An Ultrasonic Story: The Effect of External Forces on Peripheral Catheter Movement Inside the Vein

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Learning Objectives

• Quantify the movement of standard PIVCs within the vein when an external force is applied
• Discuss how the movement of PIVC within the vein may contribute to catheter failure
• Explore how preventing excessive movement can prevent catheter failure and complications
Most Common Procedure Worldwide

• PIVs are the most frequently used invasive device in hospitals (Alexandro 2018)
• Up to 90% of patients require a PIV during their hospital stay (Steere 2019)
• 350M IV catheters are sold in the US each year (Steere 2019)
• PIVC catheter dwell times are 15 times higher than CVADs (Zingg 2009)
• Up to 63% of PIVCs fail prior to completion of therapy (Helm 2015)
The Reality of IV Restarts

• The average hospital length of stay is 5.5 days (OECD)
• The average lifespan of a PIVC is 1-4 days (OECD 2023).
• Poor outcomes (Kache 2020):
  • Multiple catheters during their hospitalization
  • Unnecessary procedures
  • Increased Costs
  • Poor Patient Satisfaction
Complications Leading to Failure of PIVC

Accepted, but Unacceptable (Helm 2015)
• Infiltration: erosion or penetration of the PIVC through the vein wall
• Dislodgement: PIVC pulls out of the patient’s vein
• Phlebitis: vein irritation
• Occlusion: build-up of biological material causing the PIVC to occlude
• Infection: poor insertion technique and micropistoning

<table>
<thead>
<tr>
<th>Mode of Peripheral IV Catheter Failure</th>
<th>Range</th>
<th>Mean</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catheter-related phlebitis</td>
<td>0.1%-63.3%</td>
<td>15.4%</td>
<td>9.0%</td>
</tr>
<tr>
<td>Catheter infiltration</td>
<td>15.7%-33.8%</td>
<td>23.9%</td>
<td>22.2%</td>
</tr>
<tr>
<td>Catheter occlusion/mechanical failure</td>
<td>2.5%-32.7%</td>
<td>18.8%</td>
<td>22.8%</td>
</tr>
<tr>
<td>Catheter dislodgment</td>
<td>3.7%-9.9%</td>
<td>6.9%</td>
<td>7.0%</td>
</tr>
<tr>
<td>Catheter-related infection</td>
<td>0.0%-0.44%</td>
<td>0.2%</td>
<td>0.2%</td>
</tr>
</tbody>
</table>

*Summary of data from Tables 4 to 8.
PIVC Movement Inside the Vein

0-pound pull force
Force released and PIVC finds new resting position

1-pound pull force
External force applied to the line

4-pound pull force
Maximum skin tenting occurs based on force
Vein Damage Isn’t Visible from the Outside

• Secured externally, the catheter is not stable internally.

• Theory:
  • Movement of the catheter within the vein wall may be associated with vein wall damage
18 ga in Median Cubital
The glycocalyx:

- Layer of dense and uneven grass-like substance covering the surface of vascular endothelial cells
- Gel-like meshwork creating a physical barrier
A prospective sonographic evaluation of peripheral intravenous catheter-associated thrombophlebitis
The Journal of Vascular Access 2021 Mielke et al

- 62 catheters daily u/s assessment
- 87.10% (54) developed catheter-related thrombosis
- 40.74% (22) symptomatic.
- Increased likelihood of thrombophlebitis.
  - angle of the distal tip of the catheter against vein wall $\geq 5^\circ$
  - catheter diameter $> 1/3$ vein diameter
Early recognition of peripheral intravenous catheter failure using serial ultrasonographic assessments
A. Bahl et al Plos one 2021 Vol. 16 Issue

- PIVC failure at:
  - 46 hours - detected by ultrasound
  - 67 hours – detected by the bed side clinician (P = < 0.0001).
  - Complication begins 21 hours prior to nurse detection
What of the effects of catheter contact with endothelium cells (In Vitro)

Short Peripheral Catheter Thrombophlebitis
- Measured inflammation response to pressure and time
- Demonstrated a significantly increased secretion
  - with an increased weights ($p \leq 0.015$)
  - and incubation time
- The research showed a relationship between induced mechanical compression and the pathogenesis of SPCT.
- Minimizing the contact between the catheter and the vein wall will mitigate the pressure acting on the endothelium
  - Reducing the secretion of inflammatory factors
  - Lessen the incidence of SPCT.

Evaluating the Impact of External Forces on Peripheral Intravenous Catheter Movement: Insights from Dynamic Ultrasound Imaging

• **Primary objective**
  - To examine the change in the movement of the PIVC by applying external pull forces
    - 4, 5, and 6 lbs.
    - Randomized and blinded pull forces
    - PIVC length measured
      - With no external force applied
      - With external force applied

• **Secondary objectives:**
  - Explore predictors of catheter movement related to patient characteristics
  - Describe PIVC tip movement in relationship to the vein wall with a pull force of 4 lb
Design, Setting, Recruitment

• Prospective, blinded trial conducted under the approval of Advarra Institutional Review Board as a nonsignificant risk device study.

• Data collection: March 2, 2023, in an outpatient lab

• Recruitment: 13 healthy volunteer participants
  • 18 years of age or older
  • Alert and oriented
  • Excluded: using steroids and/or anti-coagulation medications, having habitual IV drug use, having an allergy to a skin adhesive

• First study to establish PIVC movement data with external forces
Securement and Stabilization of PIVC

- Securement used:
  - A drop of cyanoacrylate glue was placed at the PIVC insertion point
  - Large borderless 6cm by 7cm adhesive dressing applied
  - Gum mastic applied to the whole area underneath the dressing

- 20 gauge 1.25” PIVC was aseptically placed.
Imitating a Clinical Pull Force

- Secured arm with Velcro straps
- Fixture was mounted with a sliding mechanism
  - Pull force of 4, 5 or 6 lbs.
  - 20-degree angle pulling distally
- Force gauge applied
Why 4, 5, & 6 lb Pull Forces?

- Pull forces of < 4 lbs. were likely associated with activities of daily living.
- Pull forces > 4 lbs. were likely harmful forces leading to PIV failure.
- Securement dressings tend to dislodge due to a pull force as low as 6 lb.

Measurements

Catheter length with and without external force

Catheter tip angle
Catheter Tip Interaction with Vein Wall with Movement

• 4 lbs of pull force.
• Two reviewers
• Sorted by:
  • Movement without vein wall contact (yes/no)
  • Catheter tip contacts vein wall transiently during movement, but not in final resting position (yes/no)
  • Catheter tip contacts vein wall with continued contact in resting position (yes/no)
Participant Characteristics

- 13 participants were enrolled, however, 2 were excluded and not included in the final analysis
  - 1 participant had kinking of the IV after the first pull and dropped out
  - 1 participant did not have a vein that met the study criteria

- Demographics:
  - Average age 40
  - 55% male
  - 90% were white

<table>
<thead>
<tr>
<th>Variable</th>
<th>N=11</th>
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<tbody>
<tr>
<td>Age (yr.)</td>
<td>40.36±16.10</td>
</tr>
<tr>
<td>Gender</td>
<td>Gender</td>
</tr>
<tr>
<td>Female</td>
<td>5 (45.45)</td>
</tr>
<tr>
<td>Male</td>
<td>6 (54.55)</td>
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<tr>
<td>Ethnicity</td>
<td>Ethnicity</td>
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<tr>
<td>White</td>
<td>10 (90.91)</td>
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<tr>
<td>Asian</td>
<td>1 (9.09)</td>
</tr>
<tr>
<td>Height (in)</td>
<td>67.82±5.02</td>
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<tr>
<td>Weight (lb.)</td>
<td>187.36±63.26</td>
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<tr>
<td>Body mass index (kg/m²)</td>
<td>28.25±8.22</td>
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<tr>
<td>Diabetes</td>
<td>2 (18.18)</td>
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<tr>
<td>Current Smoker</td>
<td>4 (36.36)</td>
</tr>
<tr>
<td>Vein Diameter (mm)</td>
<td>3.61±1.06</td>
</tr>
<tr>
<td>Vein Depth (mm)</td>
<td>5.06±1.71</td>
</tr>
</tbody>
</table>
Results

• This study included 11 healthy participants, predominately white (90%), 40 years of age on average and a slight majority male (55%).

