct period of regression. The typical early history of regression is not present in every RTT patient and it can be difficult to elicit. We investigated the possibility that AS with no detectable abnormality of 15q11-13 may in fact result from a defect of MECP2.

Patients and methods

DNA extracted from lymphocytes of 47 patients with a clinical diagnosis of Angelman syndrome but no cytogenetic or molecular abnormality of 15q11-13 was screened for mutations within the MECP2 gene. All of these patients fulfilled the consensus diagnostic criteria for Angelman syndrome as laid down by Williams et al.14 One hundred ng DNA from each patient was amplified using the primer pairs published by Amir et al11 which span three exons and cover the coding region of the gene. Each sample was processed through 30 cycles of amplification consisting of one minute at 94°C (denaturation), one minute at 55°C (annealing), and one minute at 72°C (extension). The final extension step was 10 minutes. SSCP/heteroduplex analysis was performed using equal volumes of PCR product and formamide loading dye. Gels were run at 350 V overnight at 4°C and silver stained according to standard protocols. They were inspected for abnormally migrating bands which were then sequenced directly using the ABI Prism Dye Terminator Cycle Sequencing kit (Perkin Elmer, Applied Biosciences Division, Warrington, UK). Results were compared to the reference sequence for MECP2 (Genebank accession No X99686.) Mutations which created or abolished restriction sites were confirmed by restriction enzyme analysis of genomic DNA using appropriate enzymes. Products of restriction digestion were fractionated or electrophoresis and the products visualised under UV transillumination after ethidium bromide staining.

Results

Mutations within MECP2 were identified in four of the 25 females and one of the 22 males screened. The clinical details of these patients are summarised in table 1 and details of the mutations identified are given in table 2.

Patient 1 (fig 1) was a girl. There had been concern about her general development in the first year of life as she was a sleepy baby and...
sitting was delayed until 12 months of age. She had febrile seizures at 6 months and meningitis was suspected. She developed five words of speech but lost these during the second year of life. Her comprehension appeared to be better than her expressive speech. She had a small head circumference with a flat occiput and a prominent chin. She smiled frequently. She had a resting tremor and jerky voluntary movements but no hand wringing or hyperventilation. Her legs were stiff with a talipes deformity of one foot.

EEG showed 2-3 Hz slow wave activity in the temporal, central, and posterior regions and some other non-specific features. A clinical diagnosis of Angelman syndrome was made. Analysis of the 15q11-13 region as described above showed no abnormalities but analysis of MECP2 showed a 44 base pair deletion within exon 3 of the gene which was not present in either parent.

Patient 2 presented to the paediatric neurologist at the age of 3 years with severe developmental delay and ataxia. She had feeding problems as an infant and had been investigated for failure to thrive at 8 months. She sat at 7 months and her parents considered that her development had been normal up until that time. She had never been able to crawl or walk.

She was noted to have a marked tremor with evidence of titubation. She was microcephalic with a flat occiput and a prominent chin and drooled frequently. She had never developed speech or had seizures but a sleep EEG was reported to be abnormal. A diagnosis of Angelman syndrome was suggested. By the age of 6 years, she had developed a scoliosis. She continued to have tremulous movements but she had no hand wringing stereotypes or hyperventilation and had some purposeful hand use. Molecular analysis of chromosome 15q11-13 was normal but analysis of MECP2 showed a C to G transition at nucleotide position 376 causing a substitution of arginine for proline at amino acid position 101, which lies within the methyl binding domain of MECP2 and would therefore be likely to have an effect on protein function.

