Proteus syndrome (PS, OMIM 176920) is a hamartomatous disorder characterised by overgrowth of multiple tissues, connective tissue and epidermal naevi, and vascular malformations. These presentations are usually apparent at birth or soon after and continue to develop as the patient ages. It is named after the Greek god Proteus who, legend has it, could change his shape at will to avoid capture. It is probably the disease suffered by the Elephant Man. Tumours, mostly benign but some malignant, have also been reported in PS, generally presenting by the age of 20 years and including papillary adenocarcinoma of the testis, meningioma, and cystadenoma of the ovaries. Given the predominantly sporadic nature of this syndrome and the mosaic distribution of lesions, it has been suggested that PS may be caused by somatic mosaicism for a genetic change that is lethal in the non-mosaic state.

Clinical overlap, in the form of tissue overgrowth, macrocephaly, and the presence of lipomas, exists between PS and another hamartoma syndrome, Bannayan-Riley-Ruvalcaba syndrome (BRR, OMIM 153480), in which up to 60% of affected subjects are known to carry a germline mutation of the tumour suppressor gene PTEN. BRR also shows partial clinical overlap with Cowden syndrome (CS, OMIM 158350), in which affected subjects are at risk of developing hamartomas in multiple organs including the breast, thyroid, central nervous system, skin, and gastrointestinal tract, as well as malignant tumours of the breast, thyroid, and endometrium. PTEN is mutated in the germline in up to 80% of patients with CS. Two recent reports have shown germline, and probably germline mosaic, PTEN mutations in a subset of patients with PS or a PS-like disorder, although other studies of patients with PS have been unable to confirm these findings.

PTEN is a dual specificity phosphatase, shown in vitro to dephosphorylate protein substrates on threonine, serine, and tyrosine residues as well as lipid substrates. In the phosphatidylinositol 3-kinase (PI3-kinase) pathway, PTEN functions as a 3 phosphatase, dephosphorylating phosphatidylinositol (3,4,5) triphosphate [PtdIns(3,4,5)P3] to PtdIns(4,5)P2. When PTEN is mutant, PtdIns(3,4,5)P2 accumulates, activating the serine threonine kinase AKT, a known anti-apoptotic factor, leading to cell survival. In addition to being mutated in the germline in CS and BRR, somatic loss of function PTEN mutations are seen in a wide range of sporadic human tumours, including endometrial cancer, glioblastoma, and prostate cancer. Given the clinical overlap between PS and CS, as well as the conflicting studies of PS and PS recently published, we sought to determine whether a patient presenting with classical PS harboured a germline PTEN mutation.

MATERIALS AND METHODS

Case report

The patient, now aged 16 months, is the second child of non-consanguineous parents. He was born by normal vaginal delivery at 38 weeks of gestation after an uncomplicated pregnancy. His birth weight was 3735 g (>90th centile), length was 52.5 cm (>90th centile), and head circumference was 47.6 cm (>90th centile). His 3 year old sister is well. The patient supports the previous finding of PTEN mutation, c.507delC, and classical features of PS, including a left sided epidermal naevus following the lines of Blaschko, widespread capillary venous malformation on his chest and abdomen, multiple lipoblastomas, disproportionate overgrowth of the right leg, and a progressive course.

This mutation is predicted to prematurely truncate the COOH-terminal C2 domain of PTEN, losing regions critical for PTEN stability and protein-protein interactions. The finding of a de novo PTEN mutation in this patient supports the previous finding of PTEN mutations in two cases of PS and four cases of patients with a PS-like disorder.

Thus, the molecular diagnosis of a germline PTEN mutation classifies these PS cases, along with CS and BRR, as part of the PTEN hamartoma syndrome (PHTS) spectrum. These findings have implications for cancer risk and future clinical surveillance in patients with PS.
programme. There is no family history of thyroid carcinoma or additional stigmata, such as macrocephaly or trichilemmomas in either the proband’s mother or her relatives, as far as can be assessed, which may be consistent with a diagnosis of CS.

At birth, there was an extensive epidermal naevus on the left side of the proband’s body following the lines of Blaschko involving his left arm, hand, chest, and flank. There was also a widespread capillary venous malformation on his chest, abdomen, and right leg. There were two small palpable lesions on the right side of his chest that enlarged over the following months. A biopsy at 4 months of age of two separate lesions showed a combination of immature and mature fat cells consistent with lipoblastomatosis in one and a vascular malformation in the other. Over time he has developed multiple lipomata on his trunk which have continued to enlarge, particularly those on the thorax. At 12 months of age there was evidence of measurable, disproportionate overgrowth of the right leg. A skeletal survey at 11 months of age was normal. The capillary venous malformation and epidermal naevus have remained unchanged (fig 1).

