3q29 Deletion Syndrome

Jennifer Gladys Mulle, MHS, PhD
Associate Professor
Department of Human Genetics
Emory University School of Medicine
Thank you.
<table>
<thead>
<tr>
<th>Date</th>
<th>Topic</th>
<th>Presenters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Th, 10/29/2020</td>
<td>Overview of 3q29 Deletion</td>
<td>Dr. Jennifer Mulle</td>
</tr>
<tr>
<td>Th, 12/3/2020</td>
<td>How your health needs are addressed in research</td>
<td>Dr. Sharron Close</td>
</tr>
<tr>
<td>W, 1/13/2021</td>
<td>Cognitive Profile &amp; Social Disability</td>
<td>Drs. Celine Saulnier, Cheryl Klaiman, &amp; Stormi White</td>
</tr>
<tr>
<td>Tu, 2/2/2021</td>
<td>Anxiety, ADHD, and other neuropsychiatric symptoms</td>
<td>Drs. Lindsey Burrell, Elaine Walker, &amp; Joe Cubells</td>
</tr>
<tr>
<td>M, 3/29/2021</td>
<td>3q29 Awareness Day Celebration</td>
<td>Christa Duggan &amp; Melissa Lopez</td>
</tr>
<tr>
<td>M, 5/3/2021</td>
<td>Mental Health &amp; Psychosis</td>
<td>Drs. Elaine Walker &amp; Joe Cubells</td>
</tr>
<tr>
<td>Th, 6/25/2021</td>
<td>Medical and Physical Symptoms</td>
<td>Drs. Rossana Sanchez &amp; Michael Gambello</td>
</tr>
<tr>
<td>TBD-Aug 2021</td>
<td>Dating &amp; Interpersonal Relationships-Parent Session</td>
<td>Dr. Opal Ousley</td>
</tr>
<tr>
<td>TBD-Sept 2021</td>
<td>Dating &amp; Interpersonal Relationships-Young Adult Session</td>
<td>Dr. Amanda Palmer</td>
</tr>
<tr>
<td>F, 9/10/2021</td>
<td>Sharing Research Findings: How to spread the word</td>
<td>Drs. Jennifer Mulle &amp; Melissa Murphy</td>
</tr>
<tr>
<td>TBD-Oct 2021</td>
<td>3q29 Family Camp Weekend</td>
<td></td>
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</tbody>
</table>

All meetings are currently planned for 12-1:30 pm Eastern Time. Additional session description and speaker bios will be available on the website: https://genome.emory.edu/3q29/for-families/3q29-families-meeting/
Reporting our results

• First paper with overall description of phenotypes: *Accepted to Genetics In Medicine*

• *In development:*
  • Feeding behaviors (registry questionnaire)
  • Detailed descriptions of neurodevelopmental phenotypes
  • Unique social ability profile
  • Psychosis and subthreshold psychosis
  • Neuroimaging results
  • …and many more
What is a Copy Number Variant?

3q29 deletion = 3q29 microdeletion
What is a Copy Number Variant?

3q29 deletion = 3q29 microdeletion
What is a Copy Number Variant?

3q29 deletion = 3q29 microdeletion
First description of the 3q29 deletion:

**3q29 Microdeletion Syndrome: Clinical and Molecular Characterization of a New Syndrome**

- Willatt et al, AJHG 2005 describes six patients
- Facial dysmorphology subtle, “not striking”
- All have mild to moderate ID and language delay
- Level of developmental delay not apparent until after the first year of life
- “Autism was a feature of the behavior of two of the patients”; a 3rd pt had features of ASD but no diagnosis

**Expanding the clinical phenotype of the 3q29 microdeletion syndrome and characterization of the reciprocal microduplication**

- Ballif et al 2008, Mol Cytogenetics: 14 patients out of 14,698 with idiopathic ID referred for aCHG
- Mild to moderate ID the only feature common to all patients
- Syndrome includes:
  - Speech Delay (53%)
  - Autism/autistic features (27%)
  - Recurrent ear infections, heart defects, widely spaced teeth (13%)
“Genome-wide significant evidence was obtained for eight loci, including 1q21.1, 2p16.3 (NRXN1), 3q29, 7q11.2, 15q13.3, distal 16p11.2, proximal 16p11.2 and 22q11.2.”
What is the 3q29 deletion?

Mb on chr3q:

21 Genes in the Interval:

Typical deletion:

Low-Copy Repeats:

Rare Syndrome: 1 in 30,000 in the general population
3q29 deletion syndrome: 2010

- Developmental Delay
- Intellectual Disability
- Features of ASD

- Increased risk for schizophrenia

Birth → Childhood → Adulthood
What tools do we need to learn more?

- Animal Model?
  - Emory Investigators create the first 3q29 deletion mouse model

- Human Cohort?
  - YES! But challenging when the deletion is rare (1 in 30,000) in the general population
Our registry collects self-report data from families and, in some cases, the deletion carriers themselves.
Current Recruitment

N = 213 individuals with 3q29 deletion:

Sex: 43% Female, 57% Male

Country:
- US
- Australia
- UK
- Europe
- Canada

Race:
- Mixed race
- White: 87%
- Black
- Asian
- American Indian

Ethnicity:
- Hispanic/Latino
- Not Hispanic/Latino: 71%
- unknown/did not answer

Mean Age 12.5 years (Median 10; Range 1.8– 45.1)
## The 3q29 Registry: Data Collection Instruments

<table>
<thead>
<tr>
<th>Scale</th>
<th>Number/type of questions</th>
<th>Dimensions assessed</th>
<th>Sample question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medical and demographic questionnaire</td>
<td>20; combination of dropdown menus, matrices with dropdown menus, and checkboxes</td>
<td>Birth history, development, ear/nose/throat, GI, renal, oral/dental, and seizure</td>
<td>“At what age were the following gross motor milestones met?”</td>
</tr>
<tr>
<td>Social Responsiveness Scale (SRS)</td>
<td>65; 4-point scale</td>
<td>Social reciprocity and ASD symptoms</td>
<td>“Seems to react to people as if they are objects.”</td>
</tr>
<tr>
<td>Social Communication Questionnaire (SCQ)</td>
<td>40; yes/no</td>
<td>Social communication and history of ASD symptomology</td>
<td>“Has she/he ever gotten his/her pronouns mixed up?”</td>
</tr>
<tr>
<td>Autism Spectrum Screening Questionnaire (ASSQ)</td>
<td>27; 3-point scale</td>
<td>ASD symptoms in high-functioning individuals</td>
<td>“Accumulates facts on certain subjects but does not really understand the meaning.”</td>
</tr>
<tr>
<td>Child Behavior Checklist (CBCL) and Adult Behavior Checklist (ABCL)</td>
<td>100 (preschool), 119 (school age), or 126 (adult); 3-point scale</td>
<td>General developmental and behavioral problems</td>
<td>“Feels he/she has to be perfect.”</td>
</tr>
</tbody>
</table>
Psychiatric Disorders present in 35.8% of respondents (Average Age: 12.5 years old)

Male:Female ratio of ASD in general pop:
4:1

Male:Female ratio of ASD in 3q29 del:
1.8:1
Social Responsiveness Scale

Pollak RM et al, *Mol Autism, 2019*
Social Responsiveness Scale: 3q29 Deletion Syndrome

Pollak RM et al, Mol Autism, 2019
Social Responsiveness Scale

Severity

3q29 Deletion: ASD diagnosis reported

3q29 Deletion: No ASD diagnosis reported

Control

0:31:42

Pollak RM et al, Mol Autism, 2019
Motivating Questions

• What is the cognitive profile of individuals with 3q29 deletion syndrome?

• What is the nature of anxiety in 3q29 deletion syndrome?

• Are there other neuropsychiatric phenotypes in this population?

Answering these questions requires *direct evaluation*
Modeling the Human Neuronal Phenotype of the Schizophrenia-Associated 3q29 Deletion

• AIMS:
  • To determine and quantify the behavioral and clinical phenotype of 3q29 deletion syndrome in children and adults along four dimensions: anxiety, cognitive ability, autism spectrum, and psychosis and prodromal symptoms.
  • To create a publicly available resource of biomaterials from 3q29 deletion carriers at the Rutgers University Cell and DNA Repository (RUCDR).
  • To ascertain the functional consequences of 3q29 deletion in iPSC-derived neuronal cell lines.

Funded by NIMH 3/2017: R01 MH110701
$3.1 M
<table>
<thead>
<tr>
<th>Phenotypes measured and instruments used in this study</th>
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<tbody>
<tr>
<td><strong>Retrospective medical history:</strong> Review of major systems</td>
</tr>
<tr>
<td>Custom intake questionnaire</td>
</tr>
<tr>
<td><strong>Physical Exam</strong></td>
</tr>
<tr>
<td>Custom REDCap form</td>
</tr>
<tr>
<td><strong>Craniofacial:</strong> 2D and 3D photos</td>
</tr>
<tr>
<td><strong>Neurology exam</strong></td>
</tr>
<tr>
<td>Custom REDCap form</td>
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<tr>
<td><strong>Cerebellar cognitive affective/Schmahmann syndrome scale</strong></td>
</tr>
<tr>
<td>CCASS</td>
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<tr>
<td><strong>Cognitive ability (GCA and subtest scores)</strong></td>
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<tr>
<td>DAS-II, WASI-II</td>
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<tr>
<td><strong>Visual-Motor Integration</strong></td>
</tr>
<tr>
<td>Beery-Buktenica Developmental test of visual-motor integration, 6th ed</td>
</tr>
<tr>
<td><strong>Autism + Social disability</strong></td>
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<tr>
<td>ADOS-2, ADI-R, SRS, SCQ</td>
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<tr>
<td><strong>Anxiety</strong></td>
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<tr>
<td>ADIS-P, ADIS-C, SCID-5-RV</td>
</tr>
<tr>
<td><strong>Prodrome/Psychosis</strong></td>
</tr>
<tr>
<td>SIPS</td>
</tr>
<tr>
<td><strong>Adaptive Behavior</strong></td>
</tr>
<tr>
<td>Vineland-3</td>
</tr>
<tr>
<td><strong>Executive Function</strong></td>
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<tr>
<td>BRIEF-2</td>
</tr>
<tr>
<td><strong>General Psychopathology</strong></td>
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<tr>
<td>KSADS, SCID-5-RV</td>
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<tr>
<td>Phenotypic Measures</td>
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<tr>
<td>---------------------</td>
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<tr>
<td><strong>With incredible participation from the 3q29 deletion community, we have now evaluated 32 individuals</strong></td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Schedule - 8 thr 17 years (ADOS Mod 3 - verbally fluent)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pre-visit &amp; Arrival Day</strong></td>
</tr>
<tr>
<td>8:00 AM</td>
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<tr>
<td>8:15 AM</td>
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<tr>
<td>8:45 AM</td>
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<tr>
<td>9:00 AM</td>
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<tr>
<td>9:15 AM</td>
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<td>9:45 AM</td>
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<td>10:00 AM</td>
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<td>5:15 PM</td>
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<tr>
<td>5:30 PM</td>
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</tbody>
</table>
## Demographic info

<table>
<thead>
<tr>
<th></th>
<th>Typical Deletion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of individuals</td>
<td>32</td>
</tr>
<tr>
<td>evaluated</td>
<td></td>
</tr>
<tr>
<td>Age Range, years</td>
<td>4.8 – 39 years</td>
</tr>
<tr>
<td>(mean)</td>
<td>(14.5)</td>
</tr>
<tr>
<td>Male:female</td>
<td>20:12</td>
</tr>
<tr>
<td>Inheritance status</td>
<td>2 inherited;</td>
</tr>
<tr>
<td></td>
<td>remaining</td>
</tr>
<tr>
<td></td>
<td>de novo or unknown</td>
</tr>
<tr>
<td>Geography</td>
<td></td>
</tr>
<tr>
<td>NE</td>
<td>9</td>
</tr>
<tr>
<td>NW</td>
<td>0</td>
</tr>
<tr>
<td>SE</td>
<td>11</td>
</tr>
<tr>
<td>SW</td>
<td>5</td>
</tr>
<tr>
<td>Outside US</td>
<td>2 UK (5 subjects);</td>
</tr>
<tr>
<td></td>
<td>2 Canada</td>
</tr>
</tbody>
</table>
Medical phenotypes by system

- Fatigue
- Ear
- Nose
- Respiratory
- Allergy
- Renal
- Sleep
- Skin
- Teeth
- Heart
- Neuro
- Eye
- GI
Medical phenotypes by system

- Recurrent ear infection (22%)
- GI
- Eye
- Neuro
- Heart
- Sleep
- Skin
- Renal
- Allergy
- Respiratory
- Nose
- Ear
- Fatigue
Medical phenotypes by system

- Fatigue
- Ear
- Nose
- Respiratory
- Allergy
- Renal
- Sleep
- Skin
- Teeth
- Heart
- Neuro
- Eye
- GI

Epistaxis (nosebleeds) 22%
Medical phenotypes by system

- Fatigue
- Ear
- Nose
- Respiratory
- Allergy
- Renal
- Sleep
- Skin
- Teeth
- Heart
- Neuro
- Eye
- GI

Asthma 19%
Medical phenotypes by system

- Fatigue
- Ear
- Nose
- Respiratory
- Allergy
- Renal
- Sleep
- Skin
- Teeth
- Heart
- Neuro
- Eye
- GI

Food allergy 13%
Seasonal allergy 16%
Medical phenotypes by system

- Fatigue
- Ear
- Nose
- Respiratory
- Allergy
- Renal
- Sleep
- Skin
- Teeth
- Heart
- Neuro
- Eye
- Gl

Enuresis 22%
Medical phenotypes by system

- Fatigue
- Ear
- Nose
- Respiratory
- Allergy
- Renal
- Sleep
- Skin
- Teeth
- Heart
- Neuro
- Eye
- GI

Sleep disturbance 31%
Medical phenotypes by system

- Fatigue
- Ear
- Nose
- Respiratory
- Allergy
- Renal
- Sleep
- Skin
- Teeth
- Heart
- Neuro
- Eye
- GI

Abnormal number or size of teeth 16%
Abnormal dentition 28%
Medical phenotypes by system

0 20 40 60 80

Fatigue
Ear
Nose
Respiratory
Allergy
Renal
Sleep
Skin
Teeth
Heart
Neuro
Eye
GI

Congenital heart defect 25%
Heart murmur 22%
Medical phenotypes by system

Fatigue
Ear
Nose
Respiratory
Allergy
Renal
Sleep
Skin
Teeth
Heart
Neuro
Eye
GI

Seizures 13%
Headache or migraine 16%
Medical phenotypes by system

- Fatigue
- Ear
- Nose
- Respiratory
- Allergy
- Renal
- Sleep
- Skin
- Teeth
- Heart
- Neuro
- Eye
- GI

- Astigmatism 16%
- Myopia 16%
- Strabismus 28%
Feeding problems in infancy 59%
Feeding problems beyond infancy 16%
Failure to thrive beyond infancy 41%
Constipation 41%
Reflux 50%
Neurodevelopmental and Neuropsychiatric Diagnoses

Anxiety includes Generalized Anxiety Disorder, Specific Phobia, Separation Anxiety, Social Anxiety.
Cognitive Disability

Full-Scale IQ:

Average in the general population = 100

Avg IQ = 73
Range 40-99

2 SD below the mean = 70; cutoff for ID

Only 34% of our study subjects qualify for a diagnosis of ID: Problematic because access to many services is tied to diagnosis of ID
Cognitive Disability vs Overall Disability

Possible diagnoses:
- GAD
- Separation anxiety
- Social anxiety
- Specific phobia
- ASD
- ADHD
- Adaptive behavior
- Conduct disorder
- Enuresis
- Executive function
- Graphomotor weakness
- ODD
- Psychosis

Possible range 0 – 13
Actual Range 0-7

Measures of cognitive ability, while important in their own right, are not a useful proxy for overall disability in 3q29 deletion individuals.
Components of Intellectual Function

FSIQ
Avg = 73
Range 40-99

Verbal
Avg = 80
Range 31-106

Nonverbal Reasoning
Avg = 75
Range 53-98

Spatial Reasoning
Avg = 71
Range 34-108
These data indicate that there is pronounced graphomotor weakness in individuals with the 3q29 deletion, with a substantial deficit in motor coordination.
Visual-motor integration

Draw this:
Visual-motor integration

Draw this:

15 years

10 years

18 years

7 years

16 years

6 years

18 years

00:58:45
Social disability in 3q29 deletion syndrome

36% of our study sample qualify for an ASD diagnosis using gold-standard instruments.

39% of males
2.7% in general population
14x enriched

30% of females
0.7% in general population
42x enriched
A consistent cerebellar phenotype: volumetric reduction
Arachnoid cysts

-most often described as “benign”

-in **1113 healthy young adults** who were scanned as part of the Human Connectome Project, **11** were found to have arachnoid cysts in the “posterior fossa”

-in **23 subjects with the 3q29 deletion**, we identified **7** posterior fossa arachnoid cysts

-while these are considered benign, the high rate of these findings in our sample is surprising, and may be an important clue about what the 3q29 deletion is doing.
The 3q29 Deletion Mouse

3q29 mouse has deficits in spatial learning and memory, social interaction, acoustic startle, and amphetamine sensitivity

Cerebellar deficits are present in the 3q29 deletion mouse model

![Graph showing genotype differences in absolute cerebellar volume](chart.png)

T-test, p = 0.00016

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Absolute cerebellar volume (mm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WT</td>
<td>65.08 ± 2.1 mm³</td>
</tr>
<tr>
<td>Mut</td>
<td>56.02 ± 1.1 mm³</td>
</tr>
</tbody>
</table>

Esra Sefik
Neuroscience PhD Candidate
Cerebellum is emerging as a site of intense interest for SZ, ASD

Pubmed search for "cerebellum autism" = 991 citations
Pubmed search for "cerebellum schizophrenia" = 1291 citations

The Cerebellum, Sensitive Periods, and Autism

Altered cerebellar and cerebellum autism-related

Dysfunctional cerebellar Purkinje cells contribute to autism-like behaviour in Shank2-deficient

Cerebellar volume and cerebellocerebral structural covariance in schizophrenia: a multisite mega-analysis of 983 patients and 1349 healthy controls
Cerebellum is more than a motor control center

• Cerebellum may have fundamental cognitive and emotional functions (Klein et al 2016)

• Cerebellar cognitive affective syndrome: first proposed by Schmahmann (2004)
  Includes disturbances of executive function and impaired spatial cognition

Is cerebellar dysfunction in the causal pathway for 3q29 deletion syndrome phenotypes? Area for future study
Your participation has given us an important clue!
Conclusions

- ADHD, graphomotor weakness, and executive function deficits are present in 3q29 deletion syndrome
- There is a unique profile of cognitive vulnerability
- High burden of ASD in females
- Hypothesis: Cerebellum is a site of dysregulation

- Direct evaluation of study subjects reveals nuances of behavior, inspires data-driven hypotheses for mechanistic investigation
3q29 deletion syndrome: 2010

- Developmental Delay
- Intellectual Disability
- Features of ASD
- Increased risk for schizophrenia

Birth → Childhood → Adulthood
3q29 deletion syndrome: 2020

Developmental Delay
Intellectual Disability
Features of ASD

Increased risk for schizophrenia

Increased risk for neuropsychiatric phenotypes, especially anxiety disorders

We’re going to need a bigger graphic....
Neurons, organoids derived from study subjects: RNASeq data, proteomics, cellular phenotypes
Additional Investigations

**Single-Cell RNASeq from 3q29 deletion mouse**

- **Resolution:** 0.4
- **# of clusters:** 29
- **Total # of cells:** 71,494
- **Total # of unique genes:** 21,617

- **Cluster id**
  - 0: 8390
  - 1: 8275
  - 2: 5554
  - 3: 4591
  - 4: 4260
  - 5: 4151
  - 6: 3269
  - 7: 3070
  - 8: 2970
  - 9: 2931
  - 10: 2537
  - 11: 2461
  - 12: 2302
  - 13: 2269
  - 14: 1747
  - 15: 1579
  - 16: 1531
  - 17: 1493
  - 18: 1451
  - 19: 1359
  - 20: 1277
  - 21: 1007
  - 22: 985
  - 23: 904
  - 24: 502
  - 25: 247
  - 26: 201
  - 27: 105
  - 28: 76

- **Legend:**
  - 0 = Immature neurons
  - 1 = Astrocytes
  - 2 = OPCs
  - 3 = Immature astrocytes
  - 4 = Immature astrocytes
  - 5 = Actively proliferating neural progenitor cells
  - 6 = Migrating neuroblasts
  - 7 = Radial glia / neural stem cells
  - 8 = OPCs
  - 9 = Neurons (excitatory)
  - 10 = Intermediate neural progenitor cells
  - 11 = Neurons (excitatory)
  - 12 = Microglia
  - 13 = Hemoglobin expressing vascular endothelial cells
  - 14 = Neurons (inhibitory)
  - 15 = Neurons (excitatory)
  - 16 = Neuroblasts
  - 17 = Actively proliferating OPCs
  - 18 = Erythrocytes
  - 19 = Vascular endothelial cells
  - 20 = Newly formed / mature oligodendrocytes
  - 21 = Vascular leptomeningeal cells
  - 22 = Perivascular macrophages
  - 23 = Neurons (Cajal-Retzius cells)
  - 24 = Pericytes
  - 25 = Astrocytes
  - 26 = Choroid plexus / ependymal cells
  - 27 = Monocytes
  - 28 = Ribosomal protein genes

**Steven Sloan, MD, PhD**
Assistant Professor
Leveraging systems biology approaches to identify putative driver genes and pathways (Sefik, Purcell et al): Manuscript in review
Acknowledgements

**Human Phenotyping Team**
Emily Black
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Sookyong Koh
Elizabeth Lee
Derek Novacek
Chris Novacek
Jonathan Park
Rossana Sanchez
Celine Saulnier
Elaine Walker

**Neuroimaging**
Sarah Schultz
Longchuan Li
Britney Sholar

**Molecular and Cellular Mechanisms**
Gary Bassell
Ryan Purcell
Zhexing Wen
Steven Sloan
Esra Sefik

**Metabolism**
Becky Pollak
Paul Dawson
Dean Jones

**General Awesomeness**
Melissa Murphy
Hallie Averbach
Nikisha Sisodoya
Shanthi Cambala

**PCORI EAIN 00097**
R01 MH110701
R01 MH118534
R56 MH116994

**Treasure Your Exceptions**

**The 3q29 Deletion Registry Participants**

**3q29 Mouse**
Steve Warren
Tamara Caspary
David Weinshenker
Mike Epstein
Tim Rutkowski
Tamika Malone
Jason Schroeder

**Genomics**
Trenell Mosley
Mike Epstein
Dave Cutler
Mike Zwick
Rich Johnston

**Community Engagement**
Susan Brasher
Sharron Close

**Craniofacial studies**
Elizabeth Leslie
Grace Carlock
Bryan Mak

**My Home Team!**

jmulle@emory.edu
Question and Answer Session