2020-05-04

Table of Contents

# Material Methods Draft v1

### Mouse Husbandry

To access natural genetic variation for *Mus musculus*, wild derived inbred strains were used. The *Mus musculus* strains PWD/PhJ, PERC/Eij, WSB/EiJ, LEWE/EiJ, MSM/MsJ, MOLF/EiJ, CAST/EiJ, CZECHII/EiJ were purchased from Jackson labs (Maine, USA). The strains of KAZ/TUA, TOM/TUA, AST/TUA, and HMI/TUA were generated from frozen embryos purchased from Biological Resource Center (BRC) at Riken (Ibaraki, Japan). (<https://en.brc.riken.jp>) and rederived by the UW-Biotech centre (Madison UW). The related murid species *Mus caroli* CAROLI/EiJ and *Mus spretus* SPRET/EiJ were purchased from Jackson labs (<https://www.jax.org>) and *Mus spicilegus* SPIC/Eij from Riken. We use abriviated superscript notation for the remainder of the paper (e.g. *musculusWSB*). All mice were housed UW-Madison Biotech and MSC facilities following RARC approved protocols. A breeding colony of wild derived *Mus musculus* mice sampled from Gough Island (G) is maintained at UW Veterinary school facilities.

Mice were fed on dry standard breeder chow. Some strains sunflower seeds, nestlets and larger cages were added to improve fertility and litter survival. Adult mice were euthanized by CO asphyxiation. Neonate and embryonic mice were euthanized by decapitation following the protocols approved by the Institutional Animal Care and Use Committee at the University of Wisconsin-Madison. Over the course of data collection some breeding colonies mice were moved from facilities. Additionally the GI strain was kept at a separate facility.

### Tissue Collection and Immunohistochemistry

The dry-down spread protocol (Peters et al. 1997) was used for both spermatocytes and oocytes with adjustment for volumes. Spermatocyte spreads were collected and prepared as described in (Peterson, Miller, and Payseur 2019). The majority of mice used for MLH1 quantification were from mice between 5 and 12 weeks, while juvillne mice ageed between 12 to 15 days were used for DMC1 quantification. Both pairs of ovaries were collected from embryo or neonate mice between 16 to 21 embyronic days and 0 to 48 hours old respctively.

Whole testes or decapsulated ovaries were incubated in 3ml or 300ul of hypotonic solution for 45min. Fifteen microliters of cell slurry were transferred to 80ul of 2% PFA solution. Cells were fixed in this solution and dried in a humid chamber at room temperature overnight. The following morning, slides were treated with a photoflow wash (Kodak, cite) and stored at -20\*C if not stained immediantly.

**Immunohistochemistry**

To visualize the strucutre of meiotic chromosomes we used antibody markers for the centromere (CREST) and lateral element of of the SC (SYCP3). Double strand breaks (DSB) and crossovers were visualized with DMC1 and MLH1 respectively. The staining protocol was based on (Anderson et al. 1999) and (Koehler et al. 2002). Following a 30 minute blocking wash in 1X ABD, (normal donkey serum (Jackson ImmnuoResearch), 1X PBS, bovine serum albumin (Sigma), and Triton X-100 (Sigma) ), each slide was incubated with 60ul of a primary antibody master mix for 48 hours at 37\* C. The master mix recipe contained polyclonal anti rabbit anti-MLH1 (Calbiochem; diluted 1:50) or anti rabbit anti-DMC1 (mix of DMC1), anti goat polyclonal anti-SYCP3, (Abcam; diluted 1:50), and anti-human polyclonal antibody to CREST (Antibodies, Inc; diluted 1:200) suspended in ADB. Slides were washed twice in 50ml ADB before the first round of secondary antibody incubation for 12 hours at 37 degrees. Alexa Fluor 488 donkey anti-rabbit IgG (Invitrgoen, location; diluted to 1:100) and Coumarin AMCA donkey anti-human IgG (Jackson ImmunoResearch; diluted to 1:200) were suspended in ADB. The last incubation of Alexa Fluor 568 donkey anti-goat (Invitrogen; diluted 1:100) was incubated at 1:100 for 2 hours at 37 degrees. Slides were fixed with Prolong Gold Antifade (Invitrogen) for 24 hours after a final wash in 1x PBS.