From 5 to 8 months of age he had multiple admissions with respiratory illnesses. A CT (computerised tomography) scan of his chest and abdomen at 7 months of age showed a large lipoma of the right lateral chest wall and a smaller lipomatous lesion of the left lateral and anterior chest wall. There was no extension into the chest or abdomen. A subsequent CT chest scan performed because of persistently increased effort of breathing at 10 months showed a large anterior mediastinal mass and extensive mesenteric lymphadenopathy. There was no visceral or intracranial vascular malformation. A CT guided fine needle biopsy of the mediastinal mass showed lipoma. Laryngoscopy, bronchoscopy, and oesphagoscopy showed extrinsic compression of the left bronchus presumed secondary to the mediastinal mass. Biopsies of lesions on the right side of the thorax showed lipomata and a venous haemangioma. Endoscopy and colonoscopy performed at 10 months of age because of lower gastrointestinal bleeding and iron deficiency anaemia showed multiple sessile polyloid lesions in the jejunum and the colon. Several of the colon polyps were biopsied and on histopathology the appearance was of large bowel mucosa with prominent mucosal lymphoid tissue but no other abnormalities. Upper gastrointestinal biopsies showed mild reflux oesphagitis and gastritis only.

He has linear growth failure, crossing from the 50th centile at 10 months (73.5 cm) to between the 1st and 3rd centiles at 15 months (74.5 cm). During the same period, despite strikingly decreased muscle bulk and subcutaneous fat, his weight centile has increased from the 25th to the 50th centile, possibly owing to the rapid growth of his lipomata. Enteral feeds were started at 9 months of age. His head circumference was 48 cm (50th to 98th centile) at 15 months. He has a prominent forehead and a flat nasal bridge. Intellectually he appears to be within normal limits, although his physical condition limits his abilities. Routine karyotyping of blood lymphocytes and of skin fibroblasts from a region of skin affected by superficial vascular lesions showed a normal male karyotype, 46,XY.

Molecular analysis

PTEN mutation scanning was undertaken using DNA extracted from peripheral blood collected from the proband and his parents as well as a fibroblast cell culture established from a skin biopsy of an area affected by superficial vascular lesions. DNA was extracted using the Puregene™ DNA Purification System (Gentra Systems, Minneapolis, MI, USA). All patients, or guardians thereof, signed informed consent for genetic testing as approved by the NSW Genetics Service.

PTEN sequencing primers have been previously described.11–13 PTEN exons and flanking intronic sequences were amplified using Platinum® Taq DNA polymerase and the accompanying standard 10 × PCR buffer (Invitrogen, Adelaide, SA, Australia) with the exception of exon 1 that required the 10 × PCRx Amplification Buffer from the PCRx Enhancer System (Invitrogen, Adelaide, SA, Australia). PCR reaction conditions were as follows: 94°C annealing for five minutes; 40 cycles of 94°C for one minute, 55°C for one...
minute, and 72°C for one minute; followed by 72°C for 10 minutes. PCR products were purified using the Wizard PCR Preps DNA Purification System (Promega, Madison, WI, USA). Direct sequencing of purified PCR products was performed using the ABI Prism BigDye Terminator cycle sequencing ready reaction kit (Applied Biosystems, Perkin-Elmer Corp, USA). Purified cycle sequencing products were electrophoresed on 4.8% PAGE Plus gels (Amresco, Cleveland, OH, USA) and analysed on a 377XL automated DNA sequencer (Applied Biosystems, Perkin-Elmer Corp, USA) at the Australian Genome Research Facility (University of Queensland, St Lucia, QLD, Australia).

RESULTS
Mutation scanning of the entire coding and flanking intronic sequence of PTEN showed a de novo germline mutation in exon 6, c.507delC, in the constitutive DNA of the proband with PS but not in either of his parents (fig 2). This mutation is predicted to introduce a stop codon (TAA) 38 nucleotides downstream within exon 6 that would probably lead to premature truncation of the PTEN protein. To our knowledge, c.507delC has not been reported to be associated with either CS or BRR, nor is it reported in the Human Gene Mutation Database (http://archive.uwcm.ac.uk/uwcm/mg/hgmd0.html). PTEN scanning of the DNA extracted from a fibroblast cell line established from a skin biopsy of a region of superficial vascular lesions did not show any additional mutations that may have occurred at the somatic level in these cells or reflect germline mosaicism for PTEN. Further, both the wild type PTEN allele and the mutant allele were retained in these cells.

DISCUSSION
Difficulty in the diagnosis of PS because of both its variability of expression and clinical overlap with other conditions, including the hamartoma syndrome BRR, is well recognised. Until recently, the genetic events involved in the development of PS that may assist by providing a "molecular diagnosis" have not been understood. Two reports have, in total, described germline PTEN mutations in two of 14 (14%) patients with PS and four of six (67%) patients with a PS-like disorder. We have confirmed the presence of germline PTEN mutation in a subset of patients with PS by the identification of a de novo PTEN mutation in a patient with classical PS conforming to the criteria described by Biesecker et al. Specifically, our patient meets the mandatory general criteria for PS of mosaic distribution of lesions, a rapidly progressive clinical course, and sporadic presentation. We have confirmed the sporadic presentation at the molecular level, by the identification of a germline PTEN mutation subsequently shown to be absent in the proband's parents. No additional mutation in the PTEN coding and flanking intronic sequence was identified in this patient. In addition, positive findings in the specific criteria for the diagnosis of PS include category B, two signs (epidermal naevus and disproportionate overgrowth) and category C, two signs (evidence of dysregulated adipose tissue, with both lipomas and regional absence of fat, and venous malformation).

With the exception of R335X (exon 8) that has been identified in germline DNA from two patients with a PS-like disorder and also in CS and BRR/CS overlap families, the PTEN mutations reported in PS and PS-like disease, M35T (exon 2), W111R (exon 5), W211X (exon 6), and the mutation reported in the current study, c.507delC (exon 6), have not been previously associated with CS or BRR. Further, Zhou et al identified a second "hit" in PTEN in the form of the R130X mutation in three physically non-contiguous sites, specifically a lipomatous mass, an epidermoid naevus, and in arteriovenous malformation tissue in a patient with PS-like disorder with the R335X mutation. This mutation occurred on the opposite
allele to R335X, probably representing germline mosaicism and possibly explaining the mosaic distribution of lesions seen in this PS patient by complete inactivation of PTEN. R335X, located in the interval encoding the PTCase core motif of PTEN, is a relatively frequent mutation, seen in CS, BRR, and CS/BRR overlap families.  

We did not identify a second mutation in PTEN in DNA extracted from a skin fibroblast culture of a region of superficial vascular lesions from our proband and were able to show retention of heterozygosity at the PTEN locus in this tissue. In this way, our data are consistent with the report of five cases of PTEN mutation associated with PS or PS-like disease.  

Like the previously reported nonsense mutations in exons 6 and 8 of PTEN, c.507delC is predicted to truncate prematurely the COOH-terminal C2 domain that has been shown to be important for phospholipid membrane binding.  

This loss encompasses a PDZ-binding motif encoded by the last four amino acids of PTEN (ITKV) known to be important for protein-protein interactions, as well as PEST sequences critical for PTEN stability.  

It is possible that PTEN may be inactivated in affected tissue by epigenetic events such as methylation or, alternatively, that haploinsufficiency of PTEN was sufficient to cause much of the phenotype observed in these patients, as has been shown in tumours from one of the PTEN knock out mouse models,  

pten +/-  . However, there is clear evidence for mosaicism in this patient, as in many others with PS. Specifically, his epidermal naevus clearly follows the lines of Blaschko. Given the lack of evidence for a second PTEN mutation in this and other similar children with PS, the likelihood that a second genetic event occurs in a gene other than PTEN cannot be excluded. At least in some patients, PS may be a digenic disorder.

The child described in this study has classical features diagnostic of PS, thus confirming the findings of Zhou et al that PTEN mutations are found in a subset of patients with PS. Clearly, however, PS is a genetically heterogeneous condition and additional underlying genetic causes of this syndrome account for the majority of PS cases and remain to be identified. A total of 41 patients with either PS (n=39) or PS-like disorder (n=2) have been reported who do not have a germline PTEN mutation.  

Including the child described in this paper, a total of three patients with PS (3 of 41, 7%) and four patients with PS-like disease (4 of 6, 67%) have now been reported to have germline mutation of PTEN. The molecular diagnosis of PTEN mutation positive classifies these PS patients, along with CS and BRR, as part of the PTEN hamartoma syndrome (PHTS) spectrum. As such, patients surviving the early years of PS will likely be at a greater risk of developing thyroid, breast, and endometrial malignancies as they age and clinical surveillance for these tumours should be considered.

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