Topical Bioequivalence: Performance Evaluation In Vivo and In Vitro by Skin Stripping and IVPT

Audra L. Stinchcomb, PhD
Professor, University of Maryland School of Pharmacy
Chief Scientific Officer and Founder, F6Pharma
Outline

IVIVC

- Influence of Heat on TDS in vitro (IVPT)
- Influence of Heat on TDS in vivo (humans)

Methods to Evaluate BA for Topical Drug Products

- Tape-stripping
  (Bunge, Guy, Delgado-Charro)
- IVPT (In Vitro Permeation Tests)
Transdermal Delivery Systems (TDS)

- Reservoir Type
  - Release Liner
  - Drug Reservoir
  - Rate-controlling Membrane
  - Adhesive
  - Backing
  - Release Liner

- Matrix Type
  - Drug-In-Adhesive

**Topical Drug Products** (locally-acting)

- A) Cream
- B) Ointment
- C) Gel
- D) Lotion

- Therapy can be interrupted
- Low drug efficiency
- Systemic absorption is intended
- Blood levels ≈ Efficacy
- Occluded applications
- Highly reproducible application techniques
- Sustained and constant delivery
- BA: based on PK endpoint ($C_{\text{max}}$, $t_{\text{max}}$, AUC, etc)

- Therapy can be interrupted
- Low drug efficiency
- Systemic Absorption is NOT desirable
- Local tissue levels ≈ Efficacy
- Open applications
- Highly individualized application techniques
- Short-acting
- No straightforward BA evaluation method

Methods to Determine Bioavailability (BA)

- IVRT (in vitro release test)
- Tape-stripping
- DMD (dermal microdialysis) & dOFM (dermal open flow microperfusion)
- IVPT (in vitro permeation test)
- VCA (Vasoconstriction Assay)
- Clinical Studies
Question

Among so many methodologies, which one is considered the best?
The likely answer may be a combination of the different tests, depending on the drug, product, dosing frequency, tissue target, etc.

➡️ A **Clinical Trial** is the only approval route for generic transdermal & topical products

※ Except VCA for glucocorticoids and Acyclovir Draft Guidance
Active ingredient: Acyclovir

• **Form/Route:** Ointment; Topical
• **Recommended study:** 2 Options: *In Vitro* or *In Vivo* Study
• **I. In Vitro option:**
  • To qualify for the in vitro option for this drug product pursuant to 21 CFR 320.24 (b)(6), under which “any other approach deemed adequate by FDA to measure bioavailability or establish bioequivalence” may be acceptable for determining the bioavailability or bioequivalence (BE) of a drug product, all of the following criteria must be met:
    • i. The test and Reference Listed Drug (RLD) formulations are qualitatively and quantitatively the same (Q1/Q2).
    • ii. Acceptable comparative physicochemical characterization of the test and RLD formulations.
    • iii. Acceptable comparative in vitro drug release rate tests of acyclovir from the test and RLD formulations.
• **II. In Vivo option:**
  • Type of study: BE Study with Clinical Endpoint Design: Randomized, double-blind, parallel, placebo-controlled in vivo

Problems/Limitations of Clinical Studies

- Clinical trials are time-consuming and costly in general

For **Topical** Drug Products:
- Comparative clinical endpoint trials are relatively insensitive
- PK-based clinical trials
  - Amount of drug in blood is very small and difficult to quantify
  - Drug levels in blood can potentially be irrelevant to therapeutic activity at the site of action

  ➡️ Slows development of generic drug products

  ➡️ Burdens ($$$) healthcare system and patients
Objective

• Identify surrogate method(s) which closely simulate the complex mechanism of drug permeation through skin layers and drug retention within skin layers in vivo for selected transdermal and topical drug products

Hypothesis

• IVPT and/or other surrogate methods can predict the performance of transdermal and topical drug products in vivo

Positive Outcomes

• Examine IVPT and other surrogate methods for their relevance in developing IVIVC
• Develop IVIVC models which can predict the in vivo performance of transdermal and topical drug products
## Selected TDS