### Image Processing

Images were captured using a Zeiss Axioplan 2 microscope with AxioLab camera and Axio Vision software (Zeiss, Cambridge, UK). Preprocessing, including cropping, noise reduction, and histogram adjustments, was performed using Photoshop (v13.0). Image file names were anonymized before manual scoring of MLH1 or DMC1 foci using photoshop.

### Statistical Analysis

Mean DMC1 foci per cell for a single juvenile mouse from a subset of strains; *musculusPWD*, *musculusMSM*, *domesticusWSB*, and *domesticusG* was quantified. Differences in DMC1 counts per cell were tested by ttests. The lateral elements of the synaptonemal complex morphology and CREST/centromere number was used to stage spermatocytes. Early zygotene cells were defined as having a larger degree of indiviual centromeres and mostly complete axis signal. Late zygotene cells were identified as more paired centromeres and homolog axis (but below full synapsis).

Mean **MLH1** foci counts were quantified from cells with intact and complete karyotypes (19 acrocentric bivalents and XY for spermatocytes or 20 acrocentric bivalents for oocytes) and distinct, clear MLH1 foci. A quality score, between 1 to 5, was assigned to each cell based on staining quality and general spread of bivalents. Scores of 1 and 2 have the highest quality while those coded as a score of 5 had the lowest quality and were excluded from the final analysis. The distributions of MLH1 counts per cell was assessed for normality (supplemental figure). MLH1 foci located on the XY in spermatocytes were excluded from this study. An average of 17.9524 and 21.1961 cells were quantified for female and male mice respectively.

To characterize the SC length and chromatin compaction, two image analysis algorithms were used to quantify SC area for individual cells (Wang et al. 2019) and for individual bivalents (Peterson, Miller, and Payseur 2019). Both apply a ‘skeletonizing’ transformation to the synapsed chromosomes which produces a single pixel wide ‘trace’ of the original chromosome shape. Hand measures of pachtyene chromosomes were performed by using ImageJ/Fiji (v1.52) (Schindelin et al. 2012). To remove erroneous SC isolation from the total SC algorithm, outliers were visually assessed at the mouse level and removed from the data set. Mouse means were calculated from cell-wide total SC lengths in 2,984 out of 3,680 cells with MLH1 counts (Figure X).

The DNA Cross Over algorithm isolates single straightened bivalents from an image, and returns the SC length, and locations of green and blue signal, reflecting MLH1 foci and cetromere signal respectively. This algorithm substantially speeds the accurate measurement of bivalents, but has the limitation that not all bivalents per cell can be isolated due to overlapping bivalents. In this data set, isolation rates per cell (the number of all bivalents per cell) range from 0.508 (molossinusMSM male) to 0.716 (*musculusKAZ* female). A curation step was applied to the total single bivalent data set to remove poor measures from the algorithm. From the total set of cell images, 10,458 bivalent objects were isolated by the image analysis software. After a human curation step , 9,829 single-bivalent observations remained. The accuracy of the algorithm is high compared to hand measures after this curation step (Peterson, Miller, and Payseur 2019). From the curated single bivalent data set the proportions of bivalents by crossover number were quantified and tested by chi-square tests with the prop.test().

To account for confounding effects of sex chromosomes from pooled samples of bivalents, we considered a reduced data set including only bivalents with SC lengths below the 2nd quartile in cells with at least 17 of 20 single bivalent measures. The ‘short bivalent’ data set included the four or five shortest bivalents, and excluded the X bivalent in oocytes. A total of 678 ‘short’ bivalents were isolated from 103 oocytes and 37 spermatocytes. Although this smaller data set has decreased power, it offers a more comparable set of single bivalents to compare between the sexes. A ‘long bivalent’ data set was calculated as above, using the 4th quartille for SC lengths per cell. A total of 179 and 505 bivalents were isolated from 37 spermatoctyes and 103 oocytes respectively.

