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Short communication

Sleep-related hypermotor epilepsy (SHE): Contribution of known genes in 103 patients

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ABSTRACT

Purpose: Genetics of Sleep-related Hypermotor Epilepsy (SHE) includes mutations in several genes that cumulatively account for 30 % of families. This approximate estimate comes from different case-series, each focused on the screening of a single gene. We systematically investigated a large cohort of SHE patients to estimate the frequency of pathogenic variants in the main genes thus far implicated in this epilepsy syndrome.

Methods: We selected familial and isolated cases diagnosed with clinical/confirmed SHE who underwent genetic analysis by comparable next generation sequencing (NGS) techniques (WES/ multigene epilepsy panel). The identified heterozygous variants were classified according to the American College of Medical Genetics and Genomics guidelines.

Results: We included 103 SHE patients (M/F:61/42) who underwent NGS. Sixteen (15.5 %) were familial cases, 16.5 % had focal cortical dysplasia (FCD).

We identified three pathogenic variants in *CHRNA4* (2.9 %, CI: 0.6–8.3 %), two of whom novel; one pathogenic variant in *KCNT1* (1 %, CI: 0.02–5.29 %); four loss-of-function variants in *DEPDC5* (3.9 %, CI: 1.1–9.7 %), one of whom never reported; finally, one missense change in *NPRL2* (1 %, CI: 0.02–5.29 %), already reported as pathogenic. Three out of the four patients with *DEPDC5* variants had FCD.

Conclusions: The overall frequency of pathogenic variants in our SHE cohort was 8.7 %, 19 % and 7 % considering familial and sporadic cases, respectively. Pathogenic variants in the GATOR1-complex genes account for 5 % of the cases. *DEPDC5* shows the highest variants frequency, especially in patients with genetic-structural

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etiology. From a practical perspective, analysis of this gene is recommended even in isolated cases, because of possible implications for patient management.

1. Introduction

Sleep-related hypermotor epilepsy (SHE), previously Nocturnal Frontal Lobe Epilepsy (NFLE), is characterized by hypermotor seizures arising predominantly from sleep. Recognized etiologies include acquired injuries, structural anomalies and genetic causes [1]. The first gene for SHE, *CHRNA4* (Cholinergic Receptor Nicotinic Alpha 4 Subunit MIM *118504), was identified in 1995 by linkage analysis in a large pedigree showing an autosomal dominant pattern of transmission (ADSHE). Subsequently, mutations in two homologous genes, *CHRNB2* (Cholinergic Receptor Nicotinic Beta 2 Subunit, MIM *118507) and *CHRNA2* (Cholinergic Receptor Nicotinic Alpha 2 Subunit, MIM *118502) have been highlighted [2].

For about two decades no further genetic determinants of SHE have been identified. Only since 2012, the application of next generation sequencing (NGS) technologies allowed to study nuclear pedigrees not suitable for linkage analysis, or even sporadic cases, leading to the identification of four additional main genes: *KCNT1* (Potassium Sodium-Activated Channel Subfamily T Member 1, MIM *608167) [3], *DEPDC5* (DEP Domain Containing 5, MIM *614191) [4], *NPRL2* (NPR2-like Protein, MIM *607072) [5] and *NPRL3* (Nitrogen Permease Regulator-like 3, MIM *600928) [6].

Variants in these genes cumulatively explain about 30 % of families [7]. This is an approximate estimate coming from studies of different case-series (principally families), each focused on the screening for variants in a single SHE gene. A systematic study on the contribution of each gene to the overall disorder is lacking. We studied an Italian cohort of sporadic and familial SHE patients and assessed the frequency of pathogenic variants in the main genes implicated thus far in SHE. This would provide important perspectives for clinical genetic testing, prognosis and management of the disorder.

2. Materials and methods

The study was approved by the Ethics Committee (Prot. N 945/CE; cod CE: 13084).