<table>
<thead>
<tr>
<th></th>
<th>NicoDerm CQ&lt;sup&gt;®&lt;/sup&gt;</th>
<th>Aveva</th>
<th>Duragesic&lt;sup&gt;®&lt;/sup&gt;</th>
<th>Mylan</th>
<th>Apotex</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Patch size (cm&lt;sup&gt;2&lt;/sup&gt;)</strong></td>
<td>15.75</td>
<td>20.12</td>
<td>10.5</td>
<td>6.25</td>
<td>10.7</td>
</tr>
<tr>
<td><strong>Drug content (mg)</strong></td>
<td>Not available</td>
<td>Not available</td>
<td>4.2</td>
<td>2.55</td>
<td>2.76</td>
</tr>
<tr>
<td><strong>Rate/Area (µg/h/cm&lt;sup&gt;2&lt;/sup&gt;)</strong></td>
<td>37</td>
<td>29</td>
<td>2.4</td>
<td>4.0</td>
<td>2.3</td>
</tr>
<tr>
<td><strong>Inactive ingredients</strong></td>
<td>Ethylene vinyl acetate-copolymer, polyisobutylene and high density polyethylene between clear polyester backing</td>
<td>Acrylate adhesive, polyester, silicone adhesive</td>
<td>Polyester/ethyl vinyl acetate backing film, polyacrylate adhesive</td>
<td>Dimethicone NF, silicone adhesive, polyolefin film backing</td>
<td>Isopropoyl myristate, octyldodecanol, polybutene, polyisobutene adhesive</td>
</tr>
</tbody>
</table>
Skin Preparation

- Fresh human skin samples obtained post abdominoplasty surgery
- Dermatomed to ~250 microns
- Frozen until the day of experiment

Image obtained from the Stinchcomb Lab’s SOP
IVPT Setup

- In-line flow-through diffusion system
- Permeation area of 0.95 cm²

Images from www.ibric.org and www.permegear.com
Temperature Monitoring

- Infrared Thermometer

Human Skin Data

Mean ± SD from 2 donors with n=4 per each donor
Clinical Study Designs – Nicotine

- A four-way crossover PK study in 10 adult smokers (two nicotine TDS)

- Residual amount of nicotine in TDS was analyzed

- Temperature of skin surface was monitored throughout the study
Preliminary: IVPT Temporary (1h) Heat Effect

Human Skin Data

Mean ± SD from 4 donors for Heat and 2 donors for No Heat with n=4 per each donor
Heat application and Temperature Monitoring

- Kevlar sleeve with an opening to expose TDS, while protecting skin from other areas
- Thermometer probe adjacent to TDS
- Pre-heated heating pad
- ACE™ Bandage to ensure good contact between TDS and heating pad

Image from http://static.coleparmer.com/large_images/91427_10_5.jpg
Nicotine PK profiles

Mean ± SD from 10 Subjects

- Serum samples analyzed by S. Thomas
- LC-MS/MS method developed by I. Abdallah
IVIVC – Heat Effect on Nicotine TDS

- p > 0.05 between IVPT and clinical study results
- IVPT can predict heat effect on TDS in vivo
IVIVC – Absence of Heat

- At steady-state, $R_{in} = R_{out}$
- $R_{in} (\text{ng/hr}) = J (\text{ng/cm}^2/\text{hr}) \times \text{Area (cm}^2\text{)}$
- $R_{in} = CL \times C_{ss}$
- $CL = 72000 \text{ mL/h}$

- $p > 0.05$ between predicted and observed $C_{ss}$
- IVPT can predict the performance of TDS in vivo
Evaluation of the relative bioavailability of topical drug products by various surrogate methods and development of IVIVC

Hypothesis: Well-designed and optimized surrogate method(s) can be used to predict bioavailability and performance of topical drug products \textit{in vivo}. 
Approach

1) IVPT experiments will be done with a focus of investigating effects of different experimental conditions and techniques involved in IVPT
   - Dose amount selection
   - Dose administration techniques & rubbing effect
   - Multiple-dosing designs

2) Other surrogate methods which evaluate the drug retention within skin layers will be investigated and performed
   - Biosensors
   - Infrared Spectroscopy
   - DPK—Tape stripping

3) Obtained data through experiments, literature, and collaborators will be compared to determine which method(s) best predict the performance of topical drug products in vivo
Dermatopharmacokinetics (DPK)
Tape-stripping

Dr. Annette Bunge, CO School of Mines
Univ. of Bath--Dr. Richard Guy
Dr. Begoña Delgado-Charro
Assess BE using DPK: *Tretinoin gel 0.025%*

Comparing Products B and C to Product A (RLD)

