siRNA Therapeutics: Target Identification, Discovery and Early Development Considerations

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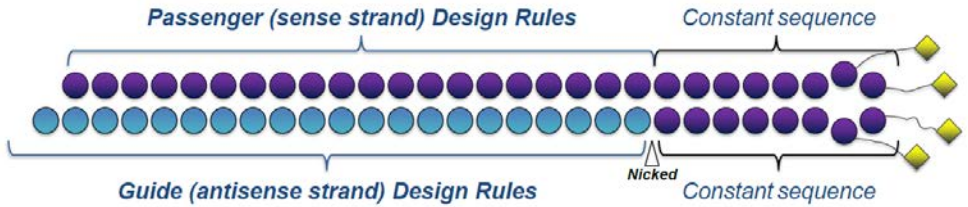
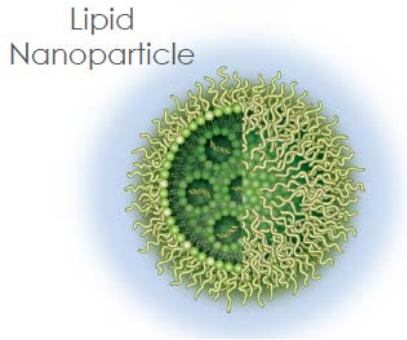
Disclosure: I am an employee of Arrowhead Pharmaceuticals

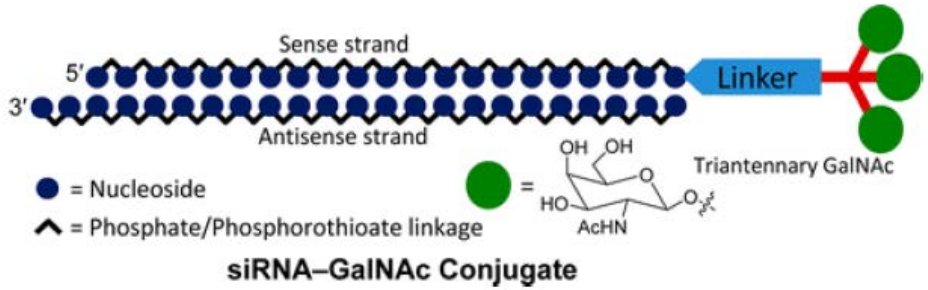
Multiple Older Platforms converging on targeting with direct conjugation of NAG

- Dicerna – GalXC™ (tetraloop)

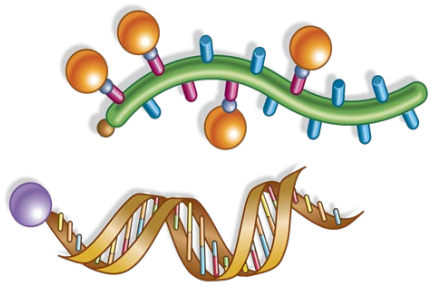


- Alnylam – Lipid Nanoparticle (LNP) to GalNAc conjugation (GalNAc-ESC/ESC+)

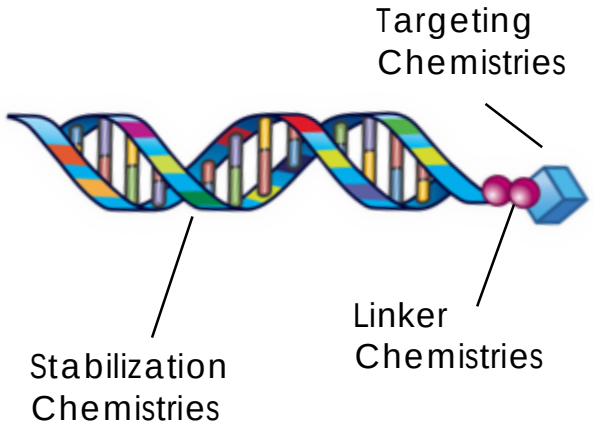




- Arrowhead – Dynamic Polyconjugates (DPC™)(2 molecules with endosomal escape) to TRiM™



