Oral delivery of a novel engineered anti-TNFα domain antibody (Vorabody™) for the treatment of Intestinal Bowel Disease

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Introduction
Crohn’s disease (CD) is a serious and lifelong chronic inflammatory bowel disease (IBD) which can affect any part of the gastrointestinal tract (GIT) but most commonly occurs in the lower part of the ileum, caecum and ascending colon.

Selective neutralisation of TNFα by antibodies is established as an effective and transformative treatment for CD. Three anti-TNFα antibodies: infliximab, adalimumab and certolizumab are currently used clinically for the treatment of CD. These monoclonal antibodies (mAbs) must be administered parenterally requiring either a hospital visit which is inconvenient for the patient, or multiple injections. This mode of administration can be painful and can also result in unwanted systemic side effects associated with long term systemic suppression of TNFα.

An oral antibody delivered locally to the site of inflammation in IBD could therefore have major benefits: ease of administration, preservation of efficacy, and the potential to minimise unwanted systemic side effects.

To date, other than protein replacement products, very few oral peptides have been commercialised, which reflects the significant challenge of oral biologic delivery.

Background
VHsquared Ltd. is a biotechnology company based in Cambridge, UK using proprietary technology to engineer domain antibodies for intestinal protease stability while retaining high potency against the target. This process generates proteins suitable for oral delivery for the treatment of immune-inflammatory GI diseases. V565, the lead compound of the VHsquared Vorabody™ platform technology, is a 115 a.a., 12.6 kDa single domain antibody with potent TNFα-neutralising activity and resistance to inactivation by intestinal proteases.

A formulation has been designed to deliver active V565 to the ileum and colon of the GIT – the areas most commonly affected by CD – by overcoming several challenges. These included ensuring that the Vorabody™ remains stable, releases at the correct target site, and that an adequate amount of drug is available where required in the ileum, caecum, and distal parts of the GIT.

Challenge 1: Increasing V565 resistance to GI proteases while retaining anti-TNFα activity

- VH domain antibodies with potent TNFα-neutralising activity were isolated from a llama phage display library.
- Engineered variants with improved protease resistance that retained potency to soluble and membrane TNFα were further humanized resulting in the fully optimised Vorabody™ V565.
- V565 is resistant to intestinal proteases (Fig.1).

Figure 1: %V565 survival after incubation in 1 mg/mL digestive enzymes at 37°C over 6 hours.

Challenge 2: Producing a formulation to minimise the risk of dose dumping and the effect of food

- V565 is produced by S. cerevisiae fermentation yielding >2 g/L.
- V565 is purified from the yeast supernatant, freeze or spray dried, formulated into 3 mm diameter mini-tablets, and encapsulated for ease of adherence to oral therapy.
- The mini-tablet formulation has sustained release characteristics such that the V565 is released over an extended period in the GIT. The selection of a multi-particulate dosage form of this type and size has a number of advantages:
  - 3 mm mini-tablets are relatively easy to make using existing equipment
  - Dosage can be altered easily by simply varying the number of mini-tablets in the capsule
  - Their small size enables the mini-tablets to exit the pylorus intact
  - The mini-tablets will distribute over the GIT maximising the chance of exposing the diseased mucosa to the drug
- The mini-tablet technology, whilst widely used in small molecule drug formulation, can only be applied to a biologic because of the robustness of the Vorabody™

Challenge 3: Protecting V565 from acid and proteases in stomach and upper GIT

- All proteins are destabilised in acid leaving them vulnerable to digestion from proteases such as pepsin prevalent in the stomach and upper GIT (Fig. 1).
- V565 mini-tablets are coated with an enteric Eudragit® L100 polymer, remaining intact until the coating begins to dissolve after exit from the stomach once a higher pH is reached (Tables 1 and 2).

Table 1: pH tolerance of Eudragit® polymers (Evonik literature).