Mimic oral BE assessment

Compare AUC & $A_{\text{max}}$

*Pershing et al., J Am Acad Dermatol 2003*
Assess BE using DPK: *Tretinoin gel 0.025%*

Comparing Products B and C to Product A (RLD)

Reach same BE conclusion using measurements at individual uptake & clearance times

Alternate metrics

Number of detectable measurements are indicated on data points if less than 49 total

*Data from Pershing; N’Dri-Stempfer et al., Pharm Res, 2008
Improved protocol developed for FDA

- 4 treatment sites / product
  - 1 uptake time & 1 clearance time
  - Duplicate determinations at each time
- Remove unabsorbed drug using isopropyl alcohol wipes
- Total drug amount = Drug from all tapes (no tapes discarded)
- Determine \( \sim all \) drug in SC by removing nearly all of the SC
  - Remove SC until TEWL > 8 x (TEWL before stripping)
  - At least 12 tape strips, but not more than 30 tape strips
  - Tape stripping area < drug application area (control both areas)
- Assess BE of uptake and clearance separately
- Analyze tape strips in groups to optimize analytical sensitivity
- Compare within each subject and then across subjects
Demonstrating the improved protocol

• Econazole nitrate 1% cream
  – Antifungal – SC is target site

• Compare 2 generic products to RLD
  – Both products Q1 and Q2 equivalent

• 6 h uptake time & 17 h clearance time
  – Chosen based on pilot study results, and
  – Convenience for subjects and operator
Econazole in SC: *Average drug amounts*

![Graph showing drug amounts for different formulations.](image)

A = Clay-Park (Generic)
B = Ortho (RLD)
C = Taro (Generic)

N’Dri-Stempfer et al., Pharm Res, 2009
Econazole in SC: *BE assessment*

Comparing Products A and C to Product B

Both A and C were conclusively BE with B after uptake and clearance, evaluated separately.

N’Dri-Stempfer *et al.*, Pharm Res, 2009
Econazole in SC: BE assessment

Comparing Products A and C to Product B

- Both A and C were conclusively BE with B after uptake and clearance, evaluated separately.
- Only 168 sites (3 products in 14 subjects with replicates for uptake & clearance = 3 x 14 x 2 x 2)
- Compare with 1176 sites in tretinoin gel study (3 products in 49 subjects with 8 sites/product = 3 x 49 x 8)

N’Dri-Stempfer et al., Pharm Res, 2009
Diclofenac: *Average drug amounts in SC*

- **V** = Voltaren
- **S** = Solaraze
- **P** = Pennsaid

ERROR BARS, 90% CI of the log mean

6 h uptake vs 17 h clearance

**Formulations**

**Drug Amount (µg)**

- **V**
- **S**
- **P**

**Drug Amount (µg)**

- **V**
- **S**
- **P**

**Color Legend**

- **Blue**
- **Red**

**n = 12**

**n = 12**
Diclofenac: BE ratio of drug amounts in SC

Comparing Products V and P to Product S

V = Voltaren
S = Solaraze
P = Pennsaid

Error bars, 90% CI of the log mean
Importance of Dose – Voltaren® gel

<table>
<thead>
<tr>
<th>Dose</th>
<th>J_{max} ± SD (µg/cm²/h)</th>
<th>T_{max} (h)</th>
<th>Cumulative Amount ± SD (µg/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 mg/cm²</td>
<td>2.29 ± 0.57</td>
<td>8</td>
<td>24.91 ± 3.38</td>
</tr>
<tr>
<td>10 mg/cm²</td>
<td>0.48 ± 0.19</td>
<td>2</td>
<td>6.10 ± 0.61</td>
</tr>
</tbody>
</table>

Mean ± SD (n=3) Yucatan Miniature Pig Skin
Importance of Dose – Pennsaid® 2%

<table>
<thead>
<tr>
<th></th>
<th>Flux (\mu g/cm^2/h)</th>
<th>Cumulative Amount (\mu g/cm^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 mg/cm(^2)</td>
<td>J(_{\text{max}}) ± SD (4.05 ± 1.06)</td>
<td>T(_{\text{max}}) (24)</td>
</tr>
<tr>
<td>5 mg/cm(^2)</td>
<td>J(_{\text{max}}) ± SD (4.59 ± 1.09)</td>
<td>T(_{\text{max}}) (6)</td>
</tr>
</tbody>
</table>
Dose Administration Techniques