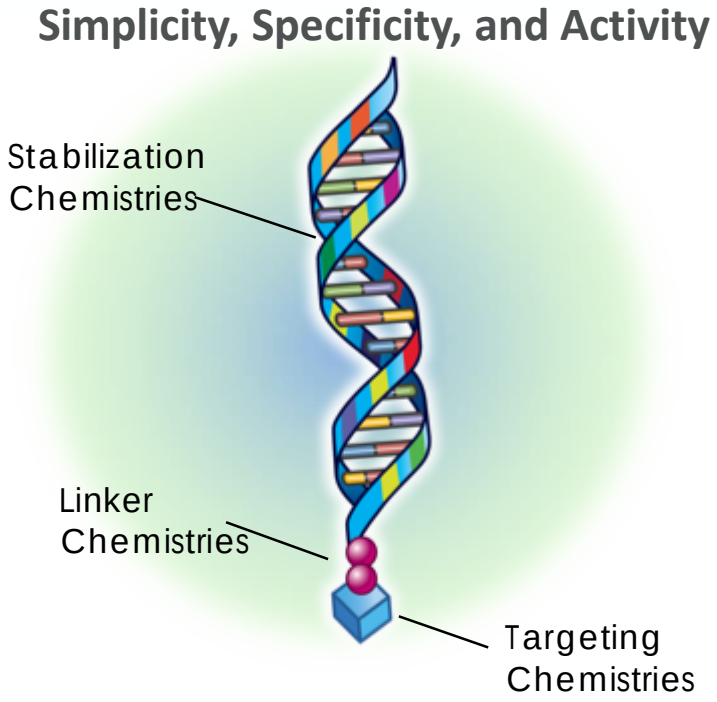
DPC™ (EX-1) and cholesterol-lined RNAi trigger
they are separately targeted to the liver



Targeted RNAi Molecule

TRiM™ platform

Arrowhead RNAi Platform: TRiM™



TRiM™ has rules and algorithms to optimize trigger sequence

- Limit cross reactivity with off target genes
- Maximize activity
- Maximize innate stability
- Rational use and placement of modifying chemistries
- RNAi chemistry insights and expertise have allowed us to see what others have not

Targeted RNAi Molecule

TRiM™ platform

Hepatic siRNA Discovery/Development

Direct conjugation with NAG allows for binding and endocytosis with highly and specifically expressed Asialoglycoprotein receptor (ASGPr) in hepatocytes

Binding of NAG to ASGPr initiates endocytosis

Key Design Elements in Hepatic Platform

- Subcutaneous dosing, monthly or less dosing frequency
- Stable and potent sequences
  - No need for the use of endosome escape moieties
- Suppression of liver production of target protein
- Expectation of wide therapeutic index

What makes an optimal hepatic RNAi gene target

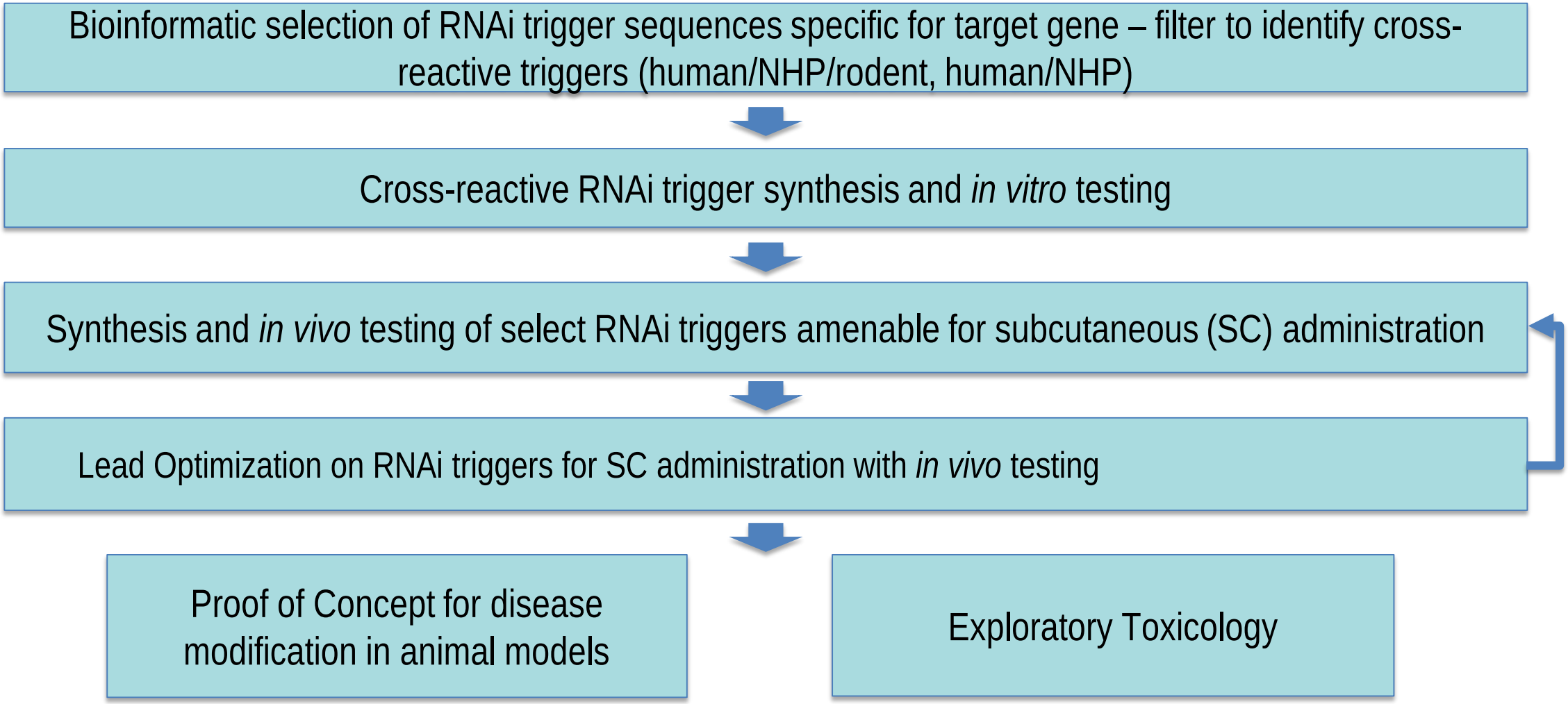
Examine diseases with limited or no treatment options, where knockdown of protein expression is hypothesized to be beneficial to disease initiation/progression

With Hepatocyte-targeted RNAi agents:

- Target is expressed in hepatocytes
  - If not primarily expressed in hepatocytes, hepatocyte expression is key for disease etiology
- Because of ease and familiarity for markets/regulators, we prefer targets that are not easily/well targeted with small molecules or mAbs
- Advantageous if sequence is cross-reactive with human, NHP, and rodent
- Secreted protein advantageous (blood-based monitoring of knockdown)
- Non-secreted protein knockdown can be monitored through liver biopsy or well characterized secondary biomarker
- Disease-relevant animal models available
  - Proof of Concept studies
  - Can be used to estimate level of knockdown required for beneficial effect

2 examples of targets: Factor XII (F12) for thrombotic disease and Alpha 1 antitrypsin (AAT) for AAT-deficiency

Hepatic RNAi agent development funnel



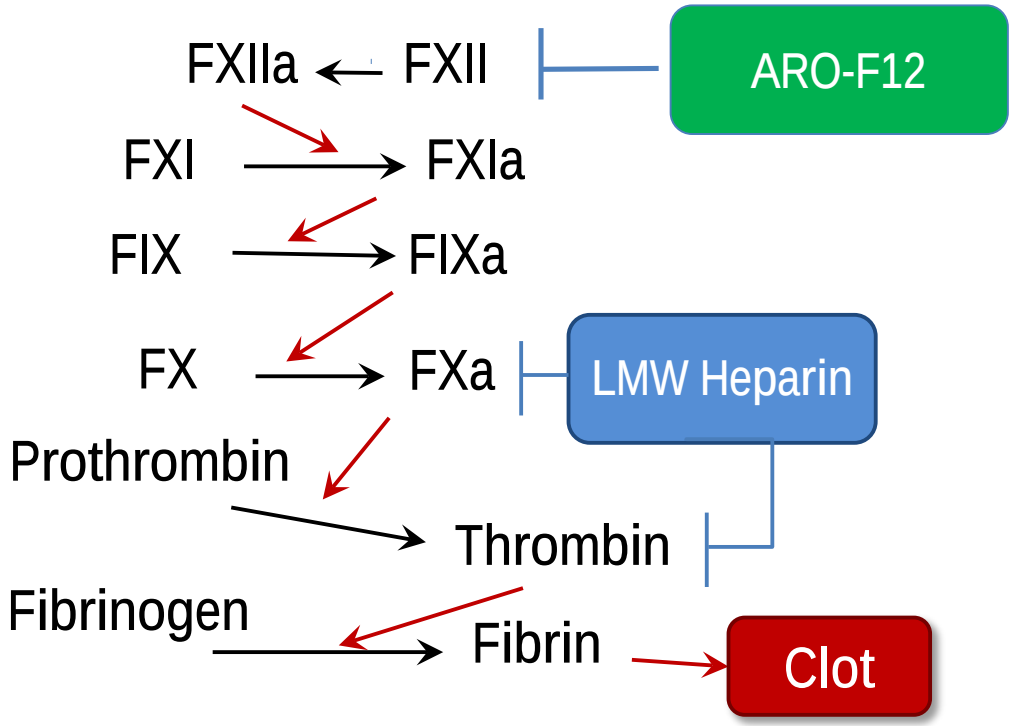
Targeting Factor XII by RNAi as a prophylactic treatment of thrombotic disease

Factor XII (F12)

- Key component of contact activation pathway (thrombosis) and kinin-kallikrein (angioedema)
- Predominantly expressed in the liver; circulates in plasma

F12 inhibition is genetically validated

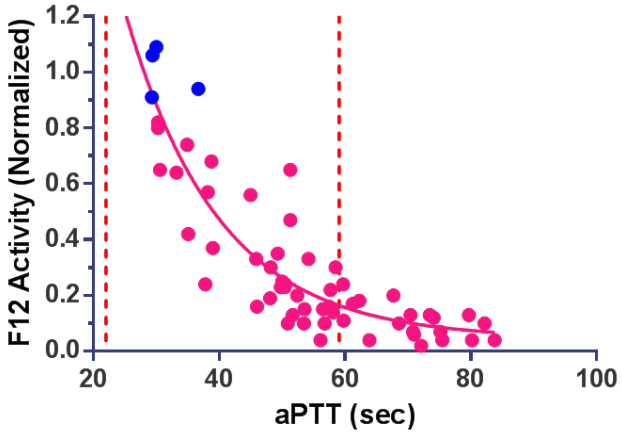
- F12-deficient mice:
  - viable and fertile[4]
  - do not show bleeding defects[4,5]
  - protected from thromboembolic disease (stroke, pulmonary embolism)[5]
- F12 deficiency in humans is *not* associated with either bleeding or thrombotic disorders[1,2,3]



[1] Girolami A. *et al.* (2004) J. Thromb. Thrombolysis 17:139–143
[2] Koster A. *et al.* (1994) Br. J. Haematol. 87:422–424
[3] Zeerleder S. *et al.* (1999) Thromb. Haemost. 82:1240–1246
[4] Pauer, H. U., *et al*. (2004) *Thromb. Haemost*. 92:503
[5] Renne, T. *et al*. (2005) *J. Exp. Med*. 202:271
* Figure modified from Albert-Weissenberger, C., *et al*. (2014) *Front. Cell Neurosci*. 8:345

Measuring F12 knockdown and effects – Serum/Plasma

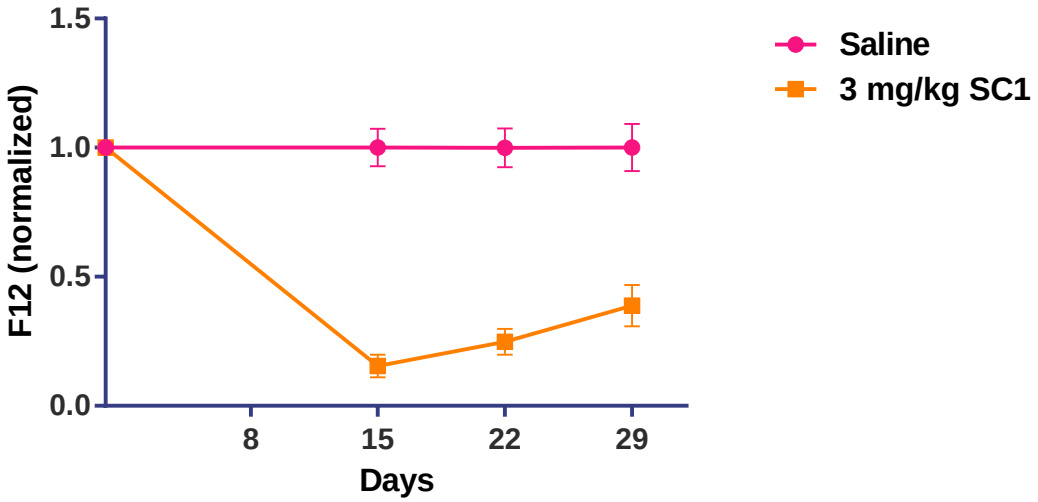
- F12 levels can be measured in mouse and NHP by ELISA-based methods to monitor knockdown
  - RNAi triggers tested are cross reactive between human, NHP and rodent
  - Mouse F12 protein (total and activated) measured by custom AlphaLISA™ (Perkin Elmer)
  - NHP F12 protein measured by human F12 ELISA (cross-reactive with NHP)
- F12 activity can be measured through a modified version of standard coagulation measure activated Partial Thromboplastin Time (aPTT)
- aPTT is inversely correlated with F12 levels (ELISA or Activity)



Examination of modified RNAi triggers in mice

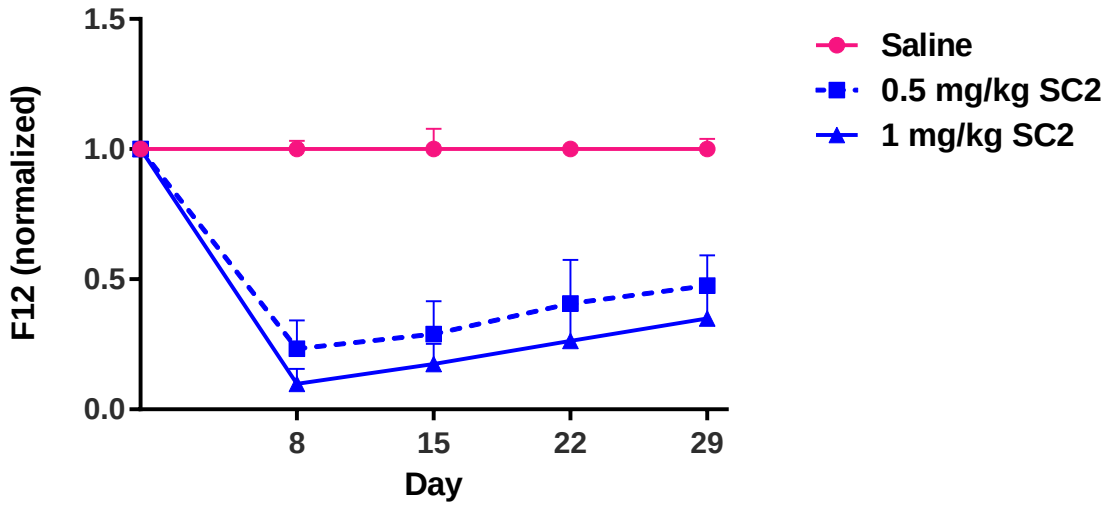
First Generation

Single 3 mg/kg SC dose
n=3/group



Second Generation

Single 0.5 or 1 mg/kg SC dose
n=4/group

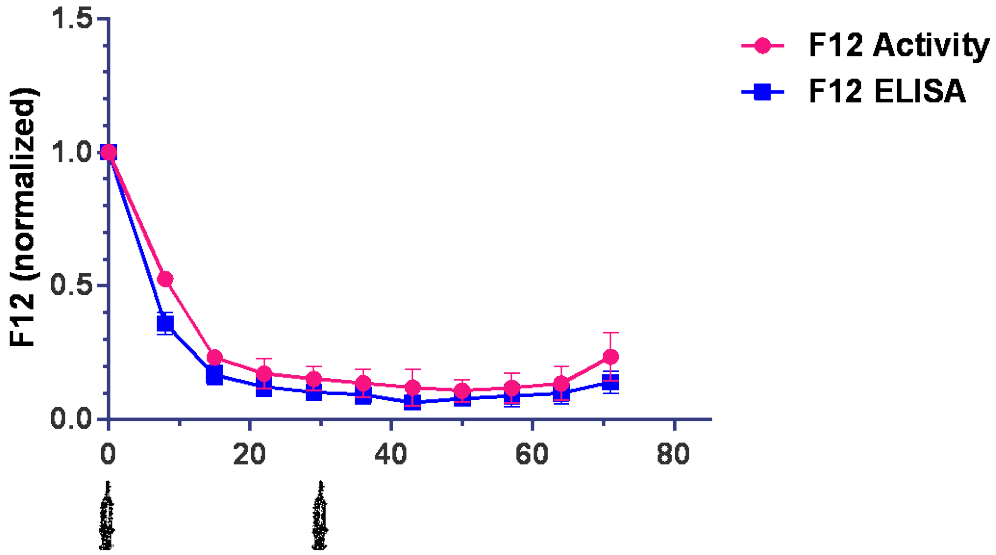


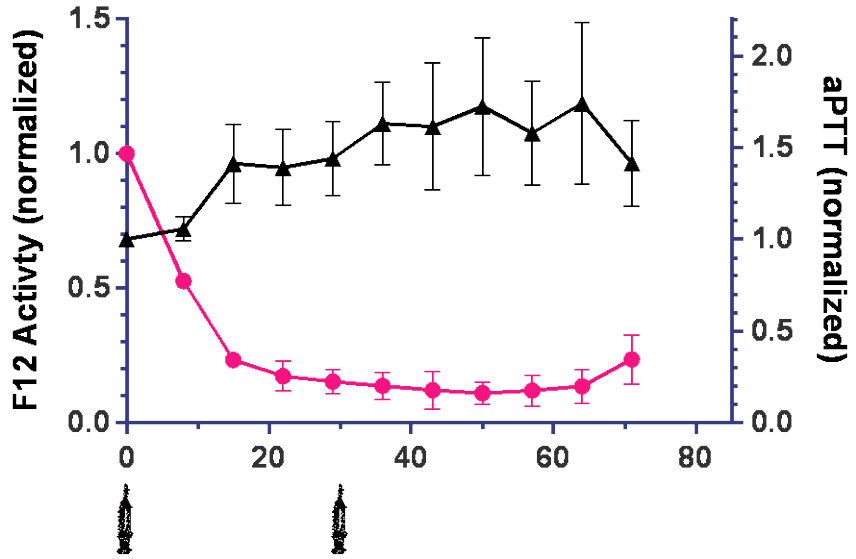
- **Modifications to SC1 to yield SC2 improved knockdown**
  - **85% at 3 mg/kg vs 91% at 1 mg/kg at nadir**
- **Dose response observed with SC2**

Second Generation Triggers – Examination in NHP

- *Initial SC dose of 3 mg/kg SC2, followed by 1.5 mg/kg dose on day 29*

n=2/group

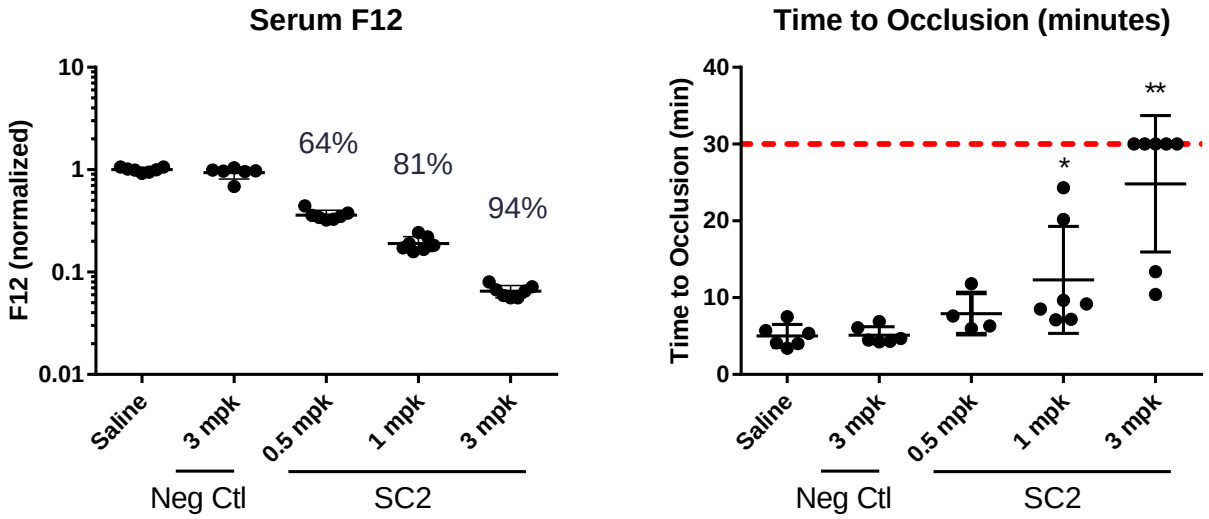




- **Achieved ~90% knockdown of F12 in NHP after the second dose at 1.5 mg/kg with >1 month duration**
- **90% knockdown of F12 activity correlates with significant increase in aPTT**
- **No changes in toxicity markers (clin chem, CBC) after dosing**

Disease-relevant Animal Modeling: Ferric-chloride study

- *Thrombus induced by exposure of carotid artery to $FeCl_3$*
- *Measure time to blood flow occlusion (thrombus formation)*
- *Single SC injection of SC2 or negative control, 2 weeks prior to challenge with $FeCl_3$, n=7/group*

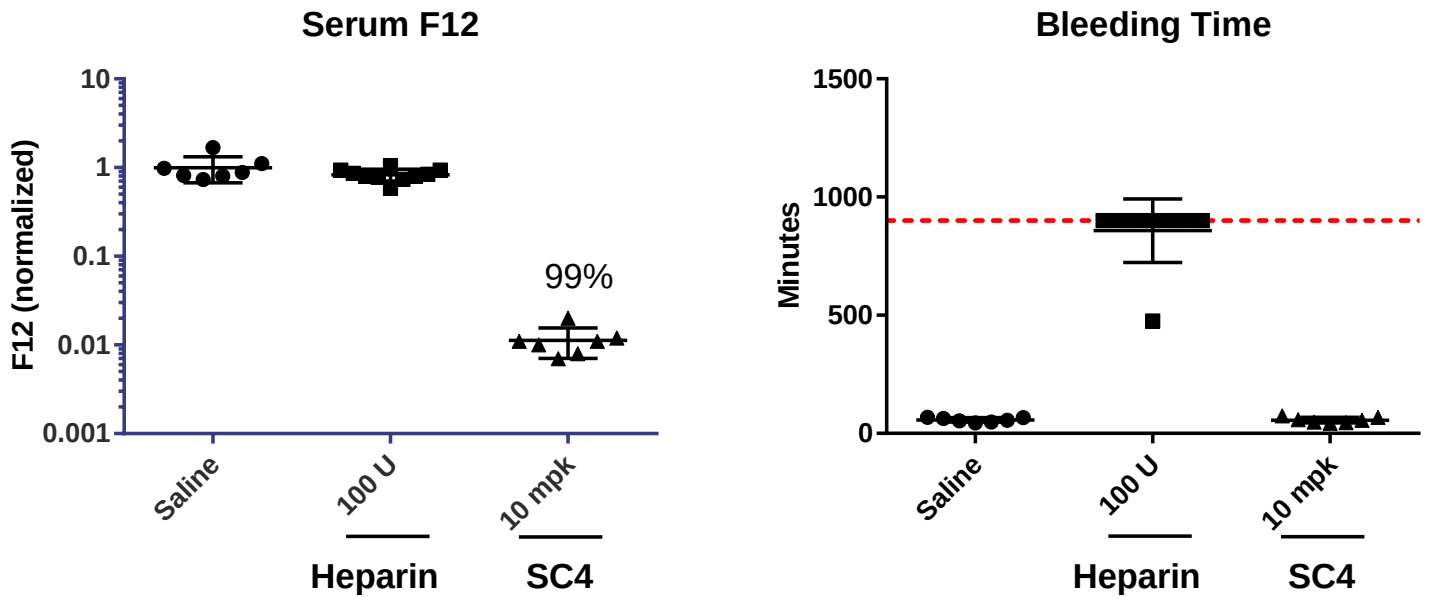


*p<0.02
**p<0.001

- **Dose response observed for inhibition of clot formation**
- **Statistically significant change in occlusion times (p<0.02) observed with >80% knockdown of serum F12**

Bleeding risk assessment through mouse modeling

- *Transverse cut of tail vein, monitor time to clotting*
- *Single dose SC4, 14 days prior to assessment, n=7/group (saline and SC4), n=10/group (heparin)*



- **No increased bleeding observed, even with 99% knockdown of F12 levels**
- **Consistent with F12 $^{(-/-)}$ mice showing no increase in bleeding over wild type controls**

Alpha-1 Antitrypsin Deficiency (AATD)

- AATD is a large scale orphan disease
  - Alpha-1 Foundation estimates 100,000+ in the US
  - Approximately 100,000+ in Europe
- Mutation in AAT gene (Z-AAT) leads to mis-folding of the protein and poor export from hepatocytes: low levels in circulation and accumulation in liver

Pathophysiology

Lung

Tissues susceptible to damage by neutrophil proteases: COPD

Treated with AAT enzyme replacement therapy

Liver

Accumulation of mutant Z-AAT protein can cause cirrhosis and HCC

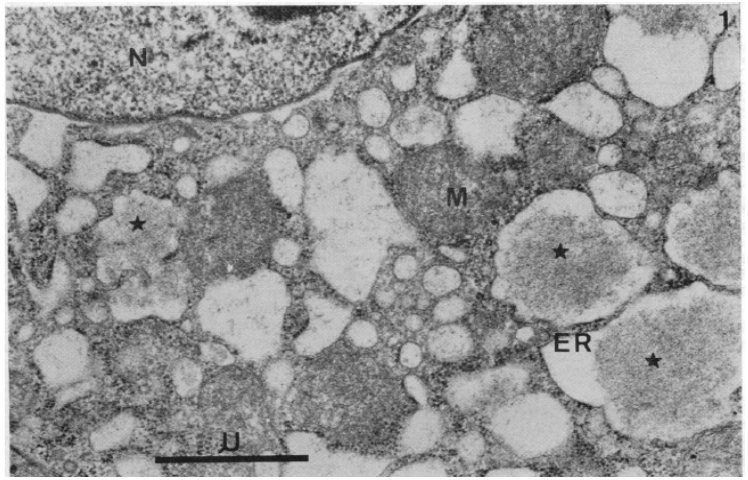
Currently no treatment

RNAi trigger mechanism of action

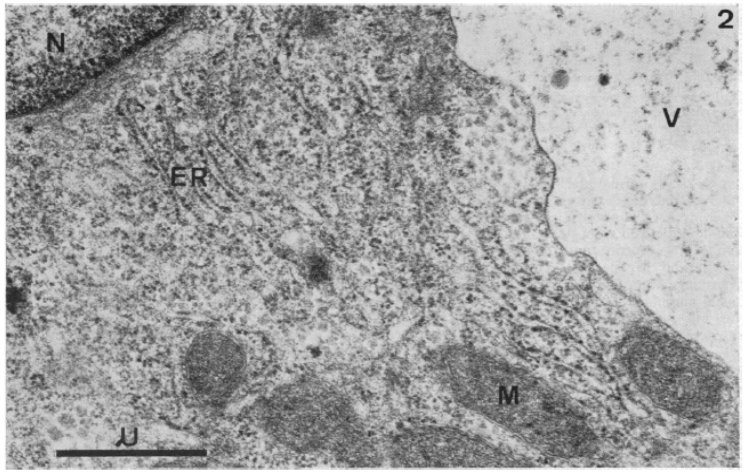
RNAi trigger designed to stop Z-AAT production by silencing AAT gene to:

- Prevent liver accumulation
- Allow clearance of accumulated protein
- Prevent cycles of cellular damage
- Prevent/Reverse progression of liver fibrosis

PiZZ phenotype (diseased)



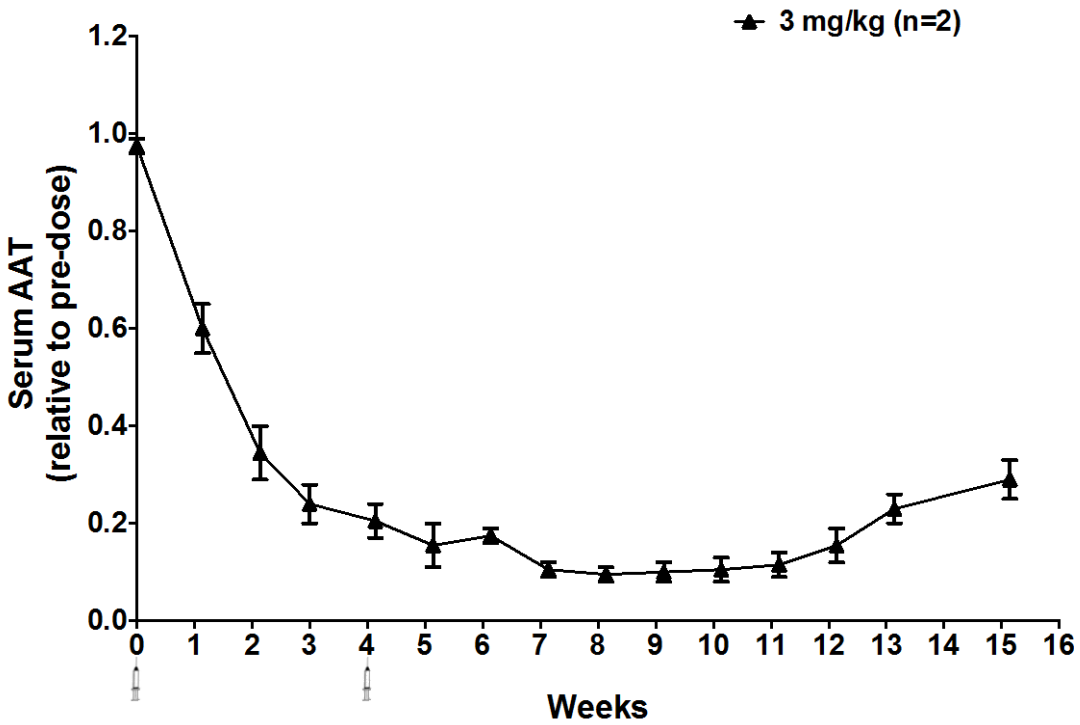
Pi null phenotype (normal)



Feldmann G et al., *Gut* 1975

ARO-AAT Provides Durable AAT knockdown: Multi-dose in NHP, dosed subcutaneously

- 92% maximum serum AAT knockdown achieved in cynomolgus monkeys
- Knockdown sustained for 7+ weeks following second dose



Durable knockdown supports once monthly or less frequent dosing

Exploratory Toxicology: ARO-AAT preliminary safety evaluation

- Based on clinical observations, clinical pathology and limited histopathology evaluations, ARO-AAT was well tolerated in the following non-GLP exploratory toxicity studies:
  - A repeated dose study in rats administered 3 weekly subcutaneous doses at dose levels of 30, 60, 120, and 300 mg/kg
  - An escalating dose study in two cynomolgus monkeys dosed weekly subcutaneously at doses up to and including 300 mg/kg

Key Considerations entering development

- FDA treats RNAi therapeutics like small molecules (CDER)
- Requirements for particular enabling studies may vary based on placement within CDER
- Coordination of required GLP studies can speed transition to clinic

Summary

- Most current RNAi agents specifically target hepatocytes through direct conjugation with NAG (ASGPr1 ligand)
- RNAi agents can be effective in knocking down expression of target protein responsible for rare/orphan diseases (AAT-deficiency) and more common conditions (Factor XII in thrombosis)
- Speed of evaluation of potency/efficacy is increased with human/NHP/rodent cross-reactive RNAi agents
- Knockdown that can be measured by blood biomarker (primary or secondary biomarker) speeds evaluation
  - Non-secreted target protein can be measured by liver biopsy, or other methods
  - ARO-F12 and ARO-AAT displayed durable knockdown of target protein in NHP
- Exploratory toxicology studies of RNAi agents support wide therapeutic index
- RNAi agents are considered as small molecules by regulatory agencies, with respect to requirements

Arrowhead Team