Amyloid-PET predicts inhibition of de novo plaque formation upon chronic γ-secretase modulator treatment

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In a positron-emission tomography (PET) study with the β-amyloid (Aβ) tracer [18F]-florbetaben, we previously showed that Aβ deposition in transgenic mice expressing Swedish mutant APP (APP-Swe) mice can be tracked in vivo. γ-Secretase modulators (GSMs) are promising therapeutic agents by reducing generation of the aggregation prone Aβ42 species without blocking general γ-secretase activity. We now aimed to investigate the effects of a novel GSM [8-(4-Fluoro-phenyl)-[1,2,4]triazolo[1,5-a]pyridin-2-yl]-[1-(3-methyl-[1,2,4]thiadiazol-5-yl)-piperidin-4-yl]-amine (RO5506284) displaying high potency in vitro and in vivo on amyloid plaque burden and used longitudinal Aβ-microPET to trace individual animals. Female transgenic (TG) APP-Swe mice aged 12 months (m) were assigned to vehicle (TG-VEH, n = 12) and treatment groups (TG-GSM, n = 12), which received daily RO5506284 (30 mg kg–1) treatment for 6 months. A total of 131 Aβ-PET recordings were acquired at baseline (12 months), follow-up 1 (16 months) and follow-up 2 (18 months, termination scan), whereupon histological and biochemical analyses of Aβ were performed. We analyzed the PET data as VOI-based cortical standard-uptake-value ratios (SUVR), using cerebellum as reference region. Individual plaque load assessed by PET remained nearly constant in the TG-GSM group during 6 months of RO5506284 treatment, whereas it increased progressively in the TG-VEH group. Baseline SUVR in TG-GSM mice correlated with Δ%-SUVR, indicating individual response prediction. Insoluble Aβ42 was reduced by 56% in the TG-GSM versus the TG-VEH group relative to the individual baseline plaque load estimates. Furthermore, plaque size histograms showed differing distribution between groups of TG mice, with fewer small plaques in TG-GSM animals. Taken together, in the first Aβ-PET study monitoring prolonged treatment with a potent GSM in an AD mouse model, we found clear attenuation of de novo amyloidogenesis. Moreover, longitudinal PET allows non-invasive assessment of individual plaque-load kinetics, thereby accommodating inter-animal variations.

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INTRODUCTION

With its exponentially increasing incidence as a function of age, Alzheimer’s disease (AD) has become the most common form of dementia, and is imposing a significant burden on health care systems of societies with aging populations.1 Neurofibrillary tangles and amyloid plaques are the histologically characterizing hallmarks of AD.2 The principal component of amyloid plaques, the β-amyloid (Aβ) peptide, is a heterogeneous cleavage product of the Aβ precursor protein (APP) generated by β- and γ-secretase. Of the several Aβ variants the Aβ42 species is widely believed to be a key factor of the disease.3 Current therapeutic options for AD include acetylcholinesterase inhibitors4 and NMDA receptor antagonists,5 both of which provide some transient amelioration of cognitive symptoms, but without any disease-modifying effects.6,7 Consequently, there is an urgent need for disease-modifying treatments such as those targeting amyloidosis. γ-Secretase inhibitors (GSIs) suppress intestinal cell differentiation and also lymphopoiesis, owing to inhibition of Notch signaling8 and a large phase III clinical trial was terminated owing to severe side effects.9 However, γ-secretase inhibition may still be a hopeful approach,10 although pharmaceutical companies may stay away from such efforts. First generation unspecific GSIs affect dendritic spine plasticity,11 which may explain reports of cognitive deterioration in AD patients with long-term GSI treatment.9,12 Interestingly, however, Notch-sparing GSIs do not seem to affect spines.13 In contrast to GSIs, γ-secretase modulators (GSMs) shift Aβ production from the more toxic Aβ42 to shorter forms, which are less apt to form amyloid aggregates. This favorable modulation of γ-secretase is obtained without affecting signaling cleavages of Notch or other critical substrates.14–16 In recent years highly potent GSMs have been developed, which target γ-secretase in the N-terminal fragment of its catalytic subunit presenilin.17–20 Owing to their profile of modulating rather than inhibiting γ-secretase cleavage, GSIs hold great potential as therapeutics with improved safety, reducing the underlying disease pathology which might ultimately alter the course of the disease. Recent testing of several GSIs in transgenic mice showed reduced plaque area fraction in cortex and hippocampus, as well
as lower plaque density during chronic treatment.\textsuperscript{21–23} A number of chronic GSM treatment studies in Tg2576 mice revealed a dose-dependent reduction of brain $\beta$-Amyloid$_{42}$ levels,\textsuperscript{21,22,24,25} whereas Rogers et al.\textsuperscript{24,25} also observed a significant decrease of total $\beta$-Amyloid levels.

