Neuromuscular Disorders 34 (2024) 61–67

Contents lists available at ScienceDirect

Neuromuscular Disorders

journal homepage: www.elsevier.com/locate/nmd

Cost-effectiveness of spinal muscular atrophy newborn screening based on real-world data in Belgium

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ARTICLE INFO

Article history:
Received 20 August 2023
Revised 21 November 2023
Accepted 30 November 2023

Keywords:
Newborn screening
Spinal muscular atrophy
Medico economic analysis
Cost-effectiveness
Cost and quality of life
Real-world data

ABSTRACT

The objective of the study was to assess the cost-effectiveness of real-world spinal muscular atrophy newborn screening followed by treatment. We modeled the lifetime cost-effectiveness of the spinal muscular atrophy newborn screening followed by treatment (screening) compared to treatment without screening (no screening) from the Belgian healthcare perspective. Real-world data, including quality of life, costs, and motor development data, were collected on 12 patients identified by screening and 43 patients identified by their symptoms. "Screening" was associated with slightly higher healthcare costs (€ 6,858,061 vs. € 6,738,120) but more quality-adjusted life years (QALY) (40.95 vs. 20.34) compared to "no screening", leading to an incremental cost-effectiveness ratio of € 5,820 per QALY gained. "Screening" was dominant from a societal perspective (negative incremental costs: € -14,457; incremental QALY = 20.61), when incorporating the burden on caregivers (negative incremental costs = € -74,353; incremental QALY = 27.51), and when the treatment was chosen by the parents (negative incremental costs = € -2,596,748; incremental QALY = 20.61). Spinal muscular atrophy newborn screening coupled with early treatment is thus cost-effective compared with late treatment following clinical diagnosis and is dominant when societal perspective, caregiver burden, and treatment based on parental preference were considered.

1. Introduction

Spinal muscular atrophy (SMA) is an autosomal recessive disorder that affects 1 in 10,000 newborns [1,2]. SMA is linked in 95 % of cases to a homozygous deletion of the *SMN1* gene, the remaining 5 % are caused by a heterozygous deletion and a point mutation on the other allele. Humans possess a variable number of copies of a closely related gene, *SMN2* [3]. The severity of SMA depends largely on *SMN2* copy number, with lower copy numbers associated with a more severe phenotype [4], but several exceptions and other genetic modifiers have been reported. In its most common and severe form, with early onset before the age of 6 months, named SMA type 1, which accounts for about 60 % of cases, 93 % of children die before the age of two years in the absence of supportive treatment [5]. Those who survive present with severe motor impairment, as they are unable to hold a sitting position. In the intermediate form of the disease, with late onset, between the age of 6 and 18 months, named SMA type 2, children can sit but cannot stand or walk. In the "milder" form SMA type 3 or 4, depending on severity and age of onset, which appears after 18 months, patients may lose their ability to walk in adolescence or adulthood or have their walking range restricted. With the emergence of new phenotypes in treated patients and the adoption of international standards of care (respiratory, orthopedic, rehabilitation, etc.) [6], a tripartite classification system based on functional capacity is sometimes used: "non-sitter", "sitter", and "walker".

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https://doi.org/10.1016/j.nmd.2023.11.013
0960-8966/

SMA is associated with substantial healthcare and societal costs and has a major impact on the quality of life of patients and their caregivers [7]. A recent systematic review revealed that the average annual cost of early-onset SMA ranged from US$ 75,047 to US$ 196,429 per year. The annual costs of the later-onset forms range from US$ 27,157 to US$ 82,474 per year [8].

Since 2016, three disease-modifying treatments have been approved. They all reduce infant mortality in early-onset SMA and improve motor functions in patients with all types of SMA [9,10]. The benefits in terms of motor improvements are strongly linked to the time of treatment initiation, with maximal benefits associated with treatment prior to onset of symptoms [11]. To be able to treat as early as possible and therefore maximize treatment efficacy, newborn screening (NBS) programs have recently been initiated in several countries [12,13]. In Belgium, the NBS program began in March 2018. To date (March 2023), more than 250,000 newborns have been screened, and 19 were identified and treated rapidly [14,15].