2.1. Population and inclusion criteria

The study population encompasses patients referred to our Institute and diagnosed with SHE according to recommended diagnostic criteria [1]. Additional cases were referred from other Italian epilepsy Centers, thanks to the collaboration with the Italian League against Epilepsy (LICE).

All patients who, after signing appropriate consent, underwent NGS analysis were included in the present study.

We enrolled 103 individuals among sporadic and familial cases, the latter defined as having at least one relative within two degrees of kinship affected with SHE and/or other epilepsy.

All probands underwent a comprehensive evaluation including

Table 1
Pathogenic and likely pathogenic variants in SHE-associated genes identified in our cohort.

GENE	FAM/SPO	IDENTIFIED PATHOGENIC VARIANTS				Inheritance	M-CAP	ACMG scores	ACMG Classification
		Chromosomal position (GrCH37)	c.DNA nucleotidic change	Protein aminoacidic change	Mutation type				
CHRNA4	Spo	g.61981912G > A$^{(W)}$	c.851C > T	p.Ser284Leu	*Missense*	*De novo*	D	PS3 + PM2 + PM6 + PP3 + PP5	Pathogenic
	Spo	g.61981912G > C$^{(W)}$	c.851C > G	**p.Ser284Trp**	*Missense*	Incomplete segregation study	D	PM1 + PM2 + PM5 + PP3	Likely Pathogenic
	Fam	g. 61981843C > A$^{(W)}$	c.920G > T	**p.Gly307Val**	*Missense*	Paternal	D	PM2 + PP1 + PP2 + PP3 + PP4	Likely Pathogenic
KCNT1	Spo	g.138671275G > A$^{(W)}$	c.2800G > A	p.Ala934Thr	*Missense*	*De novo*	D	PS2 + PS3 + PM2 + PP3 + PP5	Likely Pathogenic
DEPDC5	Spo	g.32200849dupC$^{(P)}$	c.1165dupC	p.Arg389Profs*2 [11]	Frameshift	Unknown	N/A	PVS1 + PM2 + PP3 + PP5	Likely Pathogenic
	Fam	g.32202154C > T$^{(P)}$	c.1264C > T	p.Arg422* [11]	Nonsense	Paternal	N/A	PVS1 + PM2 + PP3 + PP5	Pathogenic
	Spo	g.32156689G > A$^{(W)}$	c.193 + 1G > A	p.(?) [12]	Canonical splice-site variant	Maternal	N/A	PVS1 + PM2 + PP3 + PP5	Pathogenic
	Spo	g.32202115delA$^{(W)}$	c.1225delA	**p.Thr409Hisfs*15**	Frameshift	Unknown	N/A	PVS1 + PM2 + PP3	Pathogenic
NPRL2	Fam	g.50387121A > G$^{(W)}$	c.314T > C	p.Leu105Pro [5]	*Missense*	Maternal	D	PM2 + PP1 + PP3 + PP5	Likely Pathogenic

Abbreviations: FAM: familial; SPO: sporadic; (P) panel; (W) WES; M-CAP: Mendelian Clinically Applicable Pathogenicity; D: possibly pathogenic variant; N/A: not available.
ACGM scores to assess the variant pathogenicity according the Americans College of Medical Genetics guideline [9].
PVS1: Null variant (nonsense, frameshift, canonical ± 1 or 2 splice sites, initiation codon, single or multi-exon deletion) in a gene where LOF is a known mechanism of disease.
PM1: Located in a mutational hotspot and/or critical and well-established functional domain (e.g., active site of an enzyme) without benign variation.
PM2: Absent from controls (or at extremely low frequency if recessive).
PM6: Assumed de novo, but without confirmation of paternity and maternity.
PP1:Co-segregation with disease in multiple affected family members in a gene definitively known to cause the disease.
PP2: Missense variant in a gene that has a low rate of benign missense variation and in which missense variants are a common mechanism of disease.
PP3: Multiple lines of computational evidence support a deleterious effect on the gene or gene product (conservation, evolutionary, splicing impact, etc.).
PP4: Patient's phenotype or family history is highly specific for a disease with a single genetic etiology.
PP5: Reputable source recently reports variant as pathogenic, but the evidence is not available to the laboratory to perform an independent evaluation.
Novel pathogenic variants are indicated in bold.

video-polygraphic monitoring and targeted 3T-brain MRI.

