



## X chromosome

The X chromosome is one of the two sex chromosomes in humans (the other is the Y chromosome). The sex chromosomes form one of the 23 pairs of human chromosomes in each cell. The X chromosome spans about 155 million DNA building blocks (base pairs) and represents approximately 5 percent of the total DNA in cells.

Each person normally has one pair of sex chromosomes in each cell. Females have two X chromosomes, while males have one X and one Y chromosome. Early in embryonic development in females, one of the two X chromosomes is randomly and permanently inactivated in cells other than egg cells. This phenomenon is called X-inactivation or lyonization. X-inactivation ensures that females, like males, have one functional copy of the X chromosome in each body cell. Because X-inactivation is random, in normal females the X chromosome inherited from the mother is active in some cells, and the X chromosome inherited from the father is active in other cells.

Some genes on the X chromosome escape X-inactivation. Many of these genes are located at the ends of each arm of the X chromosome in areas known as the pseudoautosomal regions. Although many genes are unique to the X chromosome, genes in the pseudoautosomal regions are present on both sex chromosomes. As a result, men and women each have two functional copies of these genes. Many genes in the pseudoautosomal regions are essential for normal development.

Identifying genes on each chromosome is an active area of genetic research. Because researchers use different approaches to predict the number of genes on each chromosome, the estimated number of genes varies. The X chromosome likely contains 800 to 900 genes that provide instructions for making proteins. These proteins perform a variety of different roles in the body.

### Health Conditions Related to Chromosomal Changes

The following chromosomal conditions are associated with changes in the structure or number of copies of X chromosome.

#### 46,XX testicular disorder of sex development

In most individuals with 46,XX testicular disorder of sex development, the condition results from an abnormal exchange of genetic material between chromosomes (translocation). This exchange occurs as a random event during the formation of sperm cells in the affected person's father. The translocation affects the gene responsible for development of a fetus into a male (the *SRY* gene). The *SRY* gene, which is normally found on the Y chromosome, is misplaced in this disorder, almost always onto an X chromosome. A fetus with an X chromosome that carries the *SRY* gene will develop as a male despite not having a Y chromosome.

### 48,XXYY syndrome

48,XXYY syndrome is caused by the presence of an extra X chromosome and an extra Y chromosome in a male's cells. Extra genetic material from the X chromosome interferes with male sexual development, preventing the testes from functioning normally and reducing the levels of testosterone (a hormone that directs male sexual development) in adolescent and adult males. Extra copies of genes from the pseudoautosomal regions of the extra X and Y chromosomes contribute to the signs and symptoms of 48,XXYY syndrome; however, the specific genes have not been identified.

### Intestinal pseudo-obstruction

Intestinal pseudo-obstruction, a condition characterized by impairment of the coordinated waves of muscle contractions that move food through the digestive tract (peristalsis), can be caused by genetic changes involving the X chromosome.

Some individuals with intestinal pseudo-obstruction have mutations, duplications, or deletions of genetic material on the X chromosome that affect the *FLNA* gene. The protein produced from this gene, filamin A, helps form the branching network of filaments called the cytoskeleton, which gives structure to cells and allows them to change shape and move.

Researchers believe that the changes in the X chromosome that affect the *FLNA* gene impair the function of the filamin A protein. Studies suggest that impaired filamin A function affects the shape of cells in the smooth muscles of the gastrointestinal tract during development before birth, causing abnormalities in the layering of these muscles. Smooth muscles line the internal organs; they contract and relax without being consciously controlled. In the digestive tract, abnormal layering of these muscles may interfere with peristalsis.

Deletions or duplications of genetic material that affect the *FLNA* gene can also include adjacent genes on the X chromosome. Changes in adjacent genes may account for some of the other signs and symptoms, such as neurological abnormalities and unusual facial features, that occur in some affected individuals.

