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1 **Accelerating Drug Development for Neuroblastoma - New Drug**

2 **Development Strategy**

3 **An Innovative Therapies for Children with Cancer, European Network for Cancer Research in**

4 **Children and Adolescents and International Society of Paediatric Oncology Europe**

5 **Neuroblastoma Project**

6
7
8 **Running title:** New drug development strategy for neuroblastoma

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10
11 **Disclaimer**

12 The views expressed in this article are the personal views of the authors and may not be
13 understood or quoted as being made on behalf of or reflecting the position of the European
14 Medicines Agency or one of its committees or working parties.

15
16
17 **Word count: 4662**

18
19 **Three Tables:**

20 **Table 1: Targets prioritised for neuroblastoma**

21 **Table 2: Prioritised targets, agents and ongoing/planned clinical trials**

22 **Table 3: Agreed action points**

23
24 **Highlights: New drug development strategy for neuroblastoma**

25
26 **List of abbreviations**

1 **Abstract (200 words)**

2 **Introduction:** Neuroblastoma, the commonest paediatric extra-cranial tumour, remains a
3 leading cause of death from cancer in children. There is an urgent need to develop new drugs
4 to improve cure rates and reduce long-term toxicity and to incorporate molecularly targeted
5 therapies into treatment. Many potential drugs are becoming available, but have to be
6 prioritised for clinical trials due to the relatively small numbers of patients.

7
8 **Areas covered:** The current drug development model has been slow, associated with
9 significant attrition, and few new drugs have been developed for neuroblastoma.

10

11 The Neuroblastoma New Drug Development Strategy (NDDS) has: 1) established a group with
12 expertise in drug development; 2) prioritised targets and drugs according to tumour biology
13 (target expression, dependency, pre-clinical data; potential combinations; biomarkers),
14 identifying as priority targets ALK, MEK, CDK4/6, MDM2, MYCN (druggable by BET
15 bromodomain, aurora kinase, mTORC1/2) BIRC5 and checkpoint kinase 1; 3) promoted clinical
16 trials with target-prioritised drugs. Drugs showing activity can be rapidly transitioned via
17 parallel randomised trials into front-line studies.

18

19 **Expert Opinion:** The Neuroblastoma NDDS is based on the premise that optimal drug
20 development is reliant on knowledge of tumour biology and prioritisation. This approach will
21 accelerate neuroblastoma drug development and other poor prognosis childhood
22 malignancies.

23

24

1 **1. Introduction: The unmet need**

2 Neuroblastoma, the most common extra-cranial solid tumour of childhood, is a leading
3 cause of death in children between 1-4 years [1]. More than forty percent of patients are
4 considered high-risk, including children over the age of 18 months with metastatic disease
5 and those with tumours harbouring *MYCN* amplification [2]. Despite improvements in
6 intensive multi-modal therapy, including chemotherapy, high-dose therapy with
7 autologous hematopoietic stem cell rescue, surgical removal of the primary tumour,
8 radiotherapy, residual disease therapy and immunotherapy with anti-GD2 monoclonal
9 antibodies, long-term survival for children with high-risk neuroblastoma remains below
10 50% at 5 years [3-6]. The majority of patients experience relapse associated with a dismal
11 prognosis, with five-year overall survival for relapsed metastatic neuroblastoma of 8% in
12 the International Neuroblastoma Risk Group analysis [7]. Approximately one third of
13 patients are refractory to frontline therapy and have a very poor outcome [8, 9]. In
14 addition, survivors face a significant burden of late effects due to the intensity of
15 multimodal therapy [10, 11].

16
17 **2. Current Paediatric Oncology Drug Development Model for Neuroblastoma**

18 Although genomic aberrations (*MYCN*, *ALK*, *TP53*, *ATRX*, *TERT* and *RAS-MAPK*) [12-23],
19 which are molecular drivers for specific subtypes of neuroblastoma, have been described,
20 effective molecularly targeted therapies have not been introduced into current treatment
21 strategies [24]. Furthermore, currently all children with high-risk neuroblastoma receive
22 the same therapeutic approach at presentation and treatment is only modified depending
23 on response - therapy is not personalised. To date, in contrast to adult oncology, progress
24 in paediatric cancers has been slow, with a paucity of molecularly targeted drugs being
25 developed for neuroblastoma.

26
27 The availability of drugs for early phase clinical studies for neuroblastoma has been driven
28 predominantly by medicines being developed for adult malignancies. Although the
29 number of early phase clinical trials has increased as a result of the European Paediatric
30 Medicine Regulation, the development of drugs for neuroblastoma is still driven by the
31 adult condition and not the mechanism of action of the drug.

32
33 After determining the dose and safety profile in a Phase I study, drugs have been
34 evaluated in Phase II studies with no clear prioritisation to identify those with the greatest
35 potential benefit for front-line randomised trials. Furthermore, there has been a lack of

1 comprehensive molecular profiling of tumours at presentation or relapse. Finally, there
2 has been no integrated process or a forum for communication and information exchange
3 between biologists and clinicians involved in early and phase clinical trials [25].
4

5 This fragmented process has resulted in some drugs being developed with not necessarily
6 the highest biological rationale; multiple phase II studies of the same drug and with the
7 exception of anti-GD2 monoclonal antibodies, no new drugs entering front-line studies for
8 nearly two decades. New therapeutic strategies are therefore needed for these children
9 [24, 26, 27].
10

11 **3. Neuroblastoma New Drug Development Strategy (NDDS)**

12 The Innovative Therapies for Children with Cancer (ITCC), in conjunction with the European
13 Network for Cancer Research in Children and Adolescents (ENCCA) and the International
14 Society of Paediatric Oncology Europe Neuroblastoma Group (SIOPEN), has established the
15 New Drug Development Strategy (NDDS) project as part of the overall NDDS initiative
16 developed by ITCC and ENCCA. The aim is to accelerate the development of new drugs for
17 patients with neuroblastoma with the ultimate goal of improving survival.
18

19 The Neuroblastoma NDDS strategy was designed to encompass all elements of the drug
20 development process, including translational medicine from bench to bedside: molecular
21 profiling to identify new targets and potential predictive (selection) biomarkers,
22 development of relevant drugs, biological and pre-clinical research, first-in-child early
23 phase clinical studies, randomised multi-arm trials and the transition to late-phase trials
24 and the clinic. Central to the approach was the premise that optimal drug development is
25 heavily reliant on understanding tumour biology.
26

27 The process was based on the premise that involvement of all stakeholders was critical for
28 delivering an integrated system for drug evaluation and clinical trial methodology in
29 children with neuroblastoma. In view of the large number of potential targets and drugs
30 becoming available for evaluation in children with neuroblastoma, on the one hand, and
31 the genetic heterogeneity of neuroblastoma with few recurrently altered genes on the
32 other, a selection and prioritisation process was required to identify targets and drugs
33 which may be of potential benefit to such children.
34

1 This Neuroblastoma NDDS is a dynamic process, which prioritises targets and compounds
2 as new data become available. European experts in neuroblastoma biology and pre-
3 clinical and clinical drug development from fifteen research institutions in seven countries
4 are involved, and members of the European Medicines Agency (EMA) and its Paediatric
5 Committee (PDCO) are observers.

6
7 This output of the NDDS (prioritisation and an integrated approach for drug development
8 in neuroblastoma) informs clinicians designing early and late phase clinical studies,
9 highlights targets and drugs of greatest interest to the pharmaceutical industry and
10 regulators, and indicates where resources require the greatest attention from academia
11 and industry. This information would be provided for clinical trials groups and companies
12 preparing Paediatric Investigation Plans for new drugs. This NDDS strategy complements
13 that of the multi-stakeholder Paediatric Platform ACCELERATE, developed by the Cancer
14 Drug Development Forum (CDDF), ITCC, and the European Society for Paediatric Oncology
15 (SIOPE) [26], and with representatives from academia, the pharmaceutical industry,
16 regulators and, very importantly, patient representatives. ACCELERATE has developed a
17 process of mechanism of action and biology driven selection and prioritisation of
18 paediatric drug development, rather than the current process based on adult cancer
19 indications [28]. This process determines, for drugs with a known mechanism of action, if
20 that mechanism is relevant for paediatric malignancy and what is the best match with
21 tumour biology. The NDDS initiative refines this prioritisation further within
22 neuroblastoma.

23 24 **4. Biology of neuroblastoma**

25 Therapeutic targeting of identified oncogenic drivers in neuroblastoma is a key component
26 of the NDDS. The first pivotal step is to identify the molecular pathways and the tumour
27 biology that are critical drivers in neuroblastoma, focusing on gene/pathway aberrations
28 with proof of “tumour dependence”. Information on the incidence of actionable
29 mutations is the most easily obtained data for understanding tumour biology; however,
30 determining the functional dependency of the mutation, if it is an oncogenic driver or
31 whether it drives tumour development or recurrence is a more complicated next stage.
32 Next generation sequencing has demonstrated that neuroblastoma harbour fewer
33 mutations involving recurrently altered genes at diagnosis (mean 10–15 per tumour) than
34 many other, especially adult, tumours [29]. The main oncogenic drivers identified in
35 neuroblastoma include: i) *MYCN* amplification in 25% of patients [12]; ii) anaplastic

1 lymphoma kinase (*ALK*) mutations and amplification in 10-15% of cases, including those of
2 hereditary neuroblastoma [13-16]; iii) *TP53*, wild-type in the majority of neuroblastoma at
3 diagnosis, with about 2% mutation at presentation, but mutations are acquired during
4 treatment and 15% detected at relapse [17]; iv) RAS-mitogen-activated protein kinase
5 (MAPK) pathway mutations recently described in relapsed neuroblastoma (3% mutations
6 at diagnosis and 78% at relapse) [21]; v) mutations in *ATRX* (9%) reported in older patients
7 [18]; vii) TERT rearrangements reflecting telomerase activation in approximately 30% of
8 high risk cases [19, 20]; and finally vii) *PTPN11* mutations in 2.9% of tumours.[22].

9
10 The presence of *MYCN* amplification, its biological role and prognostic relevance were
11 described several decades ago [12]. However, no effective therapeutic strategy
12 demonstrating convincing evidence of MYCN inhibition has yet been translated into the
13 clinic. After incorporating all biological information available to date, a recent
14 classification of five groups of drugs targeting MYC or MYCN at different levels has been
15 reported and will allow prioritisation and development of these agents [30]. The five
16 groups of drugs comprise drugs targeting: DNA-binding functions of MYCN, transcription of
17 MYCN, synthetic-lethal interactions of MYCN, oncogenic stabilisation of MYCN protein and
18 the expression or function of MYCN.

19
20 *ALK* was described in 2008 as an oncogenic driver in neuroblastoma [13-16] and an early
21 clinical trial of crizotinib in children with *ALK* aberrations was rapidly initiated [31].
22 However, resistance to single therapy agent crizotinib has been described pre-clinically
23 and clinically with moderate response rates (1 complete response, 3 stable disease, and 7
24 progressive disease of 11 *ALK* mutated neuroblastoma) in early clinical trials compared to
25 other *ALK*-driven tumours [32]. Hence, both combinations with chemotherapy or other
26 targeted agents or more potent inhibitors are needed to overcome resistance of some *ALK*
27 mutations [33].

28
29 The tumour suppressor protein p53 is usually nuclear and wild-type at diagnosis (98% of
30 tumours) in neuroblastoma, with intact apoptotic mechanisms, although aberrations in the
31 p53/MDM2/p14^{ARF} pathway are more commonly reported. Interestingly, the p53 gene
32 *TP53* is a direct transcriptional target of MYCN and sensitises cells for MYCN-driven
33 apoptosis [34,35].

1 The appearance of activating mutations of the RAS/MAPK pathway has also been recently
2 described in a high proportion of neuroblastoma at relapse (up to 78%), some of them are
3 novel whereas others are clonally enriched at relapse [21]. Emerging data highlight the
4 importance of other targets such as the cell cycle regulator CDK4/6 [36,37].

5
6 *ATRX* gene mutations/focal deletions are mutually exclusive with *MYCN* amplification and
7 occur in 9% of high-risk patients at diagnosis [22]. *ATRX* mutations/deletions are also
8 strongly associated with the alternative lengthening of the telomeres phenotype [18, 38].
9 The clinical features of this group include older age at diagnosis, a chronic progressive
10 course and poor long-term overall survival [18]. However, to date, no novel therapies exist
11 for this important target. In 2015 genomic re-arrangements proximal to *TERT*, which
12 encodes the catalytic subunit of the telomerase enzyme, resulting in its transcriptional up-
13 regulation were described in 23-31% of high-risk cases [19, 20]. *TERT* re-arrangements are
14 also associated with poor prognosis and occur in a mutually exclusive fashion to *MYCN*
15 amplification and *ATRX* alterations. Taken together with evidence that *MYCN* also up-
16 regulates *TERT*, these recent discoveries highlight the importance of active telomere
17 maintenance in neuroblastoma pathogenesis and present a new potential therapeutic
18 target [19].

19
20 Molecular profiling of tumour tissues bio-banked at the time of diagnosis has yielded
21 important data, as reported in recent whole exome sequencing (WES)/whole genome
22 sequencing (WGS) publications [22,23]. The European ITCC initiatives are providing data
23 with the aim of discovering novel therapeutics for high-risk disease by routinely
24 molecularly profiling tumours at relapse (MOlecular Screening for CANcer Treatment
25 Optimisation [MOSCATO-01 [39], Molecular Profiling for Pediatric and Young Adult Cancer
26 Treatment Stratification [MAPPYACTS], Individualized Therapy for Relapsed Malignancies
27 in Childhood [INFORM] [40], Individualised Therapy [iTHER], and Stratified Medicine –
28 Paediatrics [SM-PAEDS], as is the Therapeutically Applicable Research to Generate
29 Effective Treatments (TARGET) project in the US, which analyses both primary and
30 relapsed neuroblastoma [41,42]. More recently, the appearance of new mutations in
31 individual patients at the time of relapse has been demonstrated for *ALK*, *TP53* and
32 *RAS/MAPK* [17, 21, 43-45]. As has been described for other cancers, these mutations are
33 detected at low levels in diagnostic samples but are enriched at relapse and several of
34 these are potentially important drug targets. Understanding the evolution of mutations in
35 neuroblastoma is of critical importance for drug development [21,43-45]. It underlines

1 that re-biopsying tumours at the time of relapse, and obtaining snap-frozen tumour and
2 paraffin-embedded material before entering early clinical trials, is increasingly important
3 and should be incorporated into clinical practice. This will provide accurate molecular
4 profiling of neuroblastoma and facilitate access to novel targeted therapies through a
5 personalised medicine approach, as well as improving our understanding of disease
6 biology and mechanisms of resistance to new, targeted therapies. The importance of
7 clonal evolution in neuroblastoma has made it necessary to study sequential samples
8 collected during targeted therapy to understand mechanisms of resistance. As sequential
9 tumour sampling may not be feasible, the role of *liquid* samples has become more
10 important. Emerging technologies allow the detection of actionable mutations in
11 circulating DNA obtained from blood samples, as has been recently shown with the
12 detection of *ALK* mutations in plasma samples [46].

14 **5. Incorporation of biological data: the transition from pre-clinical to clinical development -** 15 **prioritisation of targets in neuroblastoma**

16 A number of articles and workshop reports have been published without achieving a
17 definitive consensus defining the minimal data package required to provide proof-of-
18 concept and therefore to qualify a target or drug as sufficiently promising to take forward
19 into clinical trials for adult cancers [47-49]. For paediatric cancers, the first step should be
20 to prioritise the targets according to the level of existing evidence, then define whether
21 there are available drugs for the target, and finally establish if they are available for
22 paediatric use and whether early phase clinical trials of these agents should be prioritised.

24 Targets were pre-selected for evaluation based on the currently available data at that time
25 on molecular pathology, biology, and pre-clinical studies. The decisions to prioritise
26 targets for clinical development were taken by a consensus of clinicians, scientists and
27 academic drug development experts based on specific criteria, which included the
28 robustness of the published evidence that they were oncogenic drivers, the functional
29 dependence in neuroblastoma and whether they were strong candidates for druggable
30 targets.

32 Targets were ranked as 'high' (n=9), 'intermediate' (n=5) or 'low' (n=7) to enable
33 prioritisation based on target expression, target dependency and validation, availability of
34 pre-clinical data on efficacy, and potential combination and biomarker development. The
35 targets that were given top priority for neuroblastoma based on the available data,

1 completeness of the data and potentially available inhibitors were ALK, MEK, CDK4/6,
2 MDM2, MYCN (druggable by BET bromodomain, aurora kinase and mTORC1/2 inhibition),
3 BIRC5 and checkpoint Kinase 1 [50,51]. TORC1/2 aurora kinase and BET bromodomain
4 were ranked as high priority targets because of their action on MYCN; however, it was
5 agreed that currently no aurora kinase inhibitor exhibits optimal activity against MYCN [52-
6 54]. LIN28B [55] was identified as an important target but currently no drugs are in
7 development. Table 1 summarises the data available for each target and Table 2 the
8 clinical development of relevant drugs. For all these, the target is expressed in
9 neuroblastoma, has been validated *in vitro* and/or *in vivo* with siRNA functional
10 experiments and shows strong evidence of efficacy *in vitro* and *in vivo*. Research to
11 identify biomarkers, combinations or resistance is less well developed, but nevertheless
12 for these targets it was felt that there was sufficient data to guide initial clinical
13 development. The evidence to date suggests that some of these targets are only relevant
14 to molecular sub-populations, for example, ALK for *ALK* mutated or amplified
15 neuroblastoma. For other agents such as mTORC1/2, aurora kinase or CHK1 inhibitors,
16 evidence suggests that they will be active in MYCN driven neuroblastoma, but they could
17 also have a role in non-MYCN driven tumours.

18
19 The critical importance of combinations has been highlighted, as these may enhance
20 efficacy in the majority of instances where dysregulation of more than one biological
21 pathway is responsible for driving the disease and overcome resistance. However, the
22 mechanism of action and cumulative toxicities of additional agents must be carefully
23 considered when designing treatment regimens. A substantial logistical challenge lies in
24 the systematic evaluation of the numerous possible permutations of combinations in a
25 clinical setting [56]. In view of the limited number of children available for early phase
26 studies, a rational approach is needed for the selection of combinations, based on the
27 biology of neuroblastoma and its known biological subsets as well as pathways' data in
28 tumours treated with one agent involved in the combination. Following pre-clinical
29 evaluation of the combinations in a range of well-characterized models derived from
30 patients' tumours or genetically engineered models, a proposed combination should be
31 evaluated clinically. The study of genomic and pharmacodynamic biomarkers during the
32 clinical evaluation will exemplify a "from the bench to the bedside and back again"
33 approach. Finally there must be an awareness of unexpected or greater toxicities with
34 these combinations and extrapolation from adult experience is essential.

35

6. Drugs relevant to prioritised targets

Paediatric early phase clinical trials are ongoing or have recently closed for ALK and aurora kinase inhibitors [31,57-63].

For neuroblastoma, the responses seen with crizotinib are disappointing and are substantially lower than those seen with tumours driven by ALK translocations - inflammatory myofibroblastic tumour, anaplastic large cell lymphoma and non-small cell lung cancer [31]. The challenge then is to identify more potent drugs or combinations which can overcome the inherent resistance of ALK mutations in neuroblastoma. Currently three ALK inhibitors are marketed for the treatment of ALK driven non-small cell lung cancer (crizotinib, ceritinib and alectinib) and three more are in development in adults (brigatinib, lorlatinib and entrectinib). Paediatric trials of single agents ceritinib (LDK378) and entrectinib, as well as combinations of ALK inhibitors with mTOR or CDK4/6 inhibitors, are ongoing [61-63] and, pre-clinical data relating to lorlatinib is encouraging and a Phase I trial has been activated for ethical/IRB approval [64-66]. The optimal ALK inhibitor for neuroblastoma has yet to be determined clinically, but once identified will be evaluated in front-line studies.

Aurora kinase inhibitors are cytotoxic in their own right, as well as acting on the MYCN-aurora complex. Two aurora kinase inhibitors, alisertib and AT9283 have been evaluated in phase I studies in children with neuroblastoma [58-60]: AT9283 as a single agent and alisertib as a single agent and in combination with irinotecan and temozolomide. Activity has been observed with alisertib both as single agent and in combination. However, activity of alisertib was lowest in MYCN amplified neuroblastoma suggesting that its mechanism of action was by a cytotoxic effect rather than on the MYCN-aurora complex. This further supports the hypothesis that the optimal aurora kinase inhibitor, eliciting conformational changes on the MYCN-aurora complex, has yet to be developed [52-54].

Although mTOR inhibitors - everolimus, temsirolimus and ridaforolimus [67-71] - have been evaluated in clinical trials in children, paediatric trials of the new mTORC1/2 inhibitors have just opened and are a high priority for the paediatric academic community because the dual mTORC1/2 inhibition could overcome resistance to rapalogues.

The first-in-child trial of the CDK4/6 inhibitor ribociclib (LEE011) has been recently completed [72], with stable disease a frequent outcome, demonstrating the importance of

1 a combination approach, and trials of abemaciclib (LY2835219) and palbociclib are ongoing
2 [73,74]. Early paediatric clinical trials of the MEK inhibitors selumetinib, trametinib and
3 cobimetinib and the pan phosphatidylinositol 3-kinase (PI3K) inhibitor SF1126 [75] are in
4 progress. Additionally, MDM2, BIRC5, CHK1 and BET bromodomain inhibitors are in the
5 early clinical phases of adult development, but paediatric clinical trials have not yet
6 started. Although there is a strong biological, mechanism of action rationale for such
7 development of these inhibitors, the slowness in opening early phase paediatric studies
8 reflects that paediatric drug development is still largely centred on adult conditions and
9 not the mechanism of action based model [28].

11 **7. Transition to clinical development: considerations for early and late clinical trials**

12 Based on the foundation of the Neuroblastoma NDDS, there are four elements for clinical
13 evaluation of new drugs: early phase clinical trials, parallel randomised later-phase clinical
14 trials, molecular profiling and randomised front-line trials. Central to the overall approach
15 is the seamless transition between evaluation of a new drug for a particular molecular sub-
16 type by the Clinical Trials Committee of ITCC and evaluation specifically for relapsed
17 neuroblastoma by the Drug Development Group of SIOPEN.

18
19 The objective of an early phase clinical trial is not only to determine the paediatric
20 recommended phase II dose (RP2D), safety profile, pharmacokinetics and
21 pharmacodynamics of a drug, but also to assess preliminary signals of activity. As the
22 paediatric RP2D remains very close to the equivalent adult RP2D and toxicity profiles are
23 class-related and similar to adult drugs [76], for drugs with a wide therapeutic index, it is
24 recommended that the paediatric early phase clinical trial starts at the adult RP2D,
25 corrected for body surface area, and is a dose confirmation study. Using this approach
26 [76], pharmacokinetic profiling is critical and the exposures, clearances and other
27 pharmacokinetic parameters can be confirmed to be similar to those obtained in adults as
28 well as the toxicity profile. Conversely, if the drug has a narrow therapeutic index, then a
29 dose escalation study is required. Existing dose escalation designs such as 3+3 were
30 developed for evaluating chemotherapeutics. For molecularly targeted agents, the use of
31 these conventional dose escalation designs leads to longer study durations, studies
32 remaining closed to recruitment for long periods and more dose levels being tested. New
33 dose escalation designs, such as the Bayesian logistic regression model (BLRM) or
34 continuous reassessment method (CRM), maximise the efficiency of the dose escalation by

1 leading to a shorter duration of trials and less exposure of patients to doses below the
2 maximum tolerated dose (MTD) [78].

3
4 The inclusion of patients with the same molecular sub-type or disease in early phase trials
5 of expansion cohorts will enable a valuable assessment of activity, as well as providing
6 further data on safety and pharmacokinetics. Relatively small sized expansion cohorts can
7 inform statistically go/no-go decisions; for example an Ensign 3-stage design [79], where
8 ten patients are recruited at the RP2D, as used in the European Proof-of-Concept
9 Therapeutic Stratification Trial of Molecular Anomalies in Relapsed or Refractory Tumours
10 (ESMART)trial (NCT02813135) [80]. If there is no response in the first ten patients, then a
11 further evaluation of the drug is postponed or abandoned. However, if there is a response
12 in the first ten patients, then a further 16 patients are enrolled. Also, the recently
13 presented paediatric study on the BRAF inhibitor dabrafenib included four expansion
14 cohorts with 10 patients each, providing statistically based estimations to guide go/no go
15 decisions [81, 82].

16
17 If there is preliminary evidence of activity, then the drug is evaluated further in
18 neuroblastoma-specific, adaptive-design, parallel, randomised or multi-arm, multi-stage
19 studies. Evaluation in randomised trials is essential, as a comparison with historical
20 controls will overestimate the efficacy of the drug [83].

21
22 Finally and importantly molecular profiling of the patient's tumour at the time of
23 enrolment on an early phase clinical trial is a critical component of the strategy. Due to
24 clonal evolution and tumour heterogeneity, evaluation of archival tumour is not
25 appropriate. "Liquid biopsies" of circulating free DNA are increasingly being incorporated
26 in both early and randomised trials and will give sequential information about tumour
27 evolution and development of resistance. European ITCC initiatives are providing this
28 information by routine molecular profiling of tumours at relapse (MOSCATO-01 [39],
29 MAPPYACTS, INFORM [40], iTHER, SM-PAEDS).

30
31 Currently, the multi-pharma, multi-drug ITCC early phase clinical trial ESMART
32 (NCT02813135) [78] (which includes NDDS prioritised drugs - mTORC1/2, and CDK4/6
33 inhibitors) and the randomised SIOPEN - ITCC BEACON trial [84] provide a clear pathway
34 for the evaluation of drugs identified in the NDDS to go forward to frontline studies. Single
35 agents or combinations, which show activity in the randomised trial, are then introduced

1 into front-line therapy and evaluated further - a three-stage process from first-in-child
2 studies to front-line therapy.

3
4 By utilising this approach paediatric dose confirmation/finding studies can be conducted
5 rapidly, and activity can be determined more quickly, with meaningful comparators and
6 biological knowledge gained in parallel with prospective molecular profiling.

7 8 9 10 **8. Conclusions and action points**

11 The NDDS initiative, created by ITCC, ENNCA and SIOPEN, aims to accelerate drug
12 development by bringing together biologists, drug developers, regulators, and clinicians
13 leading early and late phase trials, to achieve a consensus. Drug development for
14 neuroblastoma must be driven by biology and knowledge of the molecular pathways,
15 tumour biology and key oncogenic drivers. Targets have been prioritised based on biology,
16 specifically target expression, target dependency and validation, and pre-clinical data on
17 efficacy, potential combinations and availability of biomarkers. Since the start of the NDDS
18 initiative, ITCC and SIOPEN have increased efforts to accelerate the development of the
19 prioritised inhibitors. Furthermore there is a clear continuum incorporating molecular
20 profiling, biological and pre-clinical data, mechanism of action driven strategy for selection
21 and prioritisation, and improved early and late phase clinical trial design to streamline the
22 drug development process (Table 3). A closer dialogue with the pharmaceutical industry
23 will further increase the efficiency of this plan, as will the introduction of a mechanism of
24 action and biology driven selection and prioritisation process in paediatric drug
25 development. This approach will guide scientists, clinicians, pharmaceutical industry and
26 regulators in the immediate future and will enable access to the most promising targeted
27 agents in the hope of improving outcomes for children with neuroblastoma, and
28 potentially other childhood malignancies.

29 30 **9. Expert Opinion**

31 The existing model of drug development for neuroblastoma is generally reactive and
32 responds to drugs being developed for adult malignancies. Furthermore, in the past there
33 has not been integration and coordination between early and late phase clinical studies.
34 Drug development is not driven by the biology of the tumour and the known genomic
35 drivers. This process results in drugs being evaluated that may not have the greatest

1 probability of activity in neuroblastoma, and their course of development is interrupted
2 and not planned, and frequently trials compete for small populations. Increased
3 collaboration and data sharing between all stakeholders is needed to avoid regulators and
4 pharma not being aware of developments, and lacking an overview of the landscape of the
5 disease, therapeutic needs and new scientific discoveries.

6
7 The approach adopted by the NDDS initiative is integrated, comprehensive, and based on
8 tumour biology, and results in a more efficient and rational process and use of valuable
9 and rare resources. The Neuroblastoma NDDS encompasses all elements of the drug
10 development process, including translational medicine from bench to bedside: molecular
11 profiling to identify new targets and potential predictive (selection) biomarkers, relevant
12 drugs, biological and pre-clinical research, first-in-child early phase clinical studies,
13 randomised multi-arm trials and the transition to late-phase trials and to front-line
14 standard of care. Central to the approach is the premise that optimal drug development is
15 reliant on understanding tumour biology. Selection of drugs should be driven by the
16 aberrant molecular pathways in neuroblastoma [28]. The biological hypotheses relevant
17 to each drug should be tested in the clinic through the use of omic and pharmacodynamic
18 ancillary biomarker studies. This approach is in contrast to the present model, where drug
19 selection is dictated by the adult indication and not necessarily by the probability that the
20 medicine will have the greatest patient benefit in childhood tumours. The major challenge
21 of the proposed model is the availability of drugs. This could be increased by including re-
22 prioritisation of drugs developed for adults, which may not be of high priority for adult
23 cancers, or by incentivising the development of drugs specifically for paediatric cancers.
24 Once this proposed model is incorporated, its results will need to be evaluated
25 prospectively to finally demonstrate that it was fit for purpose and has speeded up drug
26 development for childhood cancers.

27
28 A critical feature of the NDDS initiative is bringing together experts in neuroblastoma
29 biology and pre-clinical and clinical drug development and leaders of late-phase studies,
30 with regulators as observers. In this way information can be shared, all participants have a
31 common knowledge and decisions can be made collectively.

32
33 The Neuroblastoma NDDS has delivered three outputs:-

- 1 1. A multidisciplinary expert group has been established, with participants involved in
2 all aspects of the drug development process, which is able to have a dynamic
3 overview of all new targets and drugs available for the disease.
- 4 2. Targets have been prioritised based on target validation and completeness of non-
5 clinical data, including available inhibitors, combinations, resistance mechanisms
6 and biomarkers: ALK, MEK, CDK4/6, MDM2, MYCN (BET, Aurora kinase and
7 mTORC1/2), BIRC5 and CHK1 inhibitors. The process is dynamic, and new targets
8 and drugs are regularly reviewed.
- 9 3. Clinical trials of the prioritised targets and drugs have been promoted by liaising
10 with pharma and facilitating investigator-led trials through ITCC.

11
12 This output of the NDDS greatly assists clinicians designing early- and late-phase clinical
13 studies and the pharmaceutical industry and regulators who are made aware of targets
14 and drugs of greatest interest. Scientific advice can be sought from regulators at early
15 stages in development. Resources from academia and industry can be directed to areas
16 with greatest potential yield.

17
18 As neuroblastoma has different genomic drivers, with clonal evolution and tumour
19 heterogeneity, molecular characterisation with a precision medicine approach will be
20 critical. The ultimate goal is a therapeutic approach comprising: molecular profiling
21 tumour categorisation, molecular targeted therapy for “known” genomic drivers and a
22 strategy for biologically relevant cancer vulnerabilities.

23
24 We believe this novel approach will accelerate neuroblastoma drug development and
25 should be applied to other poor prognosis childhood malignancies.

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1	Tables
2	Table 1: Available evidence relating to potential targets in the areas: presence of the target, <i>in vitro</i> and <i>in vivo</i> target validation, <i>in vitro</i> and <i>in vivo</i> pharmacological efficacy, availability of
3	<i>in vitro</i> and <i>in vivo</i> target validation, <i>in vitro</i> and <i>in vivo</i> pharmacological efficacy, availability of
4	predictive biomarkers, potential combinations explored and resistance mechanisms
5	Table 2: Prioritised targets, agents and ongoing/planned clinical trials
6	Table 3: Summary of NDDS Strategy
7	
8	List of Abbreviations
9	
10	Highlights Box - New drug development strategy for neuroblastoma –
11	