• Highly variable among labs, researchers, and patients
  • Methods of dispensing formulation
  • Duration of rubbing
  • Force used for rubbing
  • Loss of formulation during rubbing

• Need a reproducible and clinically-relevant technique

Image from http://www.telegraph.co.uk/expat/expatlife/10441983/Pale-and-interesting.html
Four Acyclovir Cream Products

(Mean ± SE, n= 6 donors with 4-7 replicates per donor for Reference and Test products and n = 2 donors with 3-4 replicates per donor for Products A and B)
$J_{\text{max}}$ and the total amount of acyclovir permeated over 48h between Reference and Test

Comparisons of products (Mean ± SE, n= 6 donors with 4-7 replicates per donor)
Dose Administration Techniques

Positive Displacement Pipette
- Quick, convenient, low variability
- Minimal formulation loss
- Lack of rubbing effect

Inverted HPLC Vial
- Time-consuming, more variability
- Some formulation loss
- Simulates clinically-relevant rubbing effect
Dose Administration Techniques

[Graph 1]
U.S. Zovirax Cream
Flux (mg/cm²h)
Positive Displacement Pipette
Inverted HPLC Vial
Ex vivo human skin
Mean ± SD (n=4 for each technique)

[Graph 2]
U.S. Zovirax Cream
Cumulative Amount (g/cm²)
Positive Displacement Pipette
Inverted HPLC Vial
Preliminary: Dose Administration Techniques

**Pennsaid® 2% (more viscous)**

- Positive Displacement Pipette
- Inverted HPLC Vial

**Pennsaid® 1.5%**

- Positive Displacement Pipette
- Inverted HPLC Vial

Orange Arrow: dosing (~5 mg/cm² of formulation)

Mean ± SD (n=3-4)
Yucatan Miniature Pig Skin
Conclusions

• Limitations of clinical studies for topical drug products highlight the needs for developing surrogate methods to evaluate BA
• The IVPT method was able to discriminate the Reference and Test acyclovir products, based on $J_{\text{max}}$ and the total amount of acyclovir permeated over 48h
• In order for surrogate methods to be recognized by regulatory agencies, they need to be able to produce data that is reliable, low in variability and relevant to clinical settings
• Each method will have its own challenges to overcome
  – Needs to be addressed in order to evaluate IVIVC
The views expressed in this presentation do not reflect the official policies of the U.S. Food and Drug Administration or the U.S. Department of Health and Human Services; nor does any mention of trade names, commercial practices, or organization imply endorsement by the United States Government.
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Back Up
Skin Structure

Images from http://classes.midlandstech.edu/carterp/courses/bio225/chap21/ss1.htm and http://www.scienceprog.com/skin-structure/
Percutaneous Absorption (Transepidermal route)

- Dissolution of drug in vehicle
- Passive diffusion of drug out of its vehicle to skin surface
- Drug partition into SC
- Drug diffusion through SC
- Drug partition into viable epidermis
- Drug diffusion through viable epidermis
- Drug partition into dermis
- Drug diffusion through dermis
- Drug partition into blood capillary
- Systemic uptake
Factors Affecting Percutaneous Absorption

Drugs

- M.W. < 500 Dalton
- Suitable log $P_{\text{oil/water}}$
  - High log $P$ (very lipophilic) -> too much retention in the skin
  - Low log $P$ (very hydrophilic) -> difficult to cross the SC
- Unionized molecules cross SC faster

Vehicle/Formulation

(Inactive Ingredients)

- Partition coefficient, $k_{\text{membrane/vehicle}}$
- pH

Skin

- Hydration level
- Age
- Gender
- Race
- Species
- Disease state

Environmental factors

- Humidity
- Occlusion
- Heat (high temperature)

Influence of Heat on Percutaneous Absorption

1) ↑ Diffusivity of Drug from its Vehicle

+ Heat ➜
Influence of Heat on Percutaneous Absorption

2) ↑ Fluidity of Stratum Corneum Lipids

Very regular, Ordered structure

Less tightly packed, Hydrocarbon tails Disordered.

https://biochemistry3rst.wordpress.com/tag/phosphodiate/
Influence of Heat on Percutaneous Absorption

3) \( \uparrow \) Cutaneous Vasodilation

Body temperature regulation

When the body is too hot
Temperature Monitoring

- Early Heat - In Vivo
- Late Heat - In Vivo
- Early Heat - In Vitro
- Late Heat - In Vitro
Objective: to investigate whether residual patch analysis can be a potential surrogate method for predicting the extent of drug absorption from TDS.