### Klinefelter syndrome

Klinefelter syndrome is caused by the presence of one or more extra copies of the X chromosome in a male's cells. Extra genetic material from the X chromosome interferes with male sexual development, preventing the testes from functioning normally and reducing the levels of testosterone. A shortage of testosterone can lead to delayed or incomplete puberty, genital abnormalities, breast enlargement (gynecomastia), reduced facial and body hair, and an inability to have biological children (infertility). Children with Klinefelter syndrome may also have learning disabilities, delayed speech and language development, and a shy and unassuming personality.

Typically, people with Klinefelter syndrome have one extra copy of the X chromosome in each cell, for a total of two X chromosomes and one Y chromosome (47,XXY). Less commonly, affected individuals may have two or three extra X chromosomes (48,XXXY or 49,XXXXY). As the number of extra sex chromosomes increases, so does the risk of learning problems, intellectual disability, birth defects, and other health issues.

Some people with features of Klinefelter syndrome have the extra X chromosome in only some of their cells; in these individuals, the condition is described as mosaic Klinefelter syndrome (46,XY/47,XXY). Individuals with mosaic Klinefelter syndrome may have milder signs and symptoms, depending on how many cells have an additional X chromosome.

### Microphthalmia with linear skin defects syndrome

A deletion of genetic material in a region of the X chromosome called Xp22 causes microphthalmia with linear skin defects syndrome. This region includes a gene called *HCCS*, which carries instructions for producing an enzyme called holocytochrome c-type synthase. This enzyme helps produce a molecule called cytochrome c. Cytochrome c is involved in a process called oxidative phosphorylation, by which mitochondria generate adenosine triphosphate (ATP), the cell's main energy source. It also plays a role in the self-destruction of cells (apoptosis).

A deletion of genetic material that includes the *HCCS* gene prevents the production of the holocytochrome c-type synthase enzyme. In females (who have two X chromosomes), some cells produce a normal amount of the enzyme and other cells produce none. The resulting overall reduction in the amount of this enzyme leads to the signs and symptoms of microphthalmia with linear skin defects syndrome.

In males (who have only one X chromosome), a deletion that includes the *HCCS* gene results in a total loss of the holocytochrome c-type synthase enzyme. A lack of this enzyme appears to be lethal very early in development, so almost no males are born with microphthalmia with linear skin defects syndrome. A few affected individuals with male appearance who have two X chromosomes have been identified.

A reduced amount of the holocytochrome c-type synthase enzyme can damage cells by impairing their ability to generate energy. In addition, without the holocytochrome c-type synthase enzyme, the damaged cells may not be able to undergo apoptosis. These cells may instead die in a process called necrosis that causes inflammation and damages neighboring cells. During early development this spreading cell damage may lead to the eye and skin abnormalities characteristic of microphthalmia with linear skin defects syndrome.

### Triple X syndrome

Triple X syndrome (also called 47,XXX or trisomy X) results from an extra copy of the X chromosome in each of a female's cells. Females with triple X syndrome have

three X chromosomes, for a total of 47 chromosomes per cell. An extra copy of the X chromosome is associated with tall stature, learning problems, and other features in some girls and women.

Some females with triple X syndrome have an extra X chromosome in only some of their cells. This phenomenon is called 46,XX/47,XXX mosaicism.

Females with more than one extra copy of the X chromosome (48,XXXX or 49,XXXXX) have been identified, but these chromosomal changes are rare. As the number of extra sex chromosomes increases, so does the risk of learning problems, intellectual disability, birth defects, and other health issues.

### Turner syndrome

Turner syndrome results when one normal X chromosome is present in a female's cells and the other sex chromosome is missing or structurally altered. The missing genetic material affects development before and after birth, leading to short stature, ovarian malfunction, and the other features of Turner syndrome.

About half of individuals with Turner syndrome have monosomy X (45,X), which means each cell in an individual's body has only one copy of the X chromosome instead of the usual two sex chromosomes. Turner syndrome can also occur if one of the sex chromosomes is partially missing or rearranged rather than completely absent.

Some women with Turner syndrome have a chromosomal change in only some of their cells, which is known as mosaicism. Some cells have the usual two sex chromosomes (either two X chromosomes or one X chromosome and one Y chromosome), and other cells have only one copy of the X chromosome. Women with Turner syndrome caused by X chromosome mosaicism (45,X/46,XX or 45,X/46,XY) are said to have mosaic Turner syndrome.

Researchers have not determined which genes on the X chromosome are responsible for most of the features of Turner syndrome. They have, however, identified one gene called *SHOX* that is important for bone development and growth. The *SHOX* gene is located in the pseudoautosomal regions of the sex chromosomes. Missing one copy of this gene likely causes short stature and skeletal abnormalities in women with Turner syndrome.

### X-linked acrogigantism

Duplication of a small amount of genetic material on the X chromosome causes X-linked acrogigantism (X-LAG), which is characterized by abnormally fast growth beginning in infancy or early childhood. Affected individuals may have the condition as a result of enlargement (hyperplasia) of the pituitary gland or development of a noncancerous tumor in the gland (called a pituitary adenoma). The pituitary is a small gland at the base of the brain that produces hormones that control many important body functions, including growth hormone, which helps direct growth of the body. The

abnormal gland releases more growth hormone than normal, causing rapid growth in individuals with X-LAG.

The duplication, often referred to as an Xq26.3 microduplication, occurs on the long (q) arm of the chromosome at a location designated q26.3. It can include several genes, but only duplication of the *GPR101* gene is necessary to cause X-LAG. The *GPR101* gene provides instructions for making a protein whose function is unknown, although it is thought to be involved in the growth of cells in the pituitary gland or in the release of growth hormone from the gland.

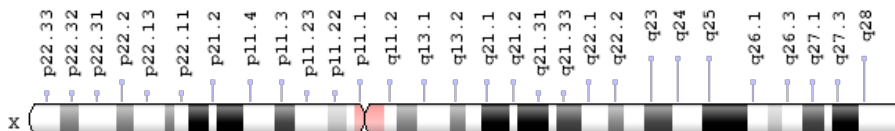
Duplication of the *GPR101* gene leads to an excess of GPR101 protein. It is unclear how extra GPR101 protein results in the development of a pituitary adenoma or hyperplasia or in the release of excess growth hormone.

### Other chromosomal conditions

Chromosomal conditions involving the sex chromosomes often affect sex determination (whether a person has the sexual characteristics of a male or a female), sexual development, and the ability to have children (fertility). The signs and symptoms of these conditions vary widely and range from mild to severe. They can be caused by missing or extra copies of the sex chromosomes or by structural changes in the chromosomes.

### **Chromosome Diagram**

Geneticists use diagrams called idiograms as a standard representation for chromosomes. Idiograms show a chromosome's relative size and its banding pattern, which is the characteristic pattern of dark and light bands that appears when a chromosome is stained with a chemical solution and then viewed under a microscope. These bands are used to describe the location of genes on each chromosome.



Credit: Genome Decoration Page/NCBI

### **Additional Information & Resources**

#### MedlinePlus

- Encyclopedia: Chromosome  
<https://medlineplus.gov/ency/article/002327.htm>

### Additional NIH Resources

- National Human Genome Research Institute: Chromosome Abnormalities  
<https://www.genome.gov/11508982/>
- National Human Genome Research Institute: Studies Expand Understanding of X Chromosome (March 2005)  
<https://www.genome.gov/13514331/>

### GeneReviews

- Microphthalmia with Linear Skin Defects Syndrome  
<https://www.ncbi.nlm.nih.gov/books/NBK7041>
- Nonsyndromic 46,XX Testicular Disorders of Sex Development  
<https://www.ncbi.nlm.nih.gov/books/NBK1416>
- X-Linked Acrogigantism  
<https://www.ncbi.nlm.nih.gov/books/NBK476671>

### Scientific Articles on PubMed

- PubMed  
<https://www.ncbi.nlm.nih.gov/pubmed?term=%28Chromosomes,+Human,+X%5BM%5D%29+AND+%28X+Chromosome%5BTI%5D%29+AND+english%5Bla%5D+AND+human%5Bmh%5D+AND+%22last+1800+days%22%5Bdp%5D>

### Research Resources

- Cancer Genetics Web  
<http://www.cancerindex.org/geneweb/clinkc23.htm>
- Database of Genomic Variants  
[http://projects.tcag.ca/variation/cgi-bin/tbrowse/tbrowse?source=hg17&table=Locus&show=table&keyword=&flop=AND&fcol=\\_C19&fcomp==&fkwd=chrX&cols=](http://projects.tcag.ca/variation/cgi-bin/tbrowse/tbrowse?source=hg17&table=Locus&show=table&keyword=&flop=AND&fcol=_C19&fcomp==&fkwd=chrX&cols=)
- Ensembl Human Map View  
[http://www.ensembl.org/Homo\\_sapiens/Location/Chromosome?chr=X;r=X:1-155270560](http://www.ensembl.org/Homo_sapiens/Location/Chromosome?chr=X;r=X:1-155270560)
- HUGO Gene Nomenclature Committee: Statistics & Downloads for Chromosome X  
<https://www.genenames.org/cgi-bin/statistics?c=X/>
- The DNA sequence of the human X chromosome. Nature. 2005 Mar 17;434(7031):325-37.  
<http://www.nature.com/articles/nature03440.pdf>
- U.S. Department of Energy: Human Genome Project Information Archive  
[https://web.ornl.gov/sci/techresources/Human\\_Genome/posters/chromosome/chromoX.shtml](https://web.ornl.gov/sci/techresources/Human_Genome/posters/chromosome/chromoX.shtml)

