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Microvascular Channel Device to Study Aggressiveness in Prostate Cancer Metastasis

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To study circulating prostate cancer cell adhesion behavior and the contribution to distance metastasis of prostate cancer, we applied a dynamic flow-based E-selectin+SDF-1 coated microchannel system to isolate and characterize a subpopulation of adhering prostate cancer cells. We found a positive correlation of cells’ aggressiveness with their adhesion/rolling ability. By using this device we then sorted prostate cancer cell lines (PC3 and DU-145) into rolling and floating populations, and tested for their behavior in vitro and in vivo. Results from our in vitro studies found that rolling cancer cells are more aggressive in nature with higher growth rate and invasion and form bigger and more colonies in soft agar and 3D sphere formation assays. To test further in vivo, an orthotopic implantation mouse model is underway. In summary, this flow based device provides a platform for isolating the most dangerous aggressive form of cancer cells which can be used for human patients’ peripheral blood for isolating and characterizing and to form a process for customized cancer treatment.
# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>2</td>
</tr>
<tr>
<td>Body</td>
<td>3</td>
</tr>
<tr>
<td>Key Research Accomplishments</td>
<td>9</td>
</tr>
<tr>
<td>Reportable Outcomes</td>
<td>9</td>
</tr>
<tr>
<td>Conclusion</td>
<td>10</td>
</tr>
<tr>
<td>References</td>
<td>11</td>
</tr>
<tr>
<td>Appendices</td>
<td></td>
</tr>
</tbody>
</table>
INTRODUCTION

Prostate cancer is the second most common cause of male cancer death in the USA. The major cause of cancer patient mortality is metastasis. Recent studies found that epithelial origin cancer cells can undergo epithelial-to-mesenchymal transition (EMT), which plays an important role in metastasis, where the cancer cells gain the genes that can transform them to behave as ‘leukocyte like’ cells to be transported through the blood stream to their metastatic destinations (1). Like leukocytes, Prostate Cancer (PRCA) cells preferentially adhere and roll on bone marrow endothelial cells (BMECs) (2, 3) where abundant E-selectin is expressed (4), subsequently initiating a cascade of activation events that eventually leads to the invasion, migration, and ultimately development of metastatic tumors (5-7). All of the observations support the notion that prostate cancer adhesion to the BMECs is a key step in the metastasis cascade. Selectin plays a very important role for capturing cancer cells from the blood stream and migrating them to the site of metastasis. (3). Activated prostate cancer cells become firmly adhered through integrin mediated interactions, and finally, the cells migrate across the endothelium under the direction of SDF-1 gradient (3). To study the mechanisms by which prostate cancer cells adhere to vessel endothelial cells, we applied a dynamic flow-based E-selectin coated microchannel system, cylindrical flow chamber. This selectin-mediated system mimics physiological events involved in normal cell trafficking such as recruitment of leukocytes during the inflammatory response and homing of hematopoietic stem cells to the bone marrow (8-10). We successfully established parameters’ for the dynamic flow-based E-selectin+SDF-1 coated microtubes, which can capture PRCA cells and allow us to study the circulating tumor cell behavior and its contribution to tumor metastasis. It was concluded that, a tube coated with 40 µg/ml of E-selectin and 10µg/ml of SDF-1β with shear stress 1 dyne/cm² is the best possible combination to collect the smallest more potent PRCA cells from the tube based circulation model (preliminary data). We used this selectin and SDF-1β coated micro-renathane tubing system, which mimics pro-metastatic vascular endothelial cell surface, for the capturing of ‘rolling/adhesive/attached’ group of PRCA cells. We found that the ‘rolling/adhesive/attached’ group of cells posses more aggressive and stem cell type characteristics compared to the ‘floating’ in our in vitro assay. In summary, our experimental in vitro data confirmed that cell rolling is a critical step in controlling cancer metastasis, and this novel flow-based device provides a system to capture and enrich metastatic cancer cells from the circulation. So further evaluation is necessary not only to identify the pathways/genes that are responsible for cancer metastasis, but also to provide a pure population for preclinical drug screening. It opens up a process for customized cancer treatment which can have more potent action and also reduce the disadvantage of multiple drug side effects.
We worked on Task 1 and Task 2 in this period of time and accomplished the following areas.

We submitted task 1 in our work statement as:

**Task 1**: Correlation of cancers’ aggressiveness with their adhesion/rolling capacity in static and dynamic flow-based status (timeframe: months 1-12).

1a: Determination of cell rolling capacity in a dynamic state (timeframe: months 1-12).
1b: Determination of cell adhesion ability in a static condition (timeframe: months 1-8).
1c: Determination of cell metastatic behavior *in vitro* (timeframe: months 1-12).

**Accomplishment of Task 1:**

Using a dynamic flow-based system, we analyzed the adhesion/rolling/attached subgroup of LNCaP, CWR22R, and BPH-1 series, and correlate with their aggressiveness. We have shown the rolling capacity of LNCaP and CWR22R series in our preliminary data, and now we continue to analyze the third cell type- BPH-1 series, from nontumorigenic, low grade tumorigenic (BCaPT10) to metastastic (BCaPMT10) cell lines. Cells which roll on the E-selectin and SDF-1β (R and D Co.) coated micro-renathane tube (Braintree Scientific, inc.) were considered as ‘rolling/adherent/attached’ cells. To perform rolling capacity, determined by rolling cell number and rolling cell velocity, we perfused BCaP10 and BCaPM10 cell lines through 2 separate coated (E-selectin + SDF-1β) tubes under microscopic guidance. Cells’ rolling behavior was video recorded for analysis. In our body, metastatic prone circulating cancer cells tether, roll and ultimately adhere on the endothelial cell surface of the capillary to where the shear stress is low. They then exert from the capillary for distant metastasis (1). *In vitro*, under shear stress the metastatic/aggressive type of prostate cancer cells should roll on the inner surface of the blood vessel mimicking E-selectin/SDF-1 coated tube and eventually adhere. So the rolling/adherent/attached cell number should be higher in more aggressive prostate cancer cells. On the other hand, prostate cancer cells which roll faster would not adhere on the surface; they would roll a few times and ultimately flush away under shear flow. The cells which do not roll at all would be given ‘0’in rolling velocity.

We defined rolling cells as cells that translated at an average velocity <50% of the calculated free stream velocity for more than 2 seconds while remaining in the field of view [FOV: 432 μm × 324 μm, using a 20x Plan Fluorite objective, NA 0.40 (Olympus America Inc., Center Valley, PA)]. Rolling cells that interacted with other cells were not included (11). We used shear stress 1 dyne/cm², which is the lowest shear stress in the capillary (12), to analyze BPH-1 series and we found that metastatic subtype BCaPM10 displayed higher rolling cell number as compared to the tumorigenic, low grade BCaPT10. As expected, rolling velocity of the BCaPT10 was higher as compared to the BCaPM10 cells. Next, we compare their invasiveness *in vitro* using BD matrigel coated (BD Bioscience) invasion chamber. We found
that metastatic BCaPM10 cells show higher invasiveness as compared to tumorigenic BCaPT10 cells (Figure 1).

Figure 1

We submitted task 2 in our work statement as:

**Task 2:** Sorting prostate cancer cells into adhesion (attached) and non-adhesion (floating) subpopulations and comparison of these two populations’ metastatic behaviors *in vitro* and *in vivo* (timeframe: months 5-24).

2a: Fractionation of prostate cancer (PRCA) cells based on rolling capacity (timeframe: months 5-20).
2b: Characterization of sorted cells metastatic behavior *in vitro* (timeframe: months 7-18).

2c: Confirmation of metastatic potential on those rolling PRCA cells *in vivo* by the orthotopic injection mice model (timeframe: months 13-24).

**Accomplishment of Task 2:**

We performed part of the Task 2a & 2b for sorting and analyzing of prostate cancer cell lines. We found that the rolling/adhesive/attached cells are more aggressive and possesses more cancer stem cell characteristics compared to the floating population in our *in vitro* assays.

For sorting prostate cancer cells, PC3 and DU-145 cell lines were used. Each type of cells was infused through the immobilized E-selectin and SDF-1β coated micro-renathane tube at 1dyne/cm² shear stress. Rolling/adherent/attached cells were collected separately from non-rolling (floating) cells. All the parameters were tested for the sorted PC3 cells, the same as we did with DU-145 cell line (1dyne/cm² shear stress, and the same concentration of immobilized E-selectin and SDF-1β). We noticed that PC3 cells have higher adhesiveness to selectin/SDF-1 coated tube as compared to DU-145 cells. The results are described in the following.

**Viability testing of Sorted Cells:**

To maintain the characteristics of sorted PC3 cells (floating vs. rolling), we collected sorted cells and characterized their behavior *in vitro* and *in vivo* for no more than two passages after sorting. First, cell viability of sorted floating and adhesion cells were determined by trypan blue staining (using Vi-CELL-XR Cell Viability Analyzer, Beckman Coulter). As shown in Table 1, the viability of all three populations is similar, ranging from 96-86%. Interestingly, the adhesion cells exhibit the lowest viability among all three, but the difference is not significant.

**Table 1:**

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<th>Parental: Before sorting</th>
<th>Floating: After sorting</th>
<th>Rolling: After sorting</th>
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<td>Viable cells (%)</td>
<td>96.8</td>
<td>94.4</td>
<td>86.7</td>
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</table>

**Aggressiveness of Sorted cells:**

Collected ‘rolling’ and ‘floating’ cells were then compared for their aggressiveness *in vitro*, freshly sorted cells were used to perform growth assay (MTT) and invasion assay using BD matrigel invasion chambers (BD Biosciences)) and static adhesion assay on HMEC-1 cells. As shown in Figure 2, rolling/adhesion/attached prostate cancer cells showed higher aggressive behavior than floating cells, where rolling cells have higher proliferation rate by the MTT assay, more invasiveness by invasive chamber assay, and possess more adhesiveness to endothelial HMEC-1 cells by a static adhesion assay.
In addition, we also tested their anchorage independent growth ability by the colony formation assay. As expected, the rolling cells formed more and bigger colonies than floating cells (figure 3). The stem cell characteristics were also compared between floating and rolling cells, due to their potential contribution to metastasis. As shown in Figure 4, the rolling PC3 cells exhibit bigger in size and higher number of 3D-sphere, the standard assay to characterize stem cells.

Figure 2: Sorted rolling/adhesion/attached PC3 and DU-145 cells demonstrate more aggressive metastatic behavior compared to non rolling (floating) cells in vitro. PRCA cells were injected into E-selectin (40ul/ml) and SDF-1 (10ul/ml) coated microtubes, under 1 dyne/cm² shear stress, and rolling (adherent/attached) cells and floating (non attached) cells were collected and their metastatic behaviors were compared. Compared to floating group the rolling group shows higher growth rate in MTT assay of PC3 (A) and DU-145 (B) sorted cells. PC3 demonstrated higher invasiveness in invasion assay (D) and more cellular attachment in static endothelial cell membrane in vitro (E). Results are the mean ± SEM of 3 experiments.
After seeing these encouraging results *in vitro*, we are now sorting cells and confirm their aggressiveness/metastasis behavior *in vivo* as proposed in Task 2c.
In summary, we have provided evidence showing this flow-based E-selectin/SDF coated tube can allow us to sort a small percentage of prostate cancer cells that represent the most dangerous populations in circulation.

After seeing these encouraging results *in vitro*, we concluded that this flow-based device can capture a small population of most aggressive prostate cancer cells in the circulation. We now continue our efforts to confirm if this remains the same *in vivo* orthotopic xenograft mouse model as proposed in Aim 2/ Task 2c.
Key Research Accomplishments

• Establishment of an *in vitro* system to analyze the rolling behavior of prostate cancer cell lines.

• Establishment of a sorting system of prostate cancer cells based on their rolling behavior: rolling/adhesion cells (<5%) and floating cells (>95%).

• Correlation of prostate cancer cells’ aggressiveness with their rolling behavior.

• In vitro characterization of sorted prostate cancer cells (floating vs. rolling) behavior and aggressiveness.

Reportable Outcomes

• Participated in a poster session of prostate cancer basic research in the American Urological Association (AUA) annual meeting in Atlanta, Georgia May 19 – May 23, 2012 (please see the appendix for documents).
CONCLUSION:

We used this selectin and SDF-1 coated micro-renathane tubing system, to capture the ‘rolling/adhesion/attached’ subpopulation of prostate cancer cells, such as PC-3 and DU145 cells under constant flow (shear stress 1 dyne/cm²). Based on their adhesion ability, prostate cancer cells were sorted into: rolling/adhesion/attached fraction which contains potentially a more aggressive cells population, and non-adhesion/floating fraction which were less aggressive sub-population. We found that the ‘rolling/adhesive’ cells are more aggressive in nature, as compared to the ‘floating’ cancer cells by in vitro assays including cell proliferation assay (MTT assay), invasion Assay, and static adhesion assay on HMEC-1 cells and anchorage-independent assay (sulf agar colony formation assay). They also demonstrated higher stemcell characteristics where bigger and more spheres were formed in rolling population. In summary, our experimental data have confirmed that cell rolling is a critical step in controlling cancer metastasis, and this novel flow-based device provides a way to capture and enrich metastatic cancer cells in the circulation. This not only leads to identifying the pathways Genes that are responsible for cancer metastasis, but also provides a pure population for preclinical drug screening. It opens up a process for customized cancer treatment which can have more potent action and also reduce the disadvantage of multiple drug side effects.
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ABSTRACT

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470 EXPRESSION OF ERG ONCOPROTEIN IS LESS FREQUENTLY AND ASSOCIATED WITH A LESS AGGRESSIVE TUMOR PHENOTYPE IN JAPANESE PROSTATE CANCER PATIENTS Takahiro Kimura*, Bungo Furusato, Jun Miki, Toshihiro Yamamoto, Hiroki Takahashi, Yuko Kamata, Tokyo, Japan, Geert J.H.L. van Leenders, Rotterdam, Netherlands, Tapio Visakorpi, Tampere, Finland, Shin Egawa, Tokyo, Japan

471 DISTINGUISHING FEATURES OF ERG ONCOPROTEIN EXPRESSION AMONG MATCHED COHORTS OF AFRICAN-AMERICAN AND CAUCASIAN-AMERICAN PROSTATE CANCER PATIENTS Philip Rosen*, Bethesda, MD, David Pfister, Aachen, Germany, Denise Young, Gyorgy Petrovits, Yongmei Chen, Albert Dobi, Rockville, MD, David McLeod, Bethesda, MD, Shyr Srivastava, Rockville, MD, Isabell Seetehmern, Silver Spring, MD

472 PROSTATE CANCER RISK ALLELES ARE PRESENT AT SIGNIFICANTLY DIFFERENT FREQUENCIES IN HEALTHY VOLUNTEERS OF DIFFERENT RACES Qiuyuan Hu*, Brian T. Holford, Chicago, IL, Stacy Loeb, New York, NY, Nikki Baumann, Rochester, MN, William J. Catalona, Chicago, IL

473 DIFFERENTIAL GENE EXPRESSION PROFILING IN PROLIFERATIVE INFLAMMATORY ATROPHIA COMPARED TO PROSTATE CARCINOMA AND HIGH GRADE PROSTATIC INTRANEOPLASIA USING FROZEN MICRODISSECTED TISSUES Maria T. Quiles, Maria A. Arbós, Ines de Torres, Carmen Bláñezquez, Jaume Reventós, Juan Morote*, Barcelona, Spain


ABSTRACT

475 RECIPROCAL REGULATION OF SLUG AND ANDROGEN RECEPTOR FACILITATES PROSTATE CANCER TO ACQUIRE CASTRATION RESISTANT AND STEM-LIKE PHENOTYPES Kajie Wu*, Xi’an, China, People’s Republic of, Crystal Gore, Dallas, TX, Lin Xie, China, People’s Republic of, Gleave Matthew, Vancouver, Canada, Ray-Chen Pang, Jin Taong Hieh, Dallas, TX, Dallin He, Xi’an, China, People’s Republic of


477 LONG CHAIN ACYL-ACOA SYNTHESIS PLAYS AN IMPORTANT ROLE IN PROSTATE CANCER PROGRESSION III: DIRECT REGULATION BY ANDROGEN RECEPTOR AND OCT1 Daisuke Obinata*, Toshiro Mita, Ken-iti Takayama, Toshihiko Urao, Taro Matsuoka, Tetsuya Fujimura, Satoshi Inoue, Satoshi Takashashi, Tokyo, Japan

478 COMBINATION OF SLC01B3 AND SLC02B1 POLYMORPHISM CAN PREDICT THE DURATION OF THE RESPONSE TO ANDROGEN DEPRIVATION THERAPY IN ADVANCED PROSTATE CANCER. Naohiro Fujimoto*, Tatsuhiko Kubo, Norio Nonomura*, Yasutomo Nakata, Koji Hatano*, Toshiro Migita, Colette Galet, Tristan Rettig, David McLeod, Bethesda, MD, Albert Dobi, Rockville, MD, David Pfister, Aachen, Germany, Denise Young, Gyorgy Petrovits, Yongmei Chen, Albert Dobi, Rockville, MD, David McLeod, Bethesda, MD, Shyr Srivastava, Rockville, MD, Isabell Seetehmern, Silver Spring, MD


480 EXPRESSION OF GANGLIOSIDES, GD1A AND SIALYL PARAGLOBOSIDE, tS IMPORTANT ROLE IN PROGRESSION OF PROSTATE CANCER. Yoshiki Yoshida, Itakayashu, Japan, Hiroki Inatomi, Munakata, Japan, Tetsuo Matsumoto, Kitakyushu, Japan

481 RECIPROCAL REGULATION OF SLUG AND ANDROGEN RECEPTOR FACILITATES PROSTATE CANCER TO ACQUIRE CASTRATION RESISTANT AND STEM-LIKE PHENOTYPES Kajie Wu*, Xi’an, China, People’s Republic of, Crystal Gore, Dallas, TX, Lin Xie, China, People’s Republic of, Gleave Matthew, Vancouver, Canada, Ray-Chen Pang, Jin Taong Hieh, Dallas, TX, Dallin He, Xi’an, China, People’s Republic of


483 LONG CHAIN ACYL-ACOA SYNTHESIS PLAYS AN IMPORTANT ROLE IN PROSTATE CANCER PROGRESSION III: DIRECT REGULATION BY ANDROGEN RECEPTOR AND OCT1 Daisuke Obinata*, Toshiro Mita, Ken-iti Takayama, Toshihiko Urao, Taro Matsuoka, Tetsuya Fujimura, Satoshi Inoue, Satoshi Takashashi, Tokyo, Japan

484 COMBINATION OF SLC01B3 AND SLC02B1 POLYMORPHISM CAN PREDICT THE DURATION OF THE RESPONSE TO ANDROGEN DEPRIVATION THERAPY IN ADVANCED PROSTATE CANCER. Naohiro Fujimoto*, Tatsuhiko Kubo, Norio Nonomura*, Yasutomo Nakata, Koji Hatano*, Toshiro Migita, Colette Galet, Tristan Rettig, David McLeod, Bethesda, MD, Albert Dobi, Rockville, MD, David Pfister, Aachen, Germany, Denise Young, Gyorgy Petrovits, Yongmei Chen, Albert Dobi, Rockville, MD, David McLeod, Bethesda, MD, Shyr Srivastava, Rockville, MD, Isabell Seetehmern, Silver Spring, MD


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487 LONG CHAIN ACYL-ACOA SYNTHESIS PLAYS AN IMPORTANT ROLE IN PROSTATE CANCER PROGRESSION III: DIRECT REGULATION BY ANDROGEN RECEPTOR AND OCT1 Daisuke Obinata*, Toshiro Mita, Ken-iti Takayama, Toshihiko Urao, Taro Matsuoka, Tetsuya Fujimura, Satoshi Inoue, Satoshi Takashashi, Tokyo, Japan

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Certificate of Attendance

This certifies that

Sayedaa Yasmin-Karim

has participated in the 2012 Annual Meeting of the American Urological Association in Atlanta, GA May 19-23, 2012

American Urological Association
Education and Research, Inc.

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