For indiviual mice the MLH1 mean, variance and coefficicent of variance per cell were investigated. We quantified mouse averages of SC based features including the mean total SC area per cell and the mean SC lengths for single bivalents. The crossover position traits crossover position for single crossover bivalents and crossover interference from double crossover interference. For double crossover bivalents the distance between two MLH1 foci, inter-focal distances (IFD), was examined in IFDraw or the normalized by the SC length IFDnorm. These traits were examined using a our model framework because they are markers of processes in the recombinaiton pathway and provide more detailed information about the recombination landscape.

All statistical analyses were done in R (v3.5.2) (Team 2015). Straight forward comparisons of groups (strain, sex) were done through t.tests(). **(outgroup species were not included for the analyses).** The full mixed model (**M1**) was built to interpret the patterns of variation using the lmer() from the lmer4 package (cite). To reflect a random sample of natural genetic variation from each subspecies, strain was coded as a random effect and tested using exactRLRT(). The main effects, subspecies, strain, and interaction were coded as fixed and tested by a chi-square test comparing the full and reduced models using drop1() and anova(). This model allows us to estimate and test the fixed effects (sex and subspecies), and variation in mean MLH1 counts due to strain effect. We use the subspecies term as a way to quantify between group variation (or divergence) and the random strain effect to quantify within group variation (or polymorphism) in a sex specific manner. The remaining general linear models, (**M2-M3**), were used to follow up on results from the full mixed model. The general linear models, **M4** were used to analyze sex specific data sets. We used this analytical framework which accounts for the nested nature across categories across all the individual mice (e.g. sex, strain subspecies) and can be applied to multiple dependent variables.

**M1 Mixed Model**

**M2 Linear Model**

**M3 Linear Model**

**M4 Linear Model**

**M4.2 Linear Model**

# References

Anderson, Lorinda K, Aaron Reeves, Lisa M Webb, and Terry Ashley. 1999. “Distribution of Crossing over on Mouse Synaptonemal Complexes Using Immunofluorescent Localization of Mlh1 Protein.” *Genetics* 151 (4). Genetics Soc America: 1569–79.

Koehler, Kara E, Jonathan P Cherry, Audrey Lynn, Patricia A Hunt, and Terry J Hassold. 2002. “Genetic Control of Mammalian Meiotic Recombination. I. Variation in Exchange Frequencies Among Males from Inbred Mouse Strains.” *Genetics* 162 (1). Genetics Soc America: 297–306.

Peters, Antoine HFM, Annemieke W. Plug, Martine J. van Vugt, and Peter De Boer. 1997. “SHORT COMMUNICATIONS A Drying-down Technique for the Spreading of Mammalian Meiocytes from the Male and Female Germline.” *Chromosome Research* 5 (1): 66–68.

Peterson, April L, Nathan D Miller, and Bret A Payseur. 2019. “Conservation of the Genome-Wide Recombination Rate in White-Footed Mice.” *Heredity* 123 (4). Nature Publishing Group: 442–57.

Schindelin, Johannes, Ignacio Arganda-Carreras, Erwin Frise, Verena Kaynig, Mark Longair, Tobias Pietzsch, Stephan Preibisch, Curtis Rueden, Stephan Saalfeld, and Benjamin Schmid. 2012. “Fiji: An Open-Source Platform for Biological-Image Analysis.” *Nature Methods* 9 (7): 676.

Team, RStudio. 2015. “RStudio: Integrated Development Environment for R.” Boston, MA. <http://www.rstudio.com>.

Wang, RJ, BL Dumont, P Jing, and BA Payseur. 2019. “A First Genetic Portrait of Synaptonemal Complex Variation.” *PLoS Genetics* 15 (8): e1008337–e1008337.