2.2. Genetic analysis

Genetic analysis was performed by two comparable NGS techniques: whole exome sequencing (WES) and a multigene NGS panel including the main SHE genes (*CHRNA4*, *CHRNB2*, *CHRNA2*, *KCNT1*, *DEPDC5*, *NPRL2*, *NPRL3*). *CRH* (corticotropin-releasing hormone, MIM *122560) and *PRIMA1* (Proline-rich membrane Anchor 1, MIM * 613851), whose variants were anecdotally implicated in inherited forms of SHE (autosomal dominant and recessive, respectively) [7,8] but not confirmed in other cases, had been not included in the epilepsy panel. Both the NGS techniques showed, for each gene, a coverage of 20X in more than about 90 % of all targeted regions, as shown in Supplemental Table 1. Supplemental material provides further details on NGS assays.

The identified variants were classified according to the American College of Medical Genetics and Genomics (ACMG) guidelines [9] and segregation verified by Sanger sequencing. For pathogenicity predictions we used M-CAP (Mendelian Clinically applicable Pathogenicity, http://bejerano.stanford.edu/mcap/) for missense variants and HSF (Human Splicing Finder v3.0, http://www.umd.be/HSF/) for splice-region variants.

2.3. Statistics

Continuous variables were presented as mean ± standard deviation, categorical variables as absolute and relative frequency (%). We used binomial Exact test to calculate 95 % confidence intervals (CI).

3. Results

3.1. Study population

We included 103 patients (M/F:61/42) diagnosed with SHE who underwent NGS. The mean age at epilepsy onset was 11.7 ± 3.65 years. Sixteen patients (15.5 %) had a family history for SHE (6.8 %) and/or other epilepsy (8.7 %). Twenty-six (25.2 %) patients had brain abnormalities on MRI or detected only after histopathologic analysis of surgical specimen. In 17 (16.5 %) the abnormalities were consistent with focal cortical dysplasia (FCD), confirmed by histopathology in four (3.9 %).

3.2. Genetic analysis

Fifteen patients underwent the multigene epilepsy panel and 88 WES (Supplemental material).

Table 1 summarizes the genetic findings. Fig. 1 provides the mutation frequency of SHE genes in the whole series and among familial and sporadic cases (1A), with the pedigrees of cases not reported (1B).

We identified three pathogenic variants in *CHRNA4* (2.9 %, CI: 0.6–8.3 %). The p.Ser284Leu (rs28931591) occurred *de novo* in a patient with early-onset refractory seizures and intellectual disability (ID) (Fig. 1B, pedigree 1). The variant is a hotspot associated with a CpG hypermutable site in the TM2 domain, the major pore-forming part of