The implementation of an NBS program comes with costs that are added to the already significant cost of treatment. It is therefore important to carry out an economic evaluation of real-world data to assess the cost-effectiveness of NBS for SMA when screening is followed by treatment. Economic evaluations are increasingly used by decision makers to efficiently optimize scarce healthcare resources. Some cost-effectiveness analyses of NBS SMA have been conducted [16–20], and these suggest that NBS is a highly cost-effective intervention. Existing studies were based on simulation models that used efficacy data from clinical trials rather than real-world NBS SMA data. This may result in a significant bias, as patients in clinical studies are selected according to strict inclusion and exclusion criteria. The early initiation of the ongoing Belgian SMA NBS program allowed us to assess the cost-effectiveness of SMA NBS followed by a disease-modifying treatment (nusinersen, onasemnogene abeparvovec, or risdiplam) compared with no SMA NBS and late treatment that began after clinical diagnosis.

2. Methods

2.1. Model structure

An economic model was used to compare the costs and outcomes, expressed in quality-adjusted life years (QALYs), for two groups of SMA patients: those identified by symptoms and those identified by NBS. Real-world data from observational studies in Liege (Belgium) were collected between 2018 and 2022 for patients in these groups. The first group included 43 SMA patients treated with a disease-modifying drug after clinical diagnosis following symptom onset (referred to as the symptomatic-treated group). These subjects were treated beginning at 2.5 months of life or later. The second group of 12 patients were not identified by symptoms (referred to as the NIS group). These subjects were identified through the NBS program and treatment began before 55 days.

A previously validated model used by the Institute for Clinical and Economic Review to analyze the cost-effectiveness of nusinersen and onasemnogene abeparvovec for treatment of SMA in the US [21,22] was adapted to estimate the cost-effectiveness of NBS. The model was developed using Microsoft ® Office Excel 2022. The model used monthly cycles and included five different health states: permanent ventilation, not-sitting, sitting, walking, and death. The model consisted of two parts: (1) a short-term model (30 months) using the actual data from the study in Liege where patients all started in the non-sitter state and the age of acquisition of sitting or standing was reported for each patient individually, and (2) a lifetime extrapolation model. The motor function milestones achieved at the end of the short-term model were assumed to be maintained until death; thus, NIS patients who were walking at 30 months of age were expected to maintain the ability to walk. The long-term model involved extrapolation of motor milestones (estimated be the same that at the end of the short-term model), permanent ventilation, and mortality. The long-term mortality risk associated with each health state was modeled by fitting survival curves to data estimated by a disease specialist for each health state. Based on expert opinion and literature [23], mortality for walkers and sitters was assumed to be the same as for the general population [24] (81 years), whereas the mean life expectancy for non-sitters was set at 20 years and that for patients with ventilation was set at 5 years. Fig. 1A illustrates the model.

In line with the Belgian guidelines for economic evaluation, a discount rate of 3 % for costs and 1.5 % for utility values were used [25]. There is no threshold for cost-effectiveness in Belgium [26]. In Europe, only the UK (€ 24,000–36,000), Poland (3 times per capita GDP, about € 40,000), Netherlands (€ 20,000 – 80,000), and Slovakia (24–35 average salaries, i.e., € 18,000–27,000) have explicit thresholds. Several other countries have an implicit threshold, which is usually between two- and three-times per capita GDP (Hungary).