• Randomly applied pull forces of 4, 5, and 6 lbs results:
  • A range of PIVC movement from 1.3 to 8.1 mm.
  • The overall mean PIVC movement was 4.65±1.88, 3.88±2.28, 5.25±2.06 for 4 lbs, 5 lbs and then 6 lbs respectively
  • There was no statistical differences in the length of movement of the PIVC among the three applied forces
PVC Movement

<table>
<thead>
<tr>
<th>Pull Force Placed on the PIV Line</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 lb</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>Catheter Length Movement (mm):</td>
</tr>
<tr>
<td>Mean ± SD</td>
</tr>
<tr>
<td>Minimum</td>
</tr>
<tr>
<td>Maximum</td>
</tr>
<tr>
<td>Range</td>
</tr>
<tr>
<td>Interquartile Range</td>
</tr>
</tbody>
</table>

- No differences in PVC movement between the forces
Potential Predictors of Catheter Movement

- No predictors of PIVC movement

There were no statistically significant differences in PIVC movement between each of the forces.

<table>
<thead>
<tr>
<th>95% CI for OR</th>
<th>Independent Predictor</th>
<th>B</th>
<th>SE</th>
<th>P</th>
<th>OR</th>
<th>Lower</th>
<th>Upper</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>4lb. Of pull force</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (yr)</td>
<td>.017</td>
<td>.039</td>
<td>.671</td>
<td>.145</td>
<td>-.070</td>
<td>.104</td>
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<tr>
<td>Gender</td>
<td>-.193</td>
<td>1.20</td>
<td>.875</td>
<td>.054</td>
<td>-2.61</td>
<td>2.52</td>
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<tr>
<td>Baseline Catheter Length (mm)</td>
<td>0.46</td>
<td>.167</td>
<td>.789</td>
<td>.092</td>
<td>-.332</td>
<td>.425</td>
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</tr>
<tr>
<td>Body Mass Index (kg/m2)</td>
<td>-.025</td>
<td>.076</td>
<td>.749</td>
<td>-.109</td>
<td>-.197</td>
<td>.147</td>
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<tr>
<td>Current Smoker (Yes/No)</td>
<td>-.818</td>
<td>.121</td>
<td>.517</td>
<td>.219</td>
<td>-3.56</td>
<td>1.93</td>
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<tr>
<td>5lb. Of Pull Force</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Age (Yr.)</td>
<td>-.070</td>
<td>.041</td>
<td>.126</td>
<td>-.490</td>
<td>-.163</td>
<td>.024</td>
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<tr>
<td>Gender</td>
<td>1.61</td>
<td>1.36</td>
<td>.265</td>
<td>.368</td>
<td>-1.46</td>
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<tr>
<td>Baseline Catheter Length (mm)</td>
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<td>.230</td>
<td>.675</td>
<td>-.143</td>
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<tr>
<td>Body Mass Index (kg/m2)</td>
<td>-.044</td>
<td>.091</td>
<td>.646</td>
<td>-.157</td>
<td>-.251</td>
<td>.163</td>
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<tr>
<td>Current Smoker (yes/no)</td>
<td>-2.13</td>
<td>1.33</td>
<td>.144</td>
<td>-.471</td>
<td>-5.14</td>
<td>.878</td>
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<tr>
<td>6 lb. of Pull Force</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Age (Yr.)</td>
<td>-.018</td>
<td>.042</td>
<td>.688</td>
<td>-.137</td>
<td>-.113</td>
<td>.078</td>
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<tr>
<td>Gender</td>
<td>-.100</td>
<td>1.31</td>
<td>.941</td>
<td>-.025</td>
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<td>2.87</td>
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<tr>
<td>Baseline Catheter Length (mm)</td>
<td>-.083</td>
<td>.205</td>
<td>.695</td>
<td>-.134</td>
<td>-.547</td>
<td>.381</td>
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<tr>
<td>Body Mass Index (kg/m2)</td>
<td>-.026</td>
<td>.083</td>
<td>.761</td>
<td>-.104</td>
<td>-.214</td>
<td>.162</td>
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<tr>
<td>Current Smoker (yes/no)</td>
<td>-.361</td>
<td>1.36</td>
<td>.796</td>
<td>-.088</td>
<td>-3.43</td>
<td>2.70</td>
<td></td>
</tr>
</tbody>
</table>
Catheter Tip Interaction with Vein Wall with Movement

- 4 lbs Pull force
- Two Reviewers
- Sorted by:
  - Movement without vein wall contact (yes/no)
  - Catheter tip contacts vein wall transiently during movement, but not in final resting position (yes/no)
  - Catheter tip contacts vein wall with continued contact in resting position (yes/no)
Catheter Tip Interaction with Vein Wall

- Movement without vein wall contact
  - 5 participants (45.5%).
- Catheter tip contacts vein wall transiently during movement but not in the final resting position
  - 0 participants
- Contacted and remained in contact with the vein wall
  - 6 participants (54.6%)
Study Limitations

• The sample size:
  • Inadequate to establish any demographic link
  • Underpowered to identify any secondary objective

• The angle of the pull force
  • One direction (20 degrees)
  • Clinical situations
    • Any direction
    • Any angle

• Additional securements
  • Cyanoacrylate at the insertion site
  • Gum mastic secured the dressing

• All participants in this study were healthy volunteers.
• Future studies should be conducted in a hospital setting with actual patients.
How does catheter movement apply to complications?

- Infiltration: erosion or penetration of the PIVC through the vein wall
- Dislodgement: PIVC pulls out of the patient’s vein
- Phlebitis: vein irritation
- Occlusion: build-up of biological material causing the PIVC to occlude
- Infection: micropositioning of the catheter

*Catheter movement may contribute to any of these complications*
A New Force-Activated Separation Device for the Prevention of Peripheral Intravenous Restarts Panza 2022

- 143 patients
- Break-away device experienced a 46% reduction in overall complications
  - 39% reduction in infiltration
  - 50% for dislodgement
  - 58% for phlebitis
- 16.7% experienced a device separation
Conclusions

• External pull forces on a PIVC of 4, 5, or 6 lbs cause substantial movement of the PIVC within the vein, ranging from 1.3 mm to 8.1 mm.
• PIVC is likely to contact the vein wall (54.6% of the time)
• Reduce PIVC movement and/or remove damaging forces from the PIVC, which could reduce vein damage via external pull forces on the IV line.
Acknowledgements

• Thanks to Haley Dirrigl, BSBME and MSBME, for development and construction of the mechanical test fixture that was critical to making this study successful.
References

- Ham 2020 - Investigation of Hospital-Onset Methicillin-Resistant Staphylococcus aureus Bloodstream Infections at Eight High Burden Acute Care Facilities in the United States
- A. Bahl, S. Johnson, N. Mielke and P. Karabon Early recognition of peripheral intravenous catheter failure using serial ultrasonographic assessments Plos one 2021 Vol. 16 Issue 6 Pages e0253243
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Connecting PIVC to the Fixture and Applying a Pull Force

• The extension tubing was connected to the force gauge by attaching a metal hook on the force gauge to the sliding clamp on the extension tubing.

• The order of pull forces (4, 5, 6 lb.) applied to each participant’s arm was randomized. A preliminary baseline measurement of the length of the PIVC in the vein and the PIVC angle was taken by ultrasound.

• The first randomized force was placed on the PIVC by moving the force gauge up the 20-degree ramp.
Capturing the Data

• Utilizing the ultrasound, the PIVC was brought into view with the pull force applied to the line, and an image was captured.

• The technician monitoring the force gauge documented the exact force being applied to the PIVC and the ultrasound tech captured the length of the PIVC remaining in the vein at the with the force applied from the captured image.

• A resting period of a minimum of 1 minute took place between pull forces.

• This process was repeated for each of the randomized pull forces of 4, 5, & 6 lbs.
Study Strengths

• To the best of the authors knowledge, this is the first study to establish PIVC movement data with external forces placed on the PIVC

• The order of the external forces were randomized and the study participant, ultrasound technician and secondary reviewers were all blinded to the external forces being applied to the line.

• These study design components increase the reliability of the results.
Data Sourcing and Randomization

• Data Sourcing
  • Researchers collected data on paper data collection forms regarding patient demographics, relevant clinical history variables, and preliminary ultrasound vein measurements.
  • The saved ultrasound images were digitally reviewed by a secondary reviewer to insure that measurements were correct.

• Randomization
  • The order of the external forces applied were randomized to minimize or prevent ordering effects.
  • Both the participant, the final image reviewer and the ultrasound technician were blinded to the order of the forces being applied
  • The participant was blinded to prevent reactivity bias due to anticipation of an increase or decrease in force being applied to the IV line.
Pull Forces on PIVCs are Important

• Previous literature has described PIVC movement as unavoidable and a common occurrence due primarily to activities of daily living\(^1\)

• The movement of the PIVC in the vein can contribute to mechanical complications: infiltration, mechanical phlebitis, occlusion and dislodgement\(^2,3\)

• Forces above 4 lbs have been shown to be disruptive to the PIVC and the dressing, potentially causing an IV restart\(^4\)
An Ultrasonic Story: The Effect of External Forces on Peripheral Catheter Movement Inside the Vein

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