Patient 3 was first seen at the age of 6 months because of slow developmental progress; in particular she was not reaching out for toys. At that time her head circumference was within the normal range. When seen at the age of 3 years she was noted to have frequent laughter with hand flapping and tongue thrusting behaviours and occasional fidgeting of her hands but no hand wringing. Her parents had observed heavy breathing on occasions. She was microcephalic and had a flat occiput and a prominent chin. Progress with her motor development had been slow. At 6 years she was sitting alone but not mobile. There was no history of regression. She had not had any seizures and an EEG was reported as normal. CT scan showed a large cisterna magna with a small cerebellar vermis and slightly large ventricles. A diagnosis of Angelman syndrome was suggested because of her

<table>
<thead>
<tr>
<th>Patient</th>
<th>Exon</th>
<th>Nucleotide change</th>
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<th>Mutation type</th>
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</table>

MBD: methyl-cytosine binding domain (85 amino acids).
TRD: transcriptional repression domain (104 amino acids).
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MECP2 detected within the 15q11-13 region. Analysis of normal EEG and no abnormality had been the most likely diagnosis, although she had a non-specific and the EEG can often be normal in the first few years of life. Two of our five patients had seizures and although three had an abnormal EEG, none had the EEG features overlapping clinical features and Scheffer et al drew attention to these clinical similarities and cautioned against making the diagnosis of AS in a girl at an early age, especially in the absence of the typical EEG appearance. Laan et al studied the EEGs of patients with Angelman syndrome and Rett syndrome at a young age. They suggested that whereas the EEG changes in AS are pathognomonic of this condition, those seen in Rett syndrome are more non-specific and the EEG can often be normal in the first few years of life. Two of our five patients had seizures and although three had an abnormal EEG, none had the EEG features

Figure 2 Patient 5 at the age of 4 years. Note stiff legged posture and small, discoloured feet.
...drome and these were frequent in the subjects...nal, has been reported as a feature of Rett syndrome. All of our patients had facial features typically associated with AS. This supports the exact boundaries. In view of the broad clinical grounds, there remains an argument as to its feet which are not a common feature of AS. Three of our patients had remarkably cold, blue rhythmically from foot to foot. Facial features were ambulant was a habit of rocking slowly and marked tremor. A further observation in those of the five who were ambulant was a habit of rocking slowly and rhythmically from foot to foot. Facial features were very similar to those seen in classical AS. Three of our patients had remarkably cold, blue feet which are not a common feature of AS.

Within any condition diagnosed on clinical grounds, there remains an argument as to its exact boundaries. In view of the broad clinical variability in Rett syndrome, Hagerman suggested diagnostic criteria for “Rett syndrome variants” to be used in girls of 10 years or over. It is in the early years, however, that parents usually seek a diagnosis and genetic advice before planning further children. It is during this period that there is most phenotypic overlap between the features of AS and RTT. In a situation where AS is diagnosed on clinical grounds alone, parents would be counselled that recurrence risks could be as high as 50% and that no specific prenatal test would be available. If it could be shown that the child had a MECP2 mutation, the recurrence risk would be much lower in the majority of cases since most arise de novo. Clearly it is possible to argue that the patients described should not now be considered to have Angelman syndrome. The observations nevertheless serve to illustrate the potential clinical value of considering MECP2 screening in the young AS patient with no 15q11-13 abnormalities, even if the patient is a male.

The phenotypic overlap between the clinical course of AS and RTT raises the question as to whether the two conditions may be aetologically related through a common pathogenesis. MeCP2 is involved in transcriptional silencing. It binds to single CpG dinucleotides throughout the genome and with the corepressor Sin3A, which binds to its transcriptional repression domain, it recruits histone deacetylases. These then act to alter chromatin configuration to prevent transcription. It has been postulated that in the presence of a MECP2 mutation, there may be overexpression of downstream genes, although a study by Xiang et al did not show an increase in levels of certain neurotransmitters within the brains of subjects with MeCP2 mutations, which would have supported this hypothesis. Overexpression of genes within the 15q11-13 region does give rise to a specific phenotype. Several subjects with a maternal duplication of this region have had autistic features, ataxia, epilepsy, learning difficulties, and subtle dysmorphic facial features. One hypothesis, therefore, is that UBE3A is one of the target genes downstream of MECP2 for which alteration of expression is particularly critical. Further investigation of this hypothesis will involve the study of those areas of the brain where UBE3A is known to be expressed.
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