2.2. Model inputs

2.2.1. Patient characteristics

Data on motor function milestones, permanent ventilation, and mortality at different time points were extracted from observational studies performed in Liege. There were two distinct populations: (1) the symptomatic-treated group of SMA patients identified by their symptoms who began treatment after 2.5 months ($n = 43$) and (2) the NIS group of SMA patients identified by NBS who began treatment before the age of 2 months ($n = 12$). Only patients aged more than 18 months were included in order to have a sufficient understanding of maximum motor level acquired. None of the patients were on permanent ventilation. Individual patient characteristics – patients' age in each category and age at the treatment initiation – are given in Appendix A. The patient's motor evolution in the short-term model is given in Appendix B. The frequency and confidence interval (CI) for the distribution: probability of being a non-sitter, sitter or walker in the treated symptomatic category are presented. For NIS patients, as they are all walkers, the CI could not be calculated.

2.2.2. Data collection

Patients or their caregivers completed a questionnaire that included sociodemographic (age and occupation) and medical questions (motor assessment, age at symptom onset, diagnosis, and treatment initiation and type). Financial costs were collected from responses to a cost questionnaire containing questions about direct medical and non-medical costs and indirect costs over the past year.

2.2.3. Utility values and cost data

Utility values were derived from Health Utilities Index 2 (HUI2). The HUI2 is a widely used general quality-of-life tool with practical value [27], especially in the SMA [28]. Health-related quality of life is scored between 0 (death) and 1.00 (perfect health). The HUI2 tool combines a comprehensive universal health status classification system with a universal utility scoring system. HUI2 examines eight health attributes: vision, hearing, speech, mobility, agility, emotion, cognition, and pain/discomfort. This makes the classification system efficient because each attribute provides unique information. We used HUI2 for all patients two years of age and older. If the patient was under six years of age, data were

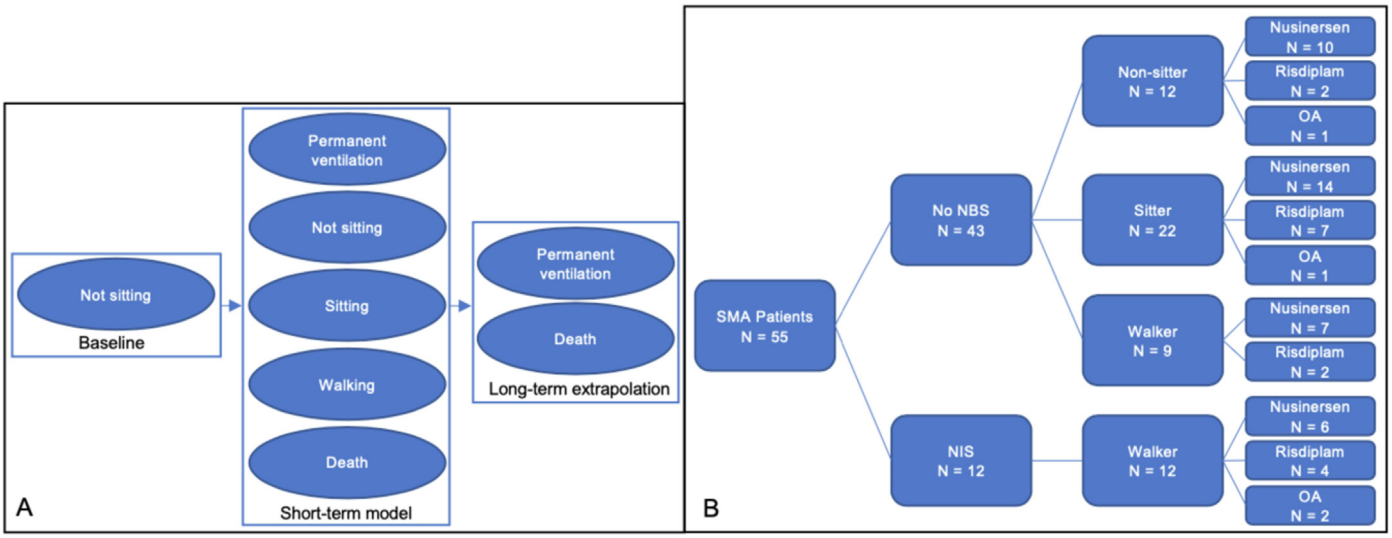

Fig. 1. A. Schematic of the model used for analysis of cost-effectiveness of SMA NBS. **B**. Schematic of patient treatment. No NBS: symptomatic-treated; OA: onasemnogene abeparvovec.