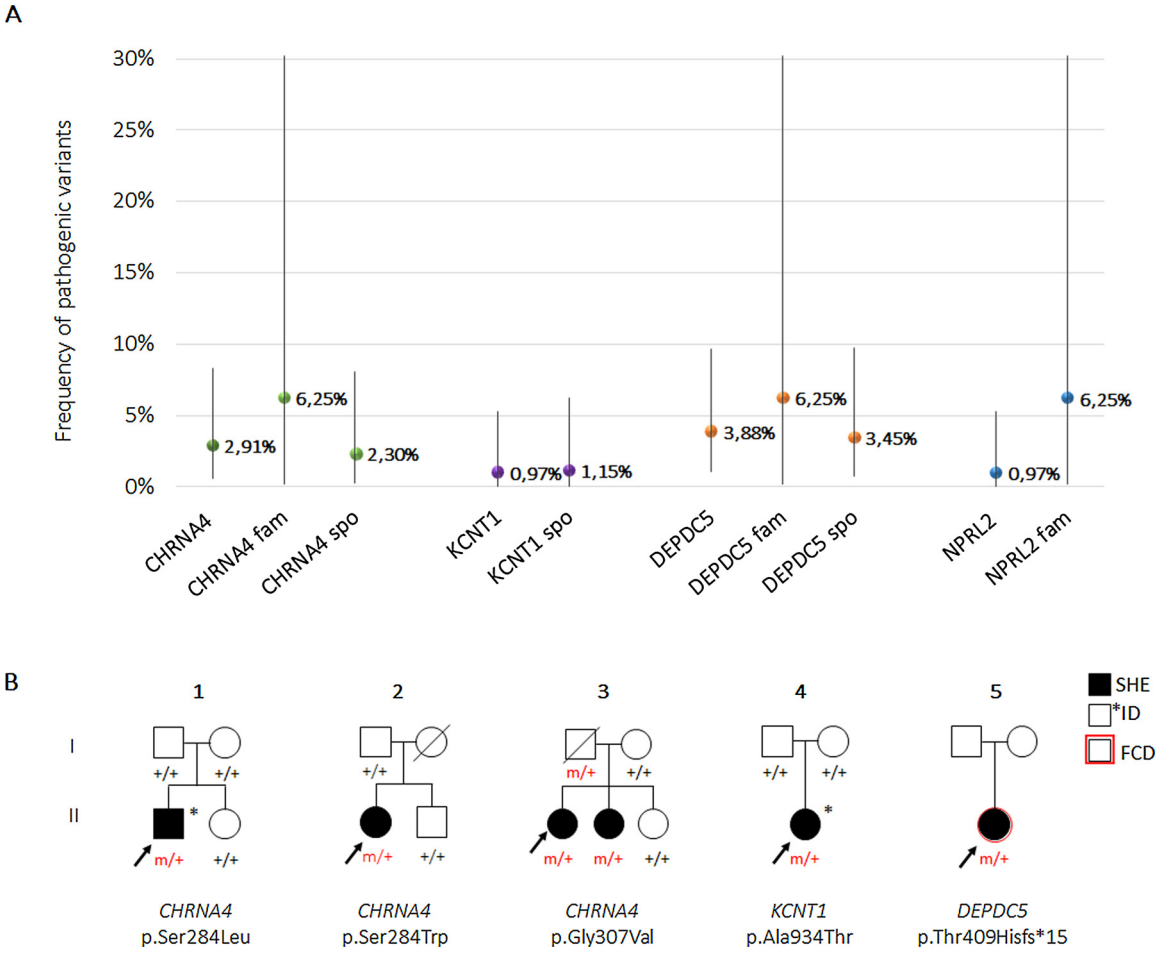

Fig. 1. A: Frequency of pathogenic variants in SHE genes in our case-series. For each mutated gene the overall frequency of mutations and their distribution among familial (fam)/sporadic (spo) cases are reported. B: pedigrees of familial/sporadic cases carrying pathogenic variants in SHE genes (unpublished cases).
Abbreviations: SHE: Sleep-related Hypermotor Epilepsy; ID: Intellectual disability; FCD: Focal Cortical Dysplasia

each nicotinic acetylcholine receptor (nAChR) subunit, and corresponds to the p.Ser252Leu mutation reported in four families and one isolated case [2]. A novel missense change p.Ser284Trp, affecting the same amino acid residue of the previous variant (p.Ser284Leu), was detected in a sporadic case with refractory SHE and borderline IQ (Fig. 1B, pedigree 2). The variant is predicted to be damaging and it is absent in the healthy father and brother (healthy mother deceased). Finally, one novel heterozygous missense change p.Gly307Val segregates in two affected sisters of the ADSHE pedigree 3 (Fig. 1B), inherited from the asymptomatic father. It is predicted as being damaging and affects a conserved amino acid residue located in the first extracellular loop between the transmembrane domains TM2 and TM3. Moreover, since missense variants with incomplete penetrance are a common mechanism of disease in *CHRNA4*-related ADSHE, we considered this change as causative (see ACMG scores, Table 1).