As shown in previous studies, small animal positron-emission tomography (PET) is a suitable non-invasive tool for monitoring the amyloid plaque load of transgenic mice in vivo,\textsuperscript{26–28} yielding excellent correlations with histological or biochemical assessments. As these transgenic models entail a large inter-animal heterogeneity with regard to extent of the pathology,\textsuperscript{29} conducting longitudinal PET studies in individual animals is highly desirable.\textsuperscript{27} In accordance with animal protection regulations such studies may also help to reduce the number of animals required.

Given this background, we aimed to monitor the progression of amyloidosis in vivo in APP-Swe mice treated for 6 months with the novel GSM $\{[1-(3-methyl-[1,2,4]thiadiazol-5-yl)-piperidin-4-yl]-[1-(3-methyl-[1,2,4]triazolo[1,5-a]pyridin-2-yl]-[1-(3-methyl-[1,2,4]thiadiazol-5-yl)-piperidin-4-yl]-amine\}$ (RO5506284) by means of small animal amyloid PET with [$^{18}$F]-florbetaben followed by ex vivo multimodal histological and biochemical assessment. We found that the GSM treatment effectively lowered \textit{de novo} amyloidogenesis over time and that longitudinal amyloid-PET monitoring effectively copes with the known inter-animal variability making it superior to classical end point analyses.

**MATERIALS AND METHODS**

**Synthesis of RO5506284**

RO5506284 (Figure 1a) was prepared as described in the patent literature.\textsuperscript{30}

**GSM potency and selectivity**

\textit{In vitro} drug potency and selectivity

In \textit{vivo} drug potency determination was performed in H4 and N2A cells overexpressing APP containing the Swedish mutation (K670N, M671L). Dose-response curves to determine IC$_{50}$ values for $\beta$-Amyloid modulation by RO5506284 were generated as outlined previously\textsuperscript{31} with the following modification: Quantification of human or mouse $\beta$-Amyloid$_{42}$ levels in cell culture supernatant were performed using AlphaLiSA kit (PerkinElmer, Waltham, MA, USA) according to the manufacturer's instructions. The cellular Notch reporter assay used a stably transected HEK293 cell line expressing human Notch1 and a luciferase reporter\textsuperscript{32} (further details are listed in Supplementary Information).

**Animals**

All experiments were performed in compliance with the Swiss federal regulations (acute treatment arm) and National Guidelines for Animal Protection, Germany, (chronic treatment arm) with approval of the local animal care committee of the Government of Oberbayern (Regierung Oberbayern), and overseen by a veterinarian. Transgenic APP-Swe mice overexpress human APP with the Swedish mutation driven by the mouse Thy1.2 promoter\textsuperscript{33} (further details are listed in Supplementary Information). Age-matched C57Bl/6 mice served as controls.

**Acute treatments and dose finding**

For \textit{acute in vivo} treatment of APP-Swe mice, the compound was administered once per os (gavage) at different doses from 3–100 mg kg$^{-1}$ and different time points from 2–24 h. Vehicle for the acute treatment was 5% ethanol (WVR Prolabo, Darmstadt, Germany), and 10% solutol (BASF Chemtrade GmbH, Burgbernheim, Germany) dissolved in sterile water (Baxter, Compton, UK). For chronic treatment, animals were administered a daily dose of 30 mg kg$^{-1}$ per os (gavage) over a period of 6 months. Vehicle for chronic treatment was 0.9% (w/v) NaCl in 0.3% (v/v) Tween-80 microususpended in sterile water, thus avoiding potential effects of long-term ethanol administration. Mice were killed by cervical dislocation at the indicated time after a single oral administration of drug or vehicle. Brains were collected, frozen on dry ice and stored at $–80 \degree\text{C}$ until analysis of soluble cerebral $\beta$-Amyloid. For the determination of soluble $\beta$-Amyloid levels, a previously described procedure was used\textsuperscript{34} (details are listed in Supplementary Information).

**RESULTS**

RO5506284 is a potent GSM

We first characterized the properties of RO5506284 (Figure 1a), a potent GSM, which selectively lowers $\beta$-Amyloid$_{42}$ and $\beta$-Amyloid$_{40}$ whereas increasing the $\beta$-Amyloid$_{38}$ concentrations. This profile is typical for many GSMs of this compound class, which is characterized by a bridged-aromatic scaffold.\textsuperscript{17,22,33,36} The $IC_{50}$ for inhibition of $\beta$-Amyloid$_{42}$ production in human H4 neuroglioma cells and mouse N2A cells both overexpressing human APP-Swe were 25.7 nM (±7.0 s.e.m., n = 4) using pharmacokinetic (PK) and pharmacodynamic (PD) analysis, plasma protein binding determination and P-glycoprotein assessment (details are listed in Supplementary Information).
and 13 nM (±3.1 s.e.m., n = 2), respectively. No inhibition of Notch processing was observed up to concentrations of 4 μM (n = 4; Figure 1b).

**Acute in vivo effects and dose finding**

In acute in vivo treatment studies, RO5506284 showed a dose-dependent decrease of brain Aβ42 production in young APP-Swe mice after a single oral dose. Aβ42 levels were significantly reduced by 40, 48 and 73% at 4 h after treatment with single doses of 10, 30 and 100 mg kg⁻¹ per os (P < 0.001, tested by one-way analysis of variance, Dunnett’s multiple comparisons test), respectively. Corresponding increases of brain Aβ38 levels were observed, whereas no major change in total Aβ levels were observed (Figure 1c).

The in vivo total plasma IC₅₀ was estimated to be 1340 ng ml⁻¹ and the free plasma IC₅₀ was calculated to be 15 nM, which is in good correlation of in vitro potency of 13 nM. On the basis of the PK/PD analysis, a single dose of 30 mg kg⁻¹ was anticipated to produce a maximal Aβ42 reduction of ~60% at 3 h post dose, a reduction of 50% at 4 h and a return to baseline after 24 h.

**Chronic GSM treatment effects**

The study plan of the chronic treatment arm is outlined in Figure 2a. Details of animal drop outs are provided in Supplementary Information. PK/PD analysis based on RO5506284 exposure in APP-Swe mice after the last day of dosing (similar PK in WT was observed) and generated acute brain Aβ reduction data suggested an average reduction of brain Aβ42 over the treatment period in the range of 20–25% (Figure 2b). Upon daily chronic treatment with 30 mg kg⁻¹ RO5506284 for 6 months, the concentration of insoluble Aβ42 was 40% lower in the TG-GSM vs the TG-VEH group (P < 0.05; Figure 2c), whereas amounts of the other Aβ species did not differ significantly (Table 1). Our randomization of TG mice resulted in allocation of three animals to the TG-GSM group with elevated Aβ-PET (42 s.d.) at the start of treatment (labeled with arrows in Figure 2c). This required scaling of results to the individual baseline amyloid level determined by PET (see below) using multivariate analysis of covariance, thereby accounting for much of the inter-animal variability. Upon making this adjustment, Aβ42 was considerably lower in TG-GSM than in TG-VEH (~56%; P < 0.001; Figure 2d), whereas amounts of the
During a therapeutic study. Thus, as exemplified the amyloid plaque load and kinetics in individual animals of non-invasive techniques, which allows determining longitudinal variation of the amyloid plaque burden further supports the need (labeled with arrows in Figure 3a). The rather high inter-animal variability to accommodate the large inter-individual differences in initial plaque load and kinetics, thus affording sensitive detection of individual treatment effects on amyloid plaque burden.

Baseline results showed a trend towards elevated SUVRCTX/CBL (+4.2%; $P = 0.11$) in the TG-GSM group compared with TG-VEH, mainly driven by the three individual animals mentioned above (labeled with arrows in Figure 3a). The rather high inter-animal variation of the amyloid plaque burden further supports the need of non-invasive techniques, which allows determining longitudinally the amyloid plaque load and kinetics in individual animals during a therapeutic study. Thus, as exemplified in Figure 3b: Animal #05 is one individual with high baseline amyloid level, which turned out to be less effectively treated, whereas animal #06 had low baseline Aβ, which did not accumulate further during follow-up, consistent with a good response to RO5506284 treatment. Animal #21 is a representative untreated individual, in which serial PET revealed a steady increase from a low baseline amyloid level.

**Figure 2.** (a) Temporal overview of the chronic GSM treatment arm, lasting from 12 months to 18 months of age, with intermediate Aβ-PET at 16 months of age. (b) PK/PD simulation of brain Aβ42 reduction effect after chronic treatment with 30 mg kg$^{-1}$ daily of RO5506284. Blue curve indicates the PK simulation based on measured plasma concentrations (blue dots; mean value in ng ml$^{-1}$ ± s.d., $n = 4$) after the last oral administration of the chronic treatment. Green curve shows simulated PD response in relation to a daily dose of 30 mg kg$^{-1}$. Area above the green curve represents the daily brain Aβ42 reduction. Green square (mean value in percentage ± s.d., $n = 10$) shows the observed Aβ42 levels after a single dose of 30 mg kg$^{-1}$. (c) Individual concentration of brain Aβ42 after chronic treatment for 6 months without accounting for individual baseline amyloid levels. Each point represents the biochemically determined amount of Aβ42 in one hemisphere of each transgenic mouse. Red indicates TG-GSM and green indicates TG-VEH mice. Arrows indicate the three animals of the TG-GSM group with elevated PET baseline estimates (>2 s.d. above group mean). (d) Individual concentration of brain Aβ42 after chronic treatment for 6 months upon adjustment by the individual baseline amyloid level, as assessed by Aβ-PET. Red indicates TG-GSM and green indicates TG-VEH mice. Arrows indicate the three animals of the TG-GSM group with elevated PET baseline estimates (>2 s.d. above group mean). The horizontal line in the middle represents the mean value. *indicates statistically significant at $P < 0.05$; **indicates statistically significant at $P < 0.001$.

Aβ-PET allows monitoring GSM efficacy in vivo

Besides demonstrating that RO5506284 is a potent GSM, substantially lowering brain Aβ42 levels in vivo upon single or prolonged treatment, monitoring with non-invasive Aβ-PET imaging was performed (see Figure 2a), acquiring a total of 131 microPET recordings. This molecular imaging technique was applied with the intention to accommodate the large inter-individual differences in initial plaque load and kinetics, thus affording sensitive detection of individual treatment effects on amyloid plaque burden.

Post mortem histochemical analyses confirm the Aβ-PET data To confirm and extend the in vivo results, methoxy-X04 staining of fibrillar Aβ was performed after the final Aβ-PET scan to investigate whether chronic RO5506284 treatment has an impact on
plaque load, density or size. Plaque load in the TG-GSM mice was reduced by 42% relative to the TG-VEH group ($P < 0.05$; Figure 4a), whereas plaque density was 48% lower in the TG-GSM group compared with TG-VEH mice ($P < 0.05$; Figure 4b). Furthermore, histogram plotting of plaque size revealed differing distributions between groups of TG mice, showing fewer ($P < 0.001$) small plaques (size < 800 $\mu m^2$) in TG-GSM animals (Figure 4c). Reduced numbers of small plaques in TG-GSM animals is consistent with a primary effect of RO5506284 on de novo amyloidogenesis, as exemplified in mouse #5 and #6 with only few but rather large plaques, whereas the TG-VEH animal #21 had a considerable number of small plaques (Figure 4d).

Terminal measurements correlate highly across modalities
There was a high correlation between final Aβ-PET findings and plaque density ($r = 0.84$; $P < 0.001$; Figure 4e), plaque load ($r = 0.79$; $P < 0.001$; Supplementary Information), and insoluble Aβ$_{42}$ levels ($r = 0.83$; $P < 0.001$; Figure 4f) as assessed in the corresponding hemisphere. Likewise, insoluble Aβ$_{42}$ levels highly correlated with plaque density ($r = 0.81$; $P < 0.001$; Figure 4g) and plaque load ($r = 0.77$; $P < 0.001$; Supplementary Information) as assessed in the contralateral hemisphere.

**DISCUSSION**

This is the first large-scale longitudinal Aβ-PET study of cerebral amyloidosis in a transgenic AD mouse model treated with a chronic disease-modifying therapy. The study also entails corroborative histopathological, as well as biochemical analyses, thus encompassing three different readout modalities for monitoring amyloidogenesis. We found that daily oral GSM treatment commencing at 12 months attenuated the subsequent rate of de novo amyloidogenesis, which supports current thinking that early initiation of intervention should be most beneficial.

Aβ-PET improves detection of GSM effects by accounting for inter-animal variability and predicts outcome
We elected to start GSM treatment at the age of 12 months in consideration that discernible plaque formation is just barely evident in the APP-Swe animals by the age of 9 months.33 In general, individual plaque loads are quite heterogeneous in AD mouse models, most notably at an early age.7,33 Starting treatment at 12 months, in order to accommodate the considerable variability of individual plaque loads, enabled us to predict response rates as a function of baseline plaque load with Aβ-PET. In the present APP-Swe mouse study, Aβ$_{42}$ levels, density of fibrillar Aβ$_{42}$ plaques and Aβ-PET signal at 18 months, all correlated well, and displayed comparable treatment effects in the contrast between TG-GSM and TG-VEH groups (Figure 4e–g). However, detection of the real longitudinal effect of GSM treatment was hampered by the slightly higher amyloidosis in the TG-GSM group at therapy initiation. We attribute this to chance, such that (after randomization) 3 of 12 mice of the TG-GSM cohort had an Aβ-PET signal at study baseline exceeding that in the saline-treated control group ($>2$ s.d.), indicating presence of established brain amyloidosis at only 12 months of age (Figure 3c). Despite RO5506284 treatment, the total Aβ levels at study termination were >30% higher in these three mice compared with any other TG mouse, indicating not only early onset, but also enhanced progression in these animals. High variability of the transgene expression is well known in this strain, and, indeed, among many transgenic AD mouse models.33,37 This phenomenon indicates that larger group numbers may be necessary in order to obtain better group randomization; alternatively, results of baseline Aβ-PET-scans could be used to allocate individuals to comparable groups prior to initiation of interventions. However, the present Aβ-PET design partially accommodates the imperfect randomization by

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**Table 1. Comprehensive overview of the study groups, with baseline and follow-up parameters in all modalities**

| Study group | Age months (BL) | Weight (g ± s.d.) | Plaque load (percentage area ± s.e.m. COVAR) | Plaque density (percentage area ± s.e.m. COVAR) |
|-------------|-----------------|------------------|--------------------------------------------|---------------------------------------------|
| APP-Swe (BL) | 12 (12 ± 1) | 38 ± 2 | 3.2 ± 1 | 0.3 ± 0.5 |
| APP-Swe (vehicle) | 12 (12 ± 1) | 40 ± 2 | 2.6 ± 1 | 0.2 ± 0.3 |
| APP-Swe (vehicle) | 12 (12 ± 1) | 42 ± 2 | 3.9 ± 1 | 0.3 ± 0.5 |
| APP-Swe (vehicle) | 12 (12 ± 1) | 16 (16 ± 1) | 1.7 ± 1 | 0.2 ± 0.3 |
| APP-Swe (vehicle) | 12 (12 ± 1) | 18 (14 ± 1) | 2.9 ± 1 | 0.3 ± 0.5 |
| APP-Swe (vehicle) | 12 (12 ± 1) | 24 (22 ± 1) | 3.3 ± 1 | 0.2 ± 0.3 |
| APP-Swe (vehicle) | 12 (12 ± 1) | 30 (28 ± 1) | 3.6 ± 1 | 0.3 ± 0.5 |

Abbreviations: BL, baseline; COVAR, covariate; FU1, follow-up 1; FU2, follow-up 2; SUVR, standard-uptake-value ratios. Column 5 indicates the Aβ-PET SUVRCTX/CBL value for each scan time (baseline, follow-up 1, follow-up 2 (termination) scans), whereas column 6 indicates Δ%-SUVRCTX/CBL between follow-up and termination scans relative to the baseline value, and column 7 indicates Δ%-SUVRCTX/CBL between follow-up scans.
accounting for elevated baseline Aβ levels in three individuals through calculation of Δ%-SUVR<sub>TX/CBL</sub> and by affording the possibility to adjust for the Aβ-PET baseline covariate in other histological and biochemical readouts. The longitudinal Aβ-PET approach sensitively detected the GSM treatment effects in the group as a whole, thus avoiding false-positive or false-negative results owing to the imperfect group randomization.

Our study revealed that high amyloid SUVR<sub>TX/CBL</sub> at baseline Aβ-PET recordings correlated positively with further increases in Aβ-PET signal despite treatment. Those animals with a relatively low cortical Aβ-PET signal at treatment start still had relatively low plaque burden at study termination. These preclinical findings that pre-existing amyloidosis is a poor precondition for therapy response are consistent with failed treatment trials of symptomatic AD patients, in whom amyloidosis may already have run its course, or otherwise produced irreversible damage.18–42

Reduced Aβ<sub>42</sub> levels in RO5506284 treated APP-Swe mice primarily lead to inhibition of de novo amyloidogenesis. It is well known that of the various APP processing products Aβ<sub>42</sub> has a particularly high amyloidogenic potential and is responsible for the initiation of plaque formation.43 Although our PK/PD analysis based on acute effect data suggested only 20–25% reduction of brain Aβ<sub>40</sub> over the treatment period we observed a significant effect on the amyloid pathology in the Tg2576 mouse model. Indeed, we found pronounced reductions (−56%; P < 0.005) of fibrillar Aβ plaques stained with methoxy-X04 in the TG-GSM group compared with TG-VEH at study termination. Significantly fewer small-sized plaques were seen in the TG-GSM animals, leading us to conclude that primarily de novo amyloidogenesis is sensitive to GSM treatment (Figure 4c). This positive result seems in line with a previous GSM treatment study in Tg2576 mice, which suggested that the modulator used in this study was likewise effective in inhibiting initiation of new Aβ plaques, but less effective in inhibiting the growth of pre-existing ones.21 Our present findings of effects on amyloid protein levels are also consistent with other reports on preclinical GSM interventions. Thus, Rogers et al.24 found a dose-dependent reduction of Aβ<sub>42</sub> and a decrease of total Aβ in Tg2576 mice treated with EVP-0015962 for 50 weeks. Imbimbo et al.22 detected a reduction of Aβ<sub>42</sub> and a decrease of Aβ<sub>40</sub> in Tg2576 mice treated with CHF5074 for 17 weeks, whereas Kounnas et al.25 found reduced Aβ<sub>42</sub>, Aβ<sub>40</sub>, and Aβ<sub>38</sub> in Tg2576 mice treated with a bridged-aromatic scaffold GSM for 7 months. Van Broeck et al.25 administered antibodies against soluble and deposited Aβ, which
Figure 4. (a) Plaque load (%) in both TG groups assessed by methoxy-X04 staining. Each dot represents the histochemically determined plaque load, using Aβ-PET baseline estimate as covariate. Red indicates TG-GSM animals and green shows TG-VEH animals. (b) Plaque density using Aβ-PET baseline estimate as covariate for one hemisphere of each TG mouse. Red indicates TG-GSM animals and green shows TG-VEH animals. The horizontal line in the middle represents the mean value. *indicates statistically significant at $P < 0.05$. (c) Histogram plotting of plaque size revealed a differing distribution between groups of TG mice, with significantly fewer small plaques in the TG-GSM animals (red). (d) Methoxy-X04 staining of representative sagittal slices in the three above mentioned animals, the right panel zooms into the areas with the largest clusters of amyloid plaques in frontal parts of cerebral cortex. (e) Correlation of final Aβ-PET estimates and plaque density shows excellent agreement. Corresponding hemispheres were used from TG-GSM (red squares) and TG-VEH (green circles) animals for this comparison. (f) Correlation of final Aβ-PET estimates and insoluble Aβ$_{42}$ levels shows excellent agreement. Corresponding hemispheres were used from TG-GSM (red squares) and TG-VEH (green circles) animals for this comparison. (g) Correlation of Aβ$_{42}$ levels and plaque density shows excellent agreement. Contralateral hemispheres were used from TG-GSM (red squares) and TG-VEH (green circles) animals for this comparison.
evoked at 7 months, a dose-dependent decrease of $\Delta A_{42}$, decreased $\Delta A_{40}$ and a reduction of $\Delta A_{38}$ in Tg2576 mice. Recommendation for upcoming treatment trials targeting $\alpha$-pathology

Because a suitable antibody clears the existing $\alpha$ deposits, whereas a GSM could also prevent de novo amyloidogenesis, we suppose that a combination treatment might prove even more efficacious than single treatment paradigms in reducing amyloidosis. Another important outcome of our study is that the serial assessment with $\alpha$-PET throughout the course of a long-term treatment study, in conjunction with histopathological and biochemical end point analyses, appears to be superior to simpler experimental paradigms, in which only the end point readouts are obtained. Given the well known inter-animal variability observed in this study, parallel $\alpha$-PET monitoring during the course of treatment, as well as normalization of results to baseline $\alpha$-PET makes the findings obtained at study end more robust and meaningful. We propose that application of serial $\alpha$-PET during treatment studies will allow for faster translation of disease-modifying approaches from the preclinical stage to the clinic.

Limitations

As we tested only a single dose up to 30 mg kg$^{-1}$ of the GSM RO506284, we cannot be certain that the maximum possible effect with minimum side effects was obtained. However, present results will provide the basis for designing a suitably powered dose-response study.

In addition, our design was not informative about protection against cognitive changes or impaired brain energy metabolism, as documented in a study by Martin-Moreno et al. However, this does not detract for our major objective, which was to obtain serial $\alpha$-PET and terminal biochemical measurements of histological plaque load and $\alpha$ levels in all animals.

CONCLUSION

This is the first large-scale serial $\alpha$-PET study during prolonged GSM treatment in a transgenic AD model. Multimodal data included biochemical and histopathological findings, in addition to the serial, non-invasive $\alpha$-PET investigations, which accommodated the large inter-individual differences in initial plaque load and kinetics, thus affording sensitive detection of treatment effects. Prediction of treatment response was facilitated by individual $\alpha$-PET measurements of baseline amyloid level. GSM treatment with RO506284 attenuated de novo amyloidogenesis compared with vehicle, in line with the notion that early treatment initiation is most likely to be beneficial. The modalities applied should not be considered in competition but rather are complementary and add further value to any single modality alone.

CONFLICT OF INTEREST

CH is an advisor of F. Hoffmann-La Roche. JB, TL and KB are employees of F. Hoffmann-La Roche. PB and AR have received speaking honoraria from Piramal Imaging. The remaining authors declare no conflict of interest.

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