Table 1
Costs for approved SMA treatments and utility values and costs for treatment of NIS and symptomatic-treated subjects.

Treatment	Costs	Administration cost[a]
Nusinersen	€ 88,300 *per injection (6 in first year and 3/year thereafter)*	€ 255 *per injection*
Onasemnogene abeparvovec	€ 1873,000 *(only one injection)*	€ 2989 *per injection*
Risdiplam	€ 289,000 *(per year)*	€ 408 *per year*
NBS	€ 5 *per child*[*]	

	Healthcare costs per year	Non-medical costs per year	Parents productivity loss per year	Utility
	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)
NIS – not symptomatic	€ 1807	€ 0	€ 1702	0.965
(n = 12)	(2397)	(0)	(33,705)	(0.14)
Symptomatic-treated – non-sitter	€ 32,153	€ 6385	€ 23,236	0.32
(n = 12)	(20,083)	(48,525)	(42,430)	(0.12)
Symptomatic-treated – sitter	€ 13,132	€ 6800	€ 3405	0.51
(n = 22)	(8130)	(29,150)	(41,281)	(0.09)
Symptomatic-treated – walker and NIS –symptomatic	€ 8725	€ 10,000	€ 2979	0.78
(n = 9)	(4927)	(15,814)	(15,321)	(0.16)

[*] *5 € leads to a cost of 66,667 € per patient detected, with an incidence of 1 in 13,333.*
[a] Administration costs include hospitalization, consultation, and examination costs. IQR: interquartile range.

reported by parents. Utility decreases with age, and this was taken into account.

In the base-case analysis, the costs were based on the Belgian guidelines for economic evaluation and included hospitalization, consultation, treatment, treatment administration costs, and NBS costs. Healthcare costs were derived from various sources including patients and caregivers, financial departments of the hospital, and the Institut National d'Assurance Maladie-Invalidité (the Belgian social security organization that pays for these services) [29]. We first measured the needs in terms of specialized consultations (doctors and physiotherapists) and specific equipment (ventilators) using questionnaires and analyses of patients' medical files. Then, we evaluated the costs using the Belgian social security costs as well as the costs provided by the hospital, enabling us to calculate costs for each individual patient.

The costs of treatment by disease-modifying therapies included the official cost of the treatment itself, the cost of hospitalization for treatment administration if applicable, and the medical consultation costs directly related to treatment delivery (Table 1). The cost of the treatment is the amount provided by the Belgian social security. In our population, patients used one of three available treatments: nusinersen, onasemnogene abeparvovec, or risdiplam (Fig. 1B). We took the percentage of patients treated in each category by each treatment and multiplied it by the cost of the respective treatment. The proportion of use of each treatment was not identical between populations. For example, NIS patients, who were younger than symptomatic-treated patients, were more likely to have been treated with onasemnogene abeparvovec, which has a marketing authorization based on patient weight. The frequency of administration is different for each treatment. In addition, five patients had their treatment as part of a clinical trial or treatment was funded through a compassionate use policy and therefore received the treatment at no cost. However, we included the costs of the treatments as if they had been paid. In 2018, only nusinersen had been approved for use in Belgium. Onasemnogene abeparvovec has been reimbursed since 1 December 2021 and is available for non-symptomatic patients if they have two or three copies of *SMN2*. Since onasemnogene abeparvovec was approved, five patients with two or three copies of *SMN2* were identified through NBS, and all were given onasemnogene abeparvovec.

The Office of Birth and Childhood (Office de la Naissance et de l'enfance) incurs the costs related to the implementation and operation of NBS. In order to estimate the cost per identified

patient, we divided the number of children screened by the number of children identified to calculate how many children must be screened to identify one patient with SMA. Since the cost of the test is € 5 per child screened, this represents a cost of € 66,667 for identification of one child.