<table>
<thead>
<tr>
<th>Eudragit® Polymer grade</th>
<th>pH at which soluble</th>
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<tbody>
<tr>
<td>L30-55</td>
<td>5.5</td>
</tr>
<tr>
<td>L100</td>
<td>6.0</td>
</tr>
<tr>
<td>L100</td>
<td>7.0</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Gl tract region</th>
<th>pH (fasted state)</th>
<th>Time to transit (hours)</th>
</tr>
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<tbody>
<tr>
<td>Stomach</td>
<td>12.2±0.3</td>
<td>0.25±0.2</td>
</tr>
<tr>
<td>Duodenum</td>
<td>6.0</td>
<td>0.5±0.7</td>
</tr>
<tr>
<td>Jejunum</td>
<td>6.6</td>
<td>1.5±2.0</td>
</tr>
<tr>
<td>Ileum</td>
<td>7.5</td>
<td>6.7±2.0</td>
</tr>
<tr>
<td>Colon</td>
<td>6.4±7.0</td>
<td>13±6.8</td>
</tr>
</tbody>
</table>

- The pharmacopeial requirement for delayed release (e.g. enteric coated) tablets is to release <10% of their content during 2 h in acid.
- V565 mini-tablet coating formulation has exceeded this requirement to ensure complete passage of the dose through the stomach, releasing no drug during 6 hours in 0.1 M HCl.
- This demonstrates tailoring small-molecule technology for biologic formulation.

Challenge 4: Optimising the Eudragit® coating thickness to target the desired regions of the GIT

1. In vitro dynamic dissolution testing

- Release of V565 from enteric coated mini-tablets was tested in a dynamic dissolution system using a USP 2 (paddles) bath (Garbacz et al, 2014). After a 2 hour period in 0.1M HCl the mini-tablets were transferred into a modified Hank’s buffer medium (bicarbonate based) which more closely matches physiological fluid.
- Results showed no release of V565 in acid, with dissolution commencing after ~2.3 hours.
- The start of release correlates to pH 6.0 (Fig. 2).

Figure 2: Dynamic dissolution. The dynamic dissolution system uses a combination of CO₂ and NH₃ bubbled through the medium to either lower or raise the pH to mimic the pH profile that the dosage form would experience as it transitions the GIT.

2. Testing in non-human primates

- V565 toxicity tests were conducted in cynomolgus monkeys, since V565 only cross-reacts with primates TNFα. To select the optimum coating for the toxicity studies, pharmacokinetic studies were conducted to test the dissolution characteristics of mini-tablets in vivo.
- Animals were dosed orally with capsules containing mini-tablets with either a thinner (Set 1) or thicker (Set 2) Eudragit® coating. GIT contents were analysed after 4h.
- V565 release in the stomachs of Set 1 animals indicated inadequate gastric protection. V565 detection further down the GIT of Set 2 animals confirmed better bio- distribution with the thicker coating, progressing into toxicity and clinical studies.
- Detection of very high concentrations of active V565 in the ileum, caecum, colon and in the faeces of Set 2 orally-dosed animals, demonstrates that active V565 survives in the intestinal tract of primates, when optimally formulated.

3. Testing in humans

- As part of a Phase 1 clinical study, 4 otherwise healthy individuals with ileostomy bags (Fig. 3) were given a single dose of V565 and ileostomy bag contents were analysed hourly.
- Peak V565 detection in the ileostomy bags occurred at 2-4 h, and V565 was detected up to 16 h in some individuals reflecting the delayed release formulation.
- In addition, high concentrations of V565 were detected in the faeces of CD patients without an ileostomy, indicating survival through the entire patient intestinal tract.

Figure 3: Ileostomy. A stoma in the ileum of a patient gives unique access to mid-GIT contents in humans.

Conclusions

- A protease-resistant, potent and selective domain antibody (Vorabody™) against TNFα has been successfully formulated for oral delivery.
- This formulation provides a delayed, sustained release of active antibody in the intestinal tract of humans, including those with Crohn’s disease.
- This formulation is unprecedented for the delivery of a biologic, and the oral delivery of high concentrations of V565 anti-TNFα Vorabody™ directly to the site of disease has the potential to revolutionise IBD treatment.
- V565 is currently in a Phase 2 clinical study in North America and Europe.

References: