Chromosome 13q deletion with Waardenburg syndrome: further evidence for a gene involved in neural crest function on 13q


Department of Medical Genetics, University of Antwerp, University Hospital, B-2610 Antwerp, Belgium
G Van Camp, M N Van Thienen, I Handig, B Van Roy, P J Willems

Department of Neurology, Boston University School of Medicine, Boston, USA
V S Rao, L A Farrer

Center for Human Genetics, Boston University School of Medicine, Boston, USA
A Milunsky, C T Baldwin

University Department of Medical Genetics, St Mary’s Hospital, Manchester, UK
A P Read

Department of Medical Genetics, University of the Free University of Brussels, Brussels, Belgium
M Bonduelle

Institute Spermalie, Bruges, Belgium
L Standaert

Department of Ophthalmology, University of Ghent, Gent, Belgium
F Meire

Correspondence to: Dr Van Camp.
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Abstract
Waardenburg syndrome (WS) is an autosomal dominant disorder characterised by pigmentary abnormalities and sensorineural deafness. It is subcategorised into type 1 (WS1) and type 2 (WS2) on the basis of the presence (WS1) or absence (WS2) of dystopia canthorum. WS1 is always caused by mutations in the PAX3 gene, whereas WS2 is caused by mutations in the microphthalmia (MITF) gene in some but not all families. An association of WS symptoms with Hirschsprung disease (HSCR) has been reported in many families. We report here a patient with characteristics of WS2 and a de novo interstitial deletion of chromosome 13q. We also describe a family with two sibs who have both WS2 and HSCR. In this family, all possible genes for WS and HSCR, but not chromosome 13q, could be excluded. As an association between chromosome 13q and HSCR/WS has been reported previously, these data suggest that there is a gene on chromosome 13q that is responsible for WS or HSCR or both.

(Waardenburg syndrome (WS) is an autosomal dominant disorder, characterised by pigmentary abnormalities of the hair, eyes, and skin. These include a white forelock, premature greying of the hair, heterochromia irides, hypopigmented irises, and white skin patches. Sensory neural hearing impairment is present in 25 to 50% of the patients. With a population frequency of approximately 1/40,000, WS is responsible for about 2% of cases of congenital deafness.¹ WS is subdivided into type 1 (WS1) and type 2 (WS2) on the basis of the presence or absence of dystopia canthorum.² After the description of a child with WS1 and a de novo inversion of 2q35-q37,³ linkage analysis in several families localised a WS1 gene to this region.⁴ ⁵ As the Splotch mutation, located in the syntenic region in the mouse, gives rise to white spotting, it has been suggested that WS and Splotch are homologous.⁶ The Splotch phenotype is caused by a mutation in the mouse Pax3 gene, a member of the paired box gene family, known to be involved in embryonic development.⁷ Many mutations have now been found in the homologous human PAX3 gene in different WS1 families.⁸ ⁹ Pooled data from the Waardenburg consortium indicate that all WS1 families are linked to PAX3.¹⁰ One form of WS2 has been localised to chromosome 3p12-p14.1 by linkage analysis.¹¹ The MITF gene, the human homologue of the mouse microphthalmia (mi) gene, is located in this region.¹² Mice with mi mutations show reduced pigmentation, microphthalmia, and hearing loss among other abnormalities. Mutations in the MITF gene have recently been found in patients with two WS2 families.¹³ However, WS2 is genetically heterogeneous, and some families are not linked to the locus on chromosome 3.

In addition to WS1 and WS2, WS type 3 has been described. WS3, or Klein-Waardenburg syndrome, is an autosomal dominant trait characterised by a WS type 1 phenotype with additional upper limb abnormalities.¹⁴ ¹⁵ Linkage analysis has not been performed, but PAX3 mutations have been found in two type 3 families.¹⁶ (A P Read, unpublished data), and limb defects are now considered to be a rare pleiotropic manifestation of WS1.¹⁷ Many patients have been reported with WS2 symptoms in combination with congenital megacolon (Hirschsprung disease, HSCR).¹⁸ ²³ The parents of these patients are unaffected and often consanguineous. For this poorly defined, heterogeneous group with apparent recessive inheritance, the term WS type 4 has been proposed.

WS and HSCR are part of a group of diseases called neurocristopathies, which are caused by an abnormal migration of neural crest cells during embryonic development. Apart from the PAX3 and MITF genes, mutations in two proto-oncogenes are known causes of neurocristopathies. Loss of function mutations in the RET proto-oncogene commonly causes HSCR without pigmentary disturbances or deafness, which is inherited as a dominant condition with reduced penetrance.²⁴ ²⁵ Mutations in the c-KIT proto-oncogene cause piebaldism, characterised by congenital white patches of skin and hair.²⁶

We identified a de novo interstitial deletion of chromosome 13q in a boy with features of WS2, suggesting that a WS gene might be located in the deleted region of chromosome 13q. Although a gene responsible for WS in the deleted region on chromosome 13 could be excluded in several WS2 families, this chromosomal region could not be excluded in a family with WS2 and HSCR.
Figure 1. (A) Idiogram of chromosome 13. The vertical bar indicates the deleted region in the WS2 patient. (B) Partial GTB banded karyotypes of the WS2 patient. The deleted chromosome 13 is shown on the right of each chromosome pair, and the deleted band is indicated on the normal chromosome.

Patients and methods
WS2 PATIENT WITH A CHROMOSOME 13 DELETION
A 6 year old boy presented with unilateral segmental heterochromia of the iris, hypopigmentation of the eye fundus, sensorineural deafness, and delayed psychomotor development (performance IQ was 62 on WPPSI scale). A linear skin depigmentation on the legs became evident after Wood lamp examination. Dystopia canthorum was not present (w index of 1.57). There were no signs of HSCR. Clinical examination of the parents showed no signs of WS.

WS2 FAMILIES
All WS2 families used in this study have been described previously.11

FAMILY WITH WS AND HSCR
The male proband of this family developed intestinal obstruction soon after birth. Laparoscopy confirmed the presence of a microcolon, which was shown to be the result of total colonic aganglionosis by microscopic examination. WS was suspected because of cutaneous piebaldism, a white forehead, white streaked eyebrows, white eyelashes, and ichromatic pale blue eyes. Dystopia canthorum was absent. Profound bilateral sensorineural deafness was shown by an auditory brainstem response test. Ophthalmological examination showed a normal retina and no other anomalies. Histological examination of the aortic wall showed a normal epidermis but an absence of melanocytes. Routine cytogenetic analysis did not show any abnormality. The family history included an older brother with similar features of WS who died from long segment HSCR. Neither parent nor three healthy sibs had any sign of WS on further examination. No consanguinity between the parents could be documented, although they both originated from a small Moroccan village of 600 inhabitants.

CYTOGENETIC ANALYSIS
Peripheral blood cultures of the WS2 patient and his parents were synchronised using the methotrexate/bromodeoxyuridine method. High resolution G banding with trypsin/basic fuchsin (GTB) was performed according to Scheres et al.27

MICROSATELLITE ANALYSIS
The following polymorphic dinucleotide repeat chromosome 13q markers were typed: D13S126, D13S118, D13S227, D13S228, D13S133, D13S137, D13S119, D13S134, D13S131, D13S144, D13S137, D13S121, D13S140, D13S125, and D13S122. All these markers have been described before,26-30 and are integrated in the genetic31 or physical30 map of chromosome 13. Experimental procedures for the amplification of microsatellites were as described.32 Microsatellite markers for the PAX3 gene, the RET gene, for markers D3S1261 and D3S1284 flanking the MITF gene, and for the GARB1 marker, located 3 cm proximal of the KIT gene on chromosome 4q, were obtained from the Genome DataBase.32

LINKAGE ANALYSIS
Linkage analysis was performed as described,11 using the computer programs Liped24 and Link-
Table 2  Two point lod scores between WS2 and chromosome 13q markers in WS families from Manchester University (UM) and Boston University (BU) not linked to PAX3

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**Results**

**CYTGENETIC ANALYSIS**

Routine karyotyping of a boy with characteristics of WS2 showed an interstitial deletion of the long arm of chromosome 13. High resolution GTB banding showed that the breakpoints of the deletion were in 13q21.2 and 13q32, respectively (fig 1). No abnormality was found in the parents.

**MOLECULAR DELINEATION OF THE DELETION**

To correlate the 13q deletion with the genetic map, 15 microsatellite genetic markers spanning the deleted region on chromosome 13q were typed in the WS patient and his parents (table 1). These markers cover approximately 40 cM of the long arm of chromosome 13. A genetic map containing most of these markers is given in fig 2. The patient is heterozygous for the proximal markers D13S126, D13S227, D13S133, D13S137, and the three most distal markers D13S140, D13S125, and D13S122. Therefore, these loci are not deleted in the patient. No paternal allele of D13S134, D13S144, and D13S137 is present in the patient, indicating that these loci are deleted from the paternal chromosome 13 in the patient (fig 3). The remaining markers D13S118, D13S228, D13S119, D13S131, and D13S121 were not informative. This analysis limits the deleted interval to the region between markers D13S137 and D13S140, a region of less than 30 cM.

**LINKAGE ANALYSIS IN WS2**

Linkage analysis with chromosome 13q markers was carried out in seven WS2 families that are not linked to the PAX3 gene on chromosome 2. Four microsatellite markers spanning the deleted region were analysed (table 1, fig 2). In the University of Manchester (UM) families, D13S118, D13S119, D13S144, and D13S121 were used. In the Boston University (BU) families, D13S131 was used instead of D13S144. The use of different markers should not affect the analysis since both D13S131 and
D13S144 are unambiguously placed between D13S119 and D13S121.\(^{38,39}\)

Table 2 presents two point lod scores between these markers and WS2 in seven different WS2 families. In none of the families tested was there evidence for linkage with chromosome 13q. Multipoint linkage analysis was performed independently in each family (data not shown). Lod scores below -2 were obtained for all inter-marker regions between D1S118 and D1S121 in all three BU families and in family UM 2, excluding the WS gene from this region. In the smaller families UM 26, UM 22, and UM 4 not all inter-marker regions were formally excluded.

**WS/HSCR FAMILY**

A family with WS and HSCR in two sibs was analysed with microsatellite markers for the PAX3 and RET genes, with marker GARB1, located 3 cM proximal of the KIT gene, and with markers D3S1261 and D3S1284, flanking the MITF gene (fig 4). For all these markers, an identical haplotype was obtained for the WS/HSCR patient and an unaffected sib (fig 4). Under the hypothesis of full penetrance, this excludes all four genes as the cause of WS/HSCR in this family. The family was also typed for a number of chromosome 13q markers, spanning the deletion found in the de novo WS2 patient (fig 4). The patient and his unaffected sibs did not share a parental haplotype for the 13q markers, indicating that the involvement of this chromosomal region as a cause of the disease can not be excluded.

**Discussion**

In this study we describe a de novo interstitial deletion of the long arm of chromosome 13 in a patient diagnosed with WS2. This suggests that a gene responsible for WS2 is located in this deleted region. Therefore, we performed linkage analysis with chromosome 13 genetic markers spanning the deleted region in seven WS2 families not linked to the PAX3 gene on chromosome 2. However, there was no evidence for linkage with these chromosome 13q markers in either of these WS2 families. Although we could not formally exclude the complete region in the three smaller families, the WS gene was excluded from all inter-marker regions by linkage analysis in the four larger families. These results indicate that the region of chromosome 13q investigated in this study does not contain a locus that is frequently responsible for WS2. After these results were obtained, Tassabehji et al\(^{44}\) reported that WS2 is the result of mutations in the MITF gene in some but not all WS2 families.

Recently, a new locus for HSCR has been mapped to chromosome 13q22 in a single large inbred family. The inheritance pattern in this family is unclear, and both recessive inheritance and dominant inheritance with reduced penetrance are possible.\(^{7}\) The gene causing HSCR in this family is located inside the chromosome.
Chromosome 13q deletion with Waardenburg syndrome: further evidence for a gene involved in neural crest function on 13q

13 region deleted in our patient. The authors also incidentally report characteristics similar to WS, including white forelock, bicoloured irides, hearing loss, and hypopigmentation of the skin, in a number of the HSCR patients. Although the authors state that it is likely that these WS characteristics segregate separately from HSCR in this pedigree, the same chromosome 13 region has been published independently by others as a possible location for a gene involved in neural crest dysfunction. Apart from our present case, five cases have been reported of HSCR associated with chromosome 13 deletions. In two of these cases, were to exclude this region. The family is too small to derive any linkage information, a chromosome 13 region could be very well be responsible for a combination of WS and HSCR. This is also supported by published data, as chromosome 13 deletions are present in several reports of patients with neural crest dysfunction. We therefore report here a possible association with the deletion of the long arm of chromosome 13, with the breakpoints 13q21.2-qter, 13q14.1-q22.3, 13q21.2-q23.2, 13q32.3-q33.2. None of these patients have been reported to have symptoms of WS, although one did have heterochromia irides. Other patients with overlapping 13q deletions have been reported who did not have HSCR. This variability is not incompatible with the presence on 13q of a WS/HSCR gene. It is possible that HSCR in these cases is a recessive entity unmasked by the deletion; in that case patients with a 13q deletion on one chromosome would only express WS/HSCR if they had a second mutation on the non-deleted chromosome. On the other hand, the inheritance could be dominant with reduced penetrance. Both hypotheses would adequately explain why some patients with 13q deletions do not have HSCR. Also, patients with gross rearrangements of 2q35 deleting PAX3 do not necessarily show signs of WS.

In summary, the findings from our study corroborate the published data from which it is clear that (1) WS is associated with HSCR in many cases, (2) HSCR is associated with 13q deletions, (3) a family with characteristics of both HSCR and WS shows linkage to chromosome 13q22. Our study shows that a patient with a 13q21.2-q32 deletion has characteristics of WS, and that WS and HSCR in two sibs of one family might be the result of a mutated gene in the same region of chromosome 13. Taken together, these data strongly suggest the existence of a gene on chromosome 13q that is involved in neural crest cell migration, causing either HSCR, WS, or a combination of both.

The recessive mouse mutation piebald lethal, a mouse model for HSCR, is characterised by striking changes in coat pigmentation and the development of metal aganglionic megacolon. The mutation is located on mouse chromosome 14 between the homologue of the human retina glial cell line, and the homologous mouse chromosome 13 region related protein 2, located on human 13q31-32. If the human-mouse synteny is conserved throughout this region, the human homologue of the gene responsible for mouse piebald lethal is a very strong candidate for the gene involved in neural crest function in this region.

Note added in proof
After this paper was submitted, a mutation was reported in the endothelin-B receptor (EDNBR) gene in the large inbred HSCR family that is linked to 13q22.3. Simultaneously, a paper was published describing mutation in the mouse EDNRB gene producing megacolon and spotted coat colour. These data indicate that the gene on 13q responsible for WS and HSCR is most likely EDNBR.

We thank Dr A. Munzich and S. Lyonnet for the genotyping of the chromosome 10 markers, and Drs H. Scheffler and J. Kooy for providing several chromosome 13 primers. Financial support has been received from the National Funds for Scientific Research (NFWO) to GVC, a grant from the University of Antwerp to GVC and FJW, NIH grant No.1848 to CTB and NIH contract 2P30-RR-0012 for the neural crest disorders in mice project. We thank Drs A. Mischer, H. Scheffer and H. Groenen for criticism of the paper. We thank Drs A. Mischer, H. Scheffer and H. Groenen for criticism of the paper.

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