2.3. Incremental analysis and sensitivity analysis

Incremental costs and QALYs were used to calculate the incremental cost-effectiveness ratios (ICERs) of symptomatic treated versus NIS patients. To assess the robustness of the analysis, various scenarios were tested, and probabilistic sensitivity analyses were completed. The following scenarios were considered: Scenario S1 used the healthcare perspective including non-medical costs. Scenario S2 reflects societal perspective (including caregiver burden, healthcare costs, non-medical costs, parents' loss of productivity, and impact on the quality of life of the caregiver). For scenario S3, treatments were distributed in the same way in both NIS and symptomatic-treated cohorts. Symptomatic-treated patients received treatments in the same proportions as NIS: 43 % received nusinersen, 28.5 % onasemnogene abeparvovec and 28.5 % risdiplam. It should be noted that this exercise does not reflect reality as the accessibility of the treatment is influenced by marketing authorizations (e.g., onasemnogene abeparvovec is limited to patients with two or three copies of *SMN2* who weigh under 12 kg and risdiplam can only be used to treated patients who are older than 2 months). Scenario S4 considered the preferences of parents for the treatment of NIS children based on the recent work of Deng et al. [30]. This study reported the choices of 18 sets of parents whose children had been diagnosed with SMA following NBS. Of these 18 children, 13 (72 %) were given onasemnogene abeparvovec, 2 (11 %) risdiplam, 1 nusinersen (5 %), and 2 (11 %) did not receive any treatment by choice of the parents. In Belgium, all patients would be treated, even if they had four copies of *SMN2*. We therefore allocated the percentage of untreated subjects to the risdiplam group. In this scenario, 5.6 % of NIS patients would be treated with nusinersen, 72.2 % with onasemnogene abeparvovec, and 22.2 % with risdiplam, and the allotment of symptomatic-treated patients to treatment groups was the same. Scenario S5 used a 10-year time horizon for (A) healthcare perspective, (B) healthcare perspective including non-medical costs, and (C) societal perspective including caregiver burden. Scenario S6 used the healthcare perspective, including non-medical costs, but non-medical costs were assumed to be similar for walkers, non-sitters, and sitters using non-medical costs of walkers. Finally, scenario S7 used a 3 % discount rate for both costs and QALYs. A probabilistic sensitivity analysis (PSA) was performed by varying all model parameters using 1000 simulation runs. Due to the limited amount of data, a mean value of ± 20 % was used in the PSA for the distribution of costs and utility values. Results of the PSA were evaluated in the cost-effectiveness plane and in the form of a cost-effectiveness acceptability curve, which demonstrated the probability that SMA NBS is cost-effective based on decision-makers willingness to pay per QALY gained.

3. Results

3.1. Utility values and costs

Utility values were estimated at 0.32, 0.51, and 0.78 for symptomatic-treated non-sitters, sitters, and walkers, respectively; and the utility value for NIS patients was 0.96 [31]. Costs and utility values of NIS patients and symptomatic-treated walkers differed, as the latter have reduced walking perimeter and difficulty in climbing stairs. Difficulties walking have a strong impact on utility values and costs partly due to additional needs (such as physiotherapy). We estimated from real-world studies [32,33] that about 40 % of patients with two copies of *SMN2* who were treated early would have utility values and costs comparable to late-onset patients. This represents 20 % of NIS patients in the cohort. In terms of cost and utility, we therefore assumed that 20 % of NIS patients would have outcomes equivalent to symptomatic-treated walkers. Table 1 summarizes the total costs and utility values for patients with SMA in the NIS group and for patients in the symptomatic-treated group based on motor milestone reached.

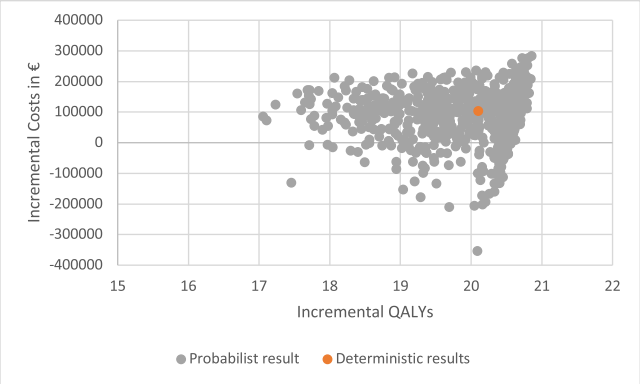

Fig. 2. Incremental cost-effectiveness plane.

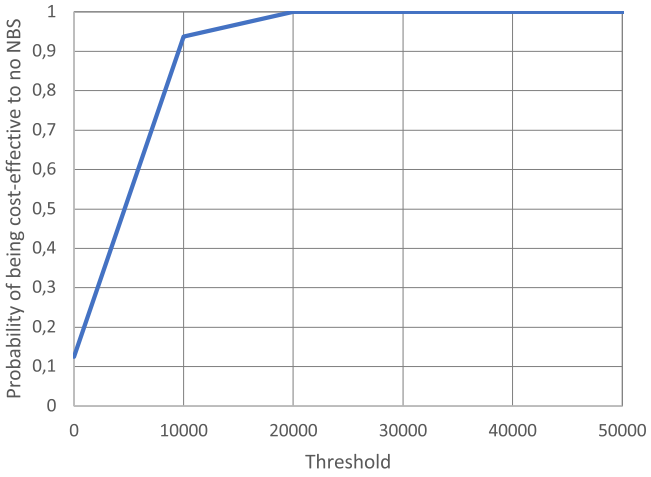

Fig. 3. Cost-effectiveness of NBS versus no NBS in base-case scenario.

3.2. Base case and sensitivity analyses

From the healthcare perspective, NIS patients cost about € 120,000 more than symptomatic-treated patients. Those patients identified and treated early had 20.61 additional QALYs over a lifetime, resulting in a cost per QALY gained of € 5820 (Table 2). In several scenarios, NBS for SMA resulted in lower costs per QALYs. The scenarios where SMA NBS was cost-effective included those when the societal perspective was included (S1), when caregiver burden was included (S2), and when treatment was selected by parents (S4). In all deterministic sensitivity analyses, the ICER was below € 60,000 per QALY gained, and, therefore, NBS could be considered as cost-effective. The cost-effectiveness was especially sensitive to the societal perspective and the choice of the treatment. PSA suggested that NBS has a 100 % probability of being cost-effective from a threshold of € 20,000 per QALY gained (Fig. 2 and Fig. 3).

Table 2
Cost-effectiveness of SMA NBS in different scenarios.

	Population[a]	Total costs	Life-years gained	QALYs gained	ICER Cost / QALY gained
Base case	NIS	€ 6858,061	46.80	40.95	€ 5820
	Post	€ 6738,120	35.80	20.34	
S1: Healthcare perspective + non-medical costs	NIS	€ 6905,202	46.80	40.95	Dominant[b]
	Post	€ 6919,659	35.80	20,34	
S2: Societal perspective	NIS	€ 6973,382	46.80	43.07	Dominant
	Post	€ 7047,735	35.80	15.56	
S3: Same distribution of treatments (health care perspective)	NIS	€ 6858,061	46.80	40.95	€ 57,749
	Post	€ 5667,953	35.80	20.34	
S4: Distribution of treatments according to parental choice	NIS	€ 3786,492	46.80	40.95	Dominant
	Post	€ 6383,240	35.80	20.34	
S5A: Healthcare perspective with a 10-year time horizon	NIS	€ 2354,936	9.30	8.04	€ 10,644
	Post	€ 2283,005	8.63	4.39	
S5B: Healthcare perspective + non-medical costs with a 10-year time horizon	NIS	€ 2485,055	9.30	8.04	Dominant
	Post	€ 2492,976	8.63	4.39	
S5C: Societal perspective with a 10-year time horizon	NIS	€ 2511,543	9.29	8.26	Dominant
	Post	€ 2566,622	8.62	3.12	
S6: Healthcare perspective + non-medical costs with same non-medical costs for all post patients	NIS	€ 6905,202	46.80	40.95	
	Post	€ 6977,589	35.80	20.34	Dominant
S7: Base case with same discount rate (3 %)	NIS	€ 6858,061	30.54	26.95	€ 8856
	Post	€ 6738,120	23.95	13.41	

[a] Post indicates subjects identified based on symptoms.
[b] "Dominated" means here a negative cost.

4. Discussion

We performed a cost-effectiveness analysis of NBS for SMA using real-world data from Belgium obtained on subjects identified by NBS or by symptoms who were treated and followed for up to 30 months. This study did not compare the cost-effectiveness of NBS per treatment type. Such a comparison would require an adequate sample size and properly designed trial. Our analysis revealed that SMA NBS had nearly similar healthcare costs to symptomatic treatment with a large gain in QALY. NBS SMA is therefore cost-effective compared to treatment of patients who are diagnosed with SMA due to onset of symptoms with a cost per QALY gained of € 5820. This result is in line with other studies that reported the cost-effectiveness, and even dominance, of NBS SMA compared to no screening. Indeed in Australia [16], in the Netherlands [19], and in the UK [20], SMA NBS was associated with lower total healthcare costs than no screening. These studies, however, used data from clinical trials for patients clinically diagnosed followed by late treatment. Only one study used real-world data for NIS patients, and motor function data and information on preferences of parents for type of treatment were not considered. Except in the UK, NIS patients included were strictly non-symptomatic at the start of treatment, which is not always the case in the real world. To our knowledge, this study is therefore the first to include real-world data. Our study is based on data collected in Belgium, which launched an SMA NBS program in 2018.

Deterministic sensitivity analyses indicated that NBS was cost-effective in all scenarios and was dominant in several including when treatment was based on parents' preferences, when a societal perspective was considered, and when caregiver burden was incorporated. Although societal perspective and caregiver burden are not part of the Belgian guidelines for economic evaluation, many other countries do take these aspects into consideration.

Although cost-effectiveness analyses are mandatory for drug reimbursement decisions, they are not yet required by the health authorities for NBS programs even if the concept of cost is part of the initial criteria for implementation [34–37]. When submitting a reimbursement to health authorities, a budget impact analysis is often included, which estimates the implications in terms of annual budget over a period of three to five years. This requires estimating the impact of the NBS, which includes the cost of screening (based on the total number of babies screened), the cost of treatment for those screened, and any reduction in costs for due to pre-symptomatic diagnosis of disease. The cost of case finding, including diagnosis and treatment of diagnosed patients, must be economically balanced against the possible expenditure for medical care as a whole.

The cost-effectiveness of NBS has been confirmed for various diseases. For instance, the cost-effectiveness of an expanded NBS program (27 diseases versus the original 7) was demonstrated in Texas in an analysis conducted on hypothetical cohorts [37]. Results of the study indicated that patient outcomes were improved by preventing morbidity and mortality of treatable disease and found that the population tested had more QALYs than the non-tested population. Although the decision to include new diseases in the NBS panel did not depend on the results of the study, the study supported the policy decision to expand the NBS program. Since 2007, the Texas NBS program has been expanded from testing for 27 diseases to testing for 57 diseases. NBS for severe combined immunodeficiency was demonstrated to be cost-effective in studies conducted in the US (from $ 27,907 to $ 53,560 per QALY gained) [38], in the Netherlands (based on literature data, € 33,400 per QALY gained) [39] and in Australia (based on screening results from the NBS pilot program in Australia, and on published literature, $ 33,600 per QALY gained) [40].

Efficacy data that show the value of early treatment of SMA and early encouraging results in other rare diseases for which therapies may soon be available such as Duchenne muscular dystrophy [41] Angelman's syndrome [42], and other neurological conditions [43] strongly suggest that NBS programs should be poised to expand in response to therapeutic development.

Our study has several limitations. First the NBS for SMA was implemented in Belgium only five years ago, and annual birth rate in Southern Belgium is about 50,000 per year. As a consequence, during the time frame of our study only 250,000 subjects were screened, and only 19 infants were diagnosed with SMA. Further, patients with short follow-up were not considered. Thus, there remains uncertainty about the consequences of treatment including effects on motor evolution and survival. We used motor function milestones to define general health states and assumed relationships between health states and survival. Moreover, the long-term effects of the currently used treatments are unknown. In line with expert opinion, the base case analyses assumed that motor milestones are maintained until death. All patients tested through the NBS program were in good health during follow up, so in the study time frame there was a lack of variability. And there is a lack of variability in the NIS category, as all our patients are walkers, which may not be true in a larger population. Additional data from a large sample with longer follow up will be needed to confirm this assumption. In addition, long-term data collection is needed to better assess long-term heterogenicity of patient evolution. Although there is no evidence that patients will regress following disease-modifying treatment [44,45], given the lack of long-term follow-up of treatment efficacy and utility data, a registry of SMA patients should be created, and patients should be followed to allow economic evaluations with additional real-world data. Finally, the cost of the diagnostic journey for patients identified by symptoms, which includes useless magnetic resonance imaging, electromyography, or gene testing, was not included in this study [46]. Inclusion of these expenses would marginally increase the cost-effectiveness of the NBS. In conclusion, SMA NBS coupled with one of the three available treatments leads to substantial better health outcomes than treatment initiated following clinical diagnosis, demonstrating the cost-effectiveness of NBS in real-world settings.

Abbreviations

CI	Confidence interval
ICER	Incremental cost-effectiveness ratio
NBS	Newborn screening
PSA	probabilistic sensitivity analysis
QALY	Quality-adjusted life years
SMA	Spinal muscular atrophy

Ethics

This research was authorized by the ethics committee of the Centre Hospitalier de la Citadelle de Liège, with reference no. B412201837118, and reference no. 1750. The patients or their caregivers gave their written informed consent for this research and for the publication of the results.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. Biogen, Novartis, and Roche funded the implementation of the newborn screening pilot program in southern Belgium for three years (2018–2020). TD's doctoral thesis was financed by the same funds.

Declaration of Competing Interest

TD has given lectures sponsored by Biogen, Novartis, and Roche. TD's doctoral thesis was financed by Biogen, Novartis and Roche funding the implementation of the newborn screening pilot programme in southern Belgium for three years (2018–2020). PT has performed paid consultancy for Roche and Novartis and served on an advisory board for Roche on SMA. ND is investigator on SMA studies for Roche, Novartis Gene Therapies, and Biogen and has received honoraria for service on scientific advisory boards of Roche and Novartis Gene Therapies. AD'A has received honoraria as a consultant and scientific advisory board member and has given sponsored lectures for Biogen, Avexis, and Roche. AD is investigator on SMA studies for Roche and Novartis Gene Therapies and has received honoraria as a scientific advisory board member of AveXis Belgium. SD has consulted for Biogen and Roche. LS is a coordinating investigator of SMA newborn screening programs in Belgium and in the UK funded by Roche, Novartis, and Biogen. He has consulted for Zentech, Biogen, Novartis, Roche, Scholar Rock, and BioHaven and has received research grants from Zentech and Perkin Elmer. MDS and MH have no conflict of interest relevant to this paper.

Acknowledgements

We are grateful for the support of patients and their caregivers who took the time to complete our questionnaires. We thank all investigators and staff involved in this study. The authors thank Jackie Wyatt for language editing.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.nmd.2023.11.013.

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