In an isolated patient with ID (Fig. 1B, pedigree 4) we identified a *de novo* pathogenic variant in *KCNT1* (1 %, CI: 0.02–5.29 %): the missense change p.Ala934Thr (rs397515403) has been already reported as pathogenic in a patient with Malignant Migrating Focal Seizures of Infancy (MMFSI) [10]. Instead, our patient had a typical SHE. She presented at age 9 years with asymmetric tonic seizures showing a spontaneous remitting-relapsing evolution, without a clear-cut drug-resistance.

We found four loss-of-function variants in *DEPDC5* (3.9 %, CI: 1.1–9.7 %): one novel frameshift (p.Thr381Hisfs*15) was detected in a sporadic case (Fig. 1B, pedigree 5), while the remaining (p.Arg389Profs*2, p.Arg422*, c.193 + 1G > A) have been already published (Table 1) [11,12]. Interestingly, three of these patients have FCD.

Finally, the p.Leu105Pro in *NPRL2* (1 %, CI: 0.02–5.29 %) was detected in one familial case already reported [5].

We also identified novel/ultra-rare missense changes in *CHRNA4*, *CHRNB2*, *KCNT1* and *DEPDC5,* classified as variants of unknown significance (VoUS) [9] (Supplementary table 2).

4. Discussion

We performed a genetic study on 103 SHE patients and provided the frequency of variants in the main genes so far implicated in SHE. The main innovation of the study is the size of the cohort investigated by a systematic approach. Overall, we identified pathogenic variants in 8.7 % of the whole. The detection rate in familial and sporadic cases was 19 % and 7 %, respectively.

Among the nAChR subunits genes, we found pathogenic variants only in *CHRNA4*, which account for about the 3 % among familial and isolated SHE cases.

Mutations in *KCNT1* account for 1.15 % of our sporadic cases. Although this gene has been implicated in early-onset refractory SHE with ID/psychiatric disorders [3] our patient did not show features of disease severity except for ID, even carrying the same *de novo* missense variant as a reported patient with MMFSI [10]. Other variants in *KCNT1* give rise to either SHE or MMFSI, suggesting that the genotype-phenotype correlations is not straightforward [13].

Altogether, we found pathogenic variants in *DEPDC5* and *NPRL2*, encoding for components of the mTOR GATOR1-complex, in about 5 % of our patients. This percentage is slight less than other cases-series implicating GATOR1-complex genes in 6.93 % of heterogeneous autosomal dominant focal epilepsies [5]. However our result is justified by the fact that isolated cases are predominant in our cohort (84.5 % versus 15.5 % familial cases). *DEPDC5* showed the highest mutational rate, especially in patients with malformations of cortical development, confirming its relevance in genetic–structural etiology of SHE. In this view, detection of mutations in this gene may represent a red flag for FCDs, the most common potentially treatable architectural disorder underlying refractory epilepsies. In apparent non-lesional cases carrying pathogenic variants of GATOR1-complex genes, repeated and careful review of targeted, high-resolution neuroimaging is needed to highlight subtle structural abnormalities susceptible of surgery. Although mutated cases who underwent epilepsy surgery are anecdotal, this has proved to be curative in most of them [11], suggesting that epileptogenesis is underpinned by a genetically-determined cerebral structural lesion, even in the presence of germline mutations.

We did not detect pathogenic variants in the gene encoding the third component of GATOR1-complex, *NPRL3,* so far implicated in five among familial and sporadic cases with SHE [11].

5. Conclusions

This study of a representative case-series of SHE confirms the genetic heterogeneity of the syndrome and the prominent role of GATOR-1 complex genes, in particular *DEPDC5*. From a clinical perspective, the sequencing of these genes is worth even in isolated cases for whom a genetic etiology is not primarily considered, because of possible implications for the diagnostic work-up and clinical management.

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Declaration of Competing Interest

None.

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