Extraction solvent, volume of extraction solvent, and the duration of extraction needs to be tested and optimized for each TDS.

For nicotine TDS, the total drug content is unknown. Therefore, unused patch was extracted using the selected extraction method.

\[
\text{Amount remaining after IVPT} \times 100 = \% \text{ drug remaining}
\]

\[
\frac{\text{Amount extracted from unused patch} - \text{Amount extracted after IVPT}}{\text{Amount extracted from unused patch}} \times 100 = \% \text{ drug remaining}
\]
Nicotine Residual TDS Extraction

\[ p > 0.05 \text{ between early vs. late heat} \Rightarrow \text{paralleled the results from IVPT} \]

\[ p > 0.05 \text{ for all treatment groups between IVPT and Residual Patch Analysis Data} \]
Evaluation of the relative bioavailability of nicotine and fentanyl TDS under the influence of heat in human subjects and development of IVIVC

Hypothesis: TDS with different formulations behave differently under the influence of heat \textit{in vivo}, which can be predicted by the \textit{in vitro} permeation tests.

Approaches:
1) A crossover pharmacokinetic clinical study, with study designs mimicking the \textit{in vitro} experimental designs
   - Sample analysis by a validated LC-MS/MS method
2) Analysis of residual drug content in patch after patch removal from clinical study
   - Sample analysis by a validated HPLC method
3) Evaluate relationships between \textit{in vitro} and \textit{in vivo} data
4) Develop IVIVC models in which IVPT data can predict the performance of TDS \textit{in vivo}
Nicotine Residual TDS Extraction

\[ \% \text{Nicotine Remaining} \]

\[ \text{NicoDerm CQ - Early Heat} \]
\[ \text{NicoDerm CQ - Late Heat} \]
\[ \text{Aveva - Early Heat} \]
\[ \text{Aveva - Late Heat} \]

\[ \text{Mean ± SD} \]

\[ p > 0.05 \text{ between early vs. late heat} \]

\[ \Rightarrow \text{paralleled the results from } in \ vivo \text{ PK and IVPT} \]
Preliminary: IVIVC – Residual TDS Analysis

- $p > 0.05$ between IVPT and clinical study results
Dermatopharmacokinetics (DPK, tape-stripping)

- Measures amount in SC measured in time after application and cleaning
- Analysis of PK parameters: AUC (area under amount in SC versus time curve), $T_{\text{max}}$, $C_{\text{max}}$
  - e.g., Pershing & Franz tretinoin studies (FDA guidance 1998-2002)
  - Complicated and same BE answer is achievable with a simpler 1-uptake and 1-clearance analysis (Bunge and Guy et al.)
Dermatopharmacokinetics (DPK, tape-stripping)

- four improvements made by Bunge and Guy et al. to the original DPK methodology
  - improved cleaning of excess drug from each test site at the end of the uptake period
  - determination and inclusion of drug from the first two tape strips in the reported total amount taken up into the SC
  - an increase in the number of tape strips collected combined with a method to ensure reliable collection of nearly all the SC
  - improved control of the tape strip sampling area within the drug application area (to avoid edge effects)
In Vitro Skin Permeation Study (IVPT)

Automated In-Line Flow Through System

Standard Franz cell

www.permegear.com
Historical IVIVC for Bioequivalence

• Previous examples of IVIVC*
  – IVPT compared with total absorption after 1 application in humans
  – Studied same drug products with same methodology (harmonization)
  – Measured the same metric (usually total % absorbed)
  – \textit{In vivo} and \textit{in vitro} results were the same
  – Relatively robust set of data demonstrates that \textit{in vitro} measurements are good representations of the \textit{in vivo} system
  – Rate and extent are coupled in the total % absorbed (i.e., rate and extent are not determined separately, 1 time point)

• Total % absorbed is not typically measured by other \textit{in vivo} methods; for example:
  – Pharmacokinetic (i.e., blood levels)
  – DPK
  – We will be incorporating this metric with DPK and PK

*also Chapter 9 in Transdermal and Topical Drug Delivery, Benson ed., Lehman et al. 2012