## Sources for This Summary

- Bender BG, Harmon RJ, Linden MG, Bucher-Bartelson B, Robinson A. Psychosocial competence of unselected young adults with sex chromosome abnormalities. *Am J Med Genet.* 1999 Apr 16;88(2): 200-6.  
*Citation on PubMed:* <https://www.ncbi.nlm.nih.gov/pubmed/10206242>
- Bender BG, Linden MG, Harmon RJ. Neuropsychological and functional cognitive skills of 35 unselected adults with sex chromosome abnormalities. *Am J Med Genet.* 2001 Sep 1;102(4): 309-13.  
*Citation on PubMed:* <https://www.ncbi.nlm.nih.gov/pubmed/11503155>
- Carrel L, Willard HF. X-inactivation profile reveals extensive variability in X-linked gene expression in females. *Nature.* 2005 Mar 17;434(7031):400-4.  
*Citation on PubMed:* <https://www.ncbi.nlm.nih.gov/pubmed/15772666>
- Clayton-Smith J, Walters S, Hobson E, Burkitt-Wright E, Smith R, Toutain A, Amiel J, Lyonnet S, Mansour S, Fitzpatrick D, Ciccone R, Ricca I, Zuffardi O, Donnai D. Xq28 duplication presenting with intestinal and bladder dysfunction and a distinctive facial appearance. *Eur J Hum Genet.* 2009 Apr;17(4):434-43. doi: 10.1038/ejhg.2008.192. Epub 2008 Oct 15.  
*Citation on PubMed:* <https://www.ncbi.nlm.nih.gov/pubmed/18854860>  
*Free article on PubMed Central:* <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2986219/>
- Doswell BH, Visootsak J, Brady AN, Graham JM Jr. Turner syndrome: an update and review for the primary pediatrician. *Clin Pediatr (Phila).* 2006 May;45(4):301-13. Review.  
*Citation on PubMed:* <https://www.ncbi.nlm.nih.gov/pubmed/16703153>
- Délot EC, Vilain EJ. Nonsyndromic 46,XX Testicular Disorders of Sex Development. 2003 Oct 30 [updated 2015 May 7]. In: Pagon RA, Adam MP, Ardinger HH, Wallace SE, Amemiya A, Bean LJH, Bird TD, Ledbetter N, Mefford HC, Smith RJH, Stephens K, editors. *GeneReviews®* [Internet]. Seattle (WA): University of Washington, Seattle; 1993-2017. Available from <http://www.ncbi.nlm.nih.gov/books/NBK1416/>  
*Citation on PubMed:* <https://www.ncbi.nlm.nih.gov/pubmed/20301589>
- Ensembl Human Map View  
[http://www.ensembl.org/Homo\\_sapiens/Location/Chromosome?chr=X;r=X:1-155270560](http://www.ensembl.org/Homo_sapiens/Location/Chromosome?chr=X;r=X:1-155270560)
- Ergun-Longmire B, Vinci G, Alonso L, Matthew S, Tansil S, Lin-Su K, McElreavey K, New MI. Clinical, hormonal and cytogenetic evaluation of 46,XX males and review of the literature. *J Pediatr Endocrinol Metab.* 2005 Aug;18(8):739-48.  
*Citation on PubMed:* <https://www.ncbi.nlm.nih.gov/pubmed/16200839>
- FitzPatrick DR, Strain L, Thomas AE, Barr DG, Todd A, Smith NM, Scobie WG. Neurogenic chronic idiopathic intestinal pseudo-obstruction, patent ductus arteriosus, and thrombocytopenia segregating as an X linked recessive disorder. *J Med Genet.* 1997 Aug;34(8):666-9.  
*Citation on PubMed:* <https://www.ncbi.nlm.nih.gov/pubmed/9279759>  
*Free article on PubMed Central:* <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1051029/>
- Frühmesser A, Kotzot D. Chromosomal variants in klinefelter syndrome. *Sex Dev.* 2011;5(3): 109-23. doi: 10.1159/000327324. Epub 2011 Apr 29. Review.  
*Citation on PubMed:* <https://www.ncbi.nlm.nih.gov/pubmed/21540567>
- Gargiulo A, Auricchio R, Barone MV, Cotugno G, Reardon W, Milla PJ, Ballabio A, Ciccodicola A, Auricchio A. Filamin A is mutated in X-linked chronic idiopathic intestinal pseudo-obstruction with central nervous system involvement. *Am J Hum Genet.* 2007 Apr;80(4):751-8. Epub 2007 Feb 26.  
*Citation on PubMed:* <https://www.ncbi.nlm.nih.gov/pubmed/17357080>  
*Free article on PubMed Central:* <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1852717/>

- Iacovazzo D, Caswell R, Bunce B, Jose S, Yuan B, Hernández-Ramírez LC, Kapur S, Caimari F, Evanson J, Ferraù F, Dang MN, Gabrovská P, Larkin SJ, Ansorge O, Rodd C, Vance ML, Ramírez-Rentería C, Mercado M, Goldstone AP, Buchfelder M, Burren CP, Gurlek A, Dutta P, Choong CS, Cheetham T, Trivellin G, Stratakis CA, Lopes MB, Grossman AB, Trouillas J, Lupski JR, Ellard S, Sampson JR, Roncaroli F, Korbonits M. Germline or somatic GPR101 duplication leads to X-linked acrogigantism: a clinico-pathological and genetic study. *Acta Neuropathol Commun.* 2016 Jun 1; 4(1):56. doi: 10.1186/s40478-016-0328-1.  
*Citation on PubMed:* <https://www.ncbi.nlm.nih.gov/pubmed/27245663>  
*Free article on PubMed Central:* <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4888203/>
- Kapur RP, Robertson SP, Hannibal MC, Finn LS, Morgan T, van Kogelenberg M, Loren DJ. Diffuse abnormal layering of small intestinal smooth muscle is present in patients with FLNA mutations and x-linked intestinal pseudo-obstruction. *Am J Surg Pathol.* 2010 Oct;34(10):1528-43. doi: 10.1097/PAS.0b013e3181f0ae47.  
*Citation on PubMed:* <https://www.ncbi.nlm.nih.gov/pubmed/20871226>
- Kuehn BM. Mysteries of the X chromosome revealed: "silent" X not always mute. *JAMA.* 2005 Apr 27;293(16):1961-2.  
*Citation on PubMed:* <https://www.ncbi.nlm.nih.gov/pubmed/15855414>
- Kutsche K, Werner W, Bartsch O, von der Wense A, Meinecke P, Gal A. Microphthalmia with linear skin defects syndrome (MLS): a male with a mosaic paracentric inversion of Xp. *Cytogenet Genome Res.* 2002;99(1-4):297-302.  
*Citation on PubMed:* <https://www.ncbi.nlm.nih.gov/pubmed/12900578>
- Lyon MF. X-chromosome inactivation and human genetic disease. *Acta Paediatr Suppl.* 2002; 91(439):107-12. Review.  
*Citation on PubMed:* <https://www.ncbi.nlm.nih.gov/pubmed/12572852>
- Map Viewer: Genes on Sequence  
<https://www.ncbi.nlm.nih.gov/mapview/maps.cgi?ORG=human&MAPS=ideogr,ugHs,genes&CHR=X>
- Morleo M, Franco B. Microphthalmia with Linear Skin Defects Syndrome. 2009 Jun 18 [updated 2011 Aug 18]. In: Pagon RA, Adam MP, Ardinger HH, Wallace SE, Amemiya A, Bean LJH, Bird TD, Ledbetter N, Mefford HC, Smith RJH, Stephens K, editors. *GeneReviews®* [Internet]. Seattle (WA): University of Washington, Seattle; 1993-2017. Available from <http://www.ncbi.nlm.nih.gov/books/NBK7041/>  
*Citation on PubMed:* <https://www.ncbi.nlm.nih.gov/pubmed/20301767>
- Rizvi AA. 46, XX man with SRY gene translocation: cytogenetic characteristics, clinical features and management. *Am J Med Sci.* 2008 Apr;335(4):307-9. doi: 10.1097/MAJ.0b013e31811ec1b4.  
*Citation on PubMed:* <https://www.ncbi.nlm.nih.gov/pubmed/18414071>



- Ross MT, Grafham DV, Coffey AJ, Scherer S, McLay K, Muzny D, Platzer M, Howell GR, Burrows C, Bird CP, Frankish A, Lovell FL, Howe KL, Ashurst JL, Fulton RS, Sudbrak R, Wen G, Jones MC, Hurler ME, Andrews TD, Scott CE, Searle S, Ramser J, Whittaker A, Deadman R, Carter NP, Hunt SE, Chen R, Cree A, Gunaratne P, Havlak P, Hodgson A, Metzker ML, Richards S, Scott G, Steffen D, Sodergren E, Wheeler DA, Worley KC, Ainscough R, Ambrose KD, Ansari-Lari MA, Aradhya S, Ashwell RI, Babbage AK, Bagguley CL, Ballabio A, Banerjee R, Barker GE, Barlow KF, Barrett IP, Bates KN, Beare DM, Beasley H, Beasley O, Beck A, Bethel G, Blechschmidt K, Brady N, Bray-Allen S, Bridgeman AM, Brown AJ, Brown MJ, Bonnini D, Bruford EA, Buhay C, Burch P, Burford D, Burgess J, Burrill W, Burton J, Bye JM, Carder C, Carrel L, Chako J, Chapman JC, Chavez D, Chen E, Chen G, Chen Y, Chen Z, Chinault C, Ciccodicola A, Clark SY, Clarke G, Clee CM, Clegg S, Clerc-Blankenburg K, Clifford K, Cobley V, Cole CