

COMMENTARY

When the dust settles: what did we learn from the bexarotene discussion?

Ina Tesseur^{1,2} and Bart De Strooper^{1,2*}

Abstract

With 27 million people affected by Alzheimer's disease (AD), any proposal of a novel avenue for drug development is hot news. When Cramer and colleagues proposed last year that they could tackle AD pathology in an AD mouse model with bexarotene, a drug already in use in the clinic for other diseases, the news was covered worldwide by the popular press. Apolipoprotein E4 is the strongest genetic risk factor for AD and bexarotene appeared to exert spectacular effects on AD pathology when tested in APP/PS1 transgenic mice. One year later the slumbering discussion on the use of bexarotene in AD exploded in a flurry of papers. Four papers question the initial optimistic claims, while two others can only partially support the original work. We summarize here the available data and try to make sense out of the controversy. The major question is what we can learn from the experiments and what these studies imply for the further development of bexarotene in the clinic.

Apolipoprotein E4 (apoE4) is the most important genetic risk factor for sporadic Alzheimer's disease (AD) and therefore an interesting drug target *per se*. Despite numerous studies trying to address by which mechanism apoE4 affects the risk for AD, a definitive answer has not yet emerged. Both the ideas that apoE4 accelerates and fails to protect against disease have been proposed [1-3]. These opposite views have important implications when devising therapeutic strategies for AD. If apoE4 accelerates the disease, then inhibition of apoE4, or the toxic pathways in which it plays a role, would be required. Practically this would imply, for instance,

inhibiting the cleavage of apoE4 into toxic fragments or blocking apoE4's effects on amyloid beta ($A\beta$) oligomerization [2,3]. If apoE4 fails to protect against AD, however, then potentiation of the function of wild-type apoE would be desirable - for instance, by generating apoE3 mimetics, which could improve the brain clearance of $A\beta$ that may be affected in APOE4 carriers [1,3].

The paper by Cramer and colleagues [4] fitted nicely into the second strategy and showed that upregulation of apoE and apoE-related pathways could improve amyloid plaque accumulation and behavior in a mouse model of AD. Moreover, it demonstrated that this was possible by administering the drug bexarotene, which was already approved by the US Food and Drug Administration (FDA) for use in humans [5]. The excitement that this possibility could rapidly become tested in real, sporadic AD patients propelled the publication into the popular press.

Bexarotene is a retinoid X receptor (RXR) agonist that induces transcription of the ATP-binding cassette transporter gene A1 (*ABCA1*), as well as apoE and other genes involved in lipid metabolism through obligatory heterodimerization of RXR with liver X receptor and peroxisome proliferator-activated receptor- γ . As a result, bexarotene induces accumulation of triglycerides *in vivo*, which can result in liver steatosis and hypertriglyceridemia [6]. ApoE and ABCA1 are expressed in the central nervous system and in the periphery and measuring their expression should give a good indication of target engagement by bexarotene in both the central nervous system and the periphery.

Given the spectacular results of Cramer and colleagues [4], it is not surprising that many research groups worldwide attempted to replicate the original study. The data are summarized in Table 1. The major claim of the original study was a rapid clearance of $A\beta$ deposits from the brains of AD model mice [4]. This claim could not be confirmed in five independent follow-up studies [7-11], despite target engagement. Interestingly, and in

* Correspondence: bart.destrooper@cme.vib-kuleuven.be

¹VIB Center for the Biology of Disease, Herestraat 49, box 602, Leuven BE3000, Belgium

²Center for Human Genetics and Institute of Neuroscience and Disease (LIND), KU Leuven and Universitaire Ziekenhuizen, Leuven B-3000, Belgium

Table 1 Overview of drug formulation and experimental outcomes of Alzheimer's disease model mice treated with Bexarotene

Research group	Drug formulation	Duration of treatment	Experimental claims					
			Target engagement (ApoE/ABCA1)	Decrease of soluble A β	Clearance of deposited A β /plaques	Behavioral improvements	<i>In vivo</i> microglia activation	Mechanism-based toxicity
Cramer <i>et al.</i> [4]	Bexarotene/Targretin in DMSO or micronized in water	3 to 14 days and 3 months	Increase	Decrease of A β 40 or A β 42 >25%	Repeated dosing of 3 to 14 days decreases A β deposits by 30 to 75%; 3-month treatment had no effects	Improved context-dependent fear memory. Improved spatial memory. Improved social behavior	Unclear whether different from control	NR
Price <i>et al.</i> [9]	Bexarotene in solutol:ethanol:water (15:10:75)	3 to 7 days	Increase	No effect	No effect	NR	NR	Increased liver weight
Fitz <i>et al.</i> [11]	Targretin in glycerol	15 days	Increase	Decrease of ISF A β 40 and A β 42 by 23 to 26%; no effect on extracted soluble A β	No effect	Improved spatial memory. Improved long-term memory	NR	NR
Veeraraghavalu <i>et al.</i> [7]	Targretin in DMSO:ethanol:sunflower oil (6.6%:4%:89.6%)	7 days	Increase	Small effects	No effect	NR	No effect	NR
Tesseur <i>et al.</i> [8]	Bexarotene in Captisol and HP- β -CD/Tween	19 days	Increase	No effect	No effect	Unclear effect on social recognition memory and fear memory	NR	Loss of body weight, irritation and breathing problems, increased grooming
LaClair <i>et al.</i> [10]	Bexarotene in DMSO or corn oil	3 to 14 days	Increase	NR	No effect	No effect on context- or conditioned stimulus-dependent fear memory	No effect	NR
Ulrich <i>et al.</i> [12]	Targretin in water	36 hours	Increase	Decrease of ISF A β 40 by 45%	NR	NR	NR	NR

A β , amyloid beta; ApoE, apolipoprotein E; DMSO, dimethyl sulfoxide; HP- β -CD, 2-hydroxypropyl- β -cyclodextrin; ISF, interstitial fluid; NR, not reported.

contrast to the bulk of their results, Cramer and colleagues reported that, after chronic daily bexarotene treatment for 3 months, they could not find a decrease in A β deposits, despite reduced soluble A β levels and target engagement [4]. This result is puzzling compared to the rest of their results and no clear explanation for this discrepancy is given. The other claims of the publication were, optimistically speaking, confirmed by some groups and not by others. For instance, three groups found lowering of soluble A β levels in interstitial fluid [11,12] or in brain extracts [7], whereas three groups found no effects [8,9,11]. From Table 1 it becomes clear that the formulation of bexarotene might be very critical in this regard. The groups who observed an effect used

Targretin for their mice. Targretin is the commercial formulation of bexarotene and contains a lot of additional 'stuff' (see detailed component list in [13]). This raises the question of whether those additional components could affect the results, especially since the bexarotene formulations used by the other groups resulted in efficient brain exposure as well, precluding the lack of target engagement as an explanation for this discrepancy. The original publication by Cramer and colleagues [4] mentioned the use of Targretin in some experiments and of bexarotene powder (in water or DMSO) in other experiments, explaining some of the confusion in the follow-up studies. The authors [14] indicated afterwards that they actually used Targretin for their dosing studies

[4] but it remains to be fully clarified what was exactly used in the different experiments of the original work [4].

The behavioral data analyzing the effects of bexarotene on cognition and memory, which are crucial for the clinic, are the most difficult and most controversial to interpret. Cramer and colleagues [4] claimed that bexarotene significantly improved spatial and fear memory in their mice. Improvement in spatial memory upon bexarotene treatment was reproduced in one follow-up study [11], but improvement of fear memory could not be reproduced [10] or was reported to be inconclusive in a third study [8]. The latter study, although inconclusive, is quite informative from another perspective. Indeed, these authors reported a series of confounding effects in the mice treated with the drug - that is, severe loss of total body weight, breathing problems, and increased grooming - indicating that the mice felt rather uncomfortable and might even suffer from the treatment [8]. Although the authors of the Cramer and colleagues' study interpreted the behavioral data of the latter study in their response-comment as confirmative of their original data [14], the authors of the latter study were much less positive and indicated that the animals might have been too sick to allow any confirmative conclusions [8]. In addition to these side effects, Price and colleagues [9] reported evidence that bexarotene significantly increased liver weight in treated mice, indicating liver steatosis.

FDA files report that bexarotene induces severe upregulation of triglyceride and total cholesterol levels in many patients, and high-density lipoprotein cholesterol is lowered in 25% of treated patients [5]. As the dyslipidemia is reversible after stopping the treatment, this may not pose major issues when treating cancer patients for a limited time. However, AD patients at risk might need treatment for many years, and in such cases the dyslipidemia would become chronic and could seriously compromise cardiovascular health.

Finally, the original publication of Cramer and colleagues [4] claimed a significant upregulation of microglial activation in bexarotene-treated animals. However, some control stainings and quantifications were lacking in the manuscript, making it difficult to ascertain how definitive these observations were. Indeed, two independent follow-up studies did not see effects on microglia activation [7,10].

Conclusion

Collectively, the above summarized data neither support nor contradict the hypothesis that apoE4 fails to protect against AD and the question is still open. It is clear that the original data published by Cramer and colleagues [4] were interpreted with a lot of optimism, which is

understandable given the huge unmet needs in the field. Given the central role of apoE4 in the risk for AD, the proposed approach remains potentially interesting. For the time being, however, we strongly suggest that researchers and clinicians interested in this work perform their own additional preclinical validation before starting clinical trials with bexarotene in humans. In addition, given the reported side effects and possible risks, 'off-counter' use of Targretin by desperate AD patients should be tempered until all the raised issues have been sufficiently clarified.

Abbreviations

AD: Alzheimer's disease; apoE: Apolipoprotein E; A β : Amyloid beta; DMSO: Dimethyl sulfoxide; FDA: US Food and Drug Administration; RXR: Retinoid X receptor.

Competing interests

BDS is consultant for Janssen Pharmaceutica, Remynd NV and Envivo Pharmaceuticals.

Acknowledgements

This work was supported by the Fund for Scientific Research Flanders, the KU Leuven, a Methusalem grant from the KU Leuven and the Flemish government, the Foundation for Alzheimer Research (SAO/FRMA) to BDS. BDS is the Arthur Bax and Anna Vanluffelen chair for Alzheimer's disease.

Published: 7 November 2013

References

1. Sharifov OF, Nayyar G, Garber DW, Handattu SP, Mishra VK, Goldberg D, Anantharamaiah GM, Gupta H: **Apolipoprotein E mimetics and cholesterol-lowering properties.** *Am J Cardiovasc Drugs* 2011, **11**:371-381.
2. Mahley RW, Huang Y: **Apolipoprotein E sets the stage: response to injury triggers neuropathology.** *Neuron* 2012, **76**:871-885.
3. Liu CC, Kanekiyo T, Xu H, Bu G: **Apolipoprotein E and Alzheimer disease: risk, mechanisms and therapy.** *Nat Rev Neurol* 2013, **9**:106-118.
4. Cramer PE, Cirrito JR, Wesson DW, Lee CY, Karlo JC, Zinn AE, Casali BT, Restivo JL, Goebel WD, James MJ, Brunden KR, Wilson DA, Landreth GE: **ApoE-directed therapeutics rapidly clear beta-amyloid and reverse deficits in AD mouse models.** *Science* 2012, **335**:1503-1506.
5. FDA: *Targretin Drug Approval Package.* [http://www.accessdata.fda.gov/drugsatfda_docs/nda/99/21055_Targretin.cfm].
6. Lalloyer F, Pedersen TA, Gross B, Lestavel S, Yous S, Vallez E, Gustafsson JA, Mandrup S, Fiévet C, Staels B, Tailleux A: **Rexinoid bexarotene modulates triglyceride but not cholesterol metabolism via gene-specific permissivity of the RXR/LXR heterodimer in the liver.** *Arterioscler Thromb Vasc Biol* 2009, **29**:1488-1495.
7. Veeraghavulu K, Zhang C, Miller S, Hefendehl JK, Rajapaksha TW, Ulrich J, Jucker M, Holtzman DM, Tanzi RE, Vassar R, Sisodia SS: **Comment on "ApoE-directed therapeutics rapidly clear beta-amyloid and reverse deficits in AD mouse models".** *Science* 2013, **340**:924-f.
8. Tesseur I, Lo AC, Roberfroid A, Dietvorst S, Van Broeck B, Borgers M, Gijsen H, Moechars D, Mercken M, Kemp J, D'Hooge R, De Strooper B: **Comment on "ApoE-directed therapeutics rapidly clear beta-amyloid and reverse deficits in AD mouse models".** *Science* 2013, **340**:924-e.
9. Price AR, Xu G, Siemienski ZB, Smithson LA, Borchelt DR, Golde TE, Felsenstein KM: **Comment on "ApoE-directed therapeutics rapidly clear beta-amyloid and reverse deficits in AD mouse models".** *Science* 2013, **340**:924-d.
10. LaClair KD, Manaye KF, Lee DL, Allard JS, Savonenko AV, Troncoso JC, Wong PC: **Correction: treatment with bexarotene, a compound that increases apolipoprotein-E, provides no cognitive benefit in mutant APP/PS1 mice.** *Mol Neurodegener* 2013, **8**:26.
11. Fitz NF, Cronican AA, Lefterov I, Koldamova R: **Comment on "ApoE-directed therapeutics rapidly clear beta-amyloid and reverse deficits in AD mouse models".** *Science* 2013, **340**:924-c.

12. Ulrich JD, Burchett JM, Restivo JL, Schuler DR, Verghese PB, Mahan TE, Landreth GE, Castellano JM, Jiang H, Cirrito JR, Holtzman DM: **In vivo measurement of apolipoprotein E from the brain interstitial fluid using microdialysis.** *Mol Neurodegener* 2013, **8**:13.
13. Drugs.com: *Targretin*. [<http://www.drugs.com/uk/targretin-capsules-1302.htm>].
14. Landreth GE, Cramer PE, Lakher MM, Cirrito JR, Wesson DW, Brunden KR, Wilson DA: **Response to comments on "ApoE-directed therapeutics rapidly clear beta-amyloid and reverse deficits in AD mouse models".** *Science* 2013, **340**:924-g.

doi:10.1186/alzrt218

Cite this article as: Tesseur and De Strooper: **When the dust settles: what did we learn from the bexarotene discussion?** *Alzheimer's Research & Therapy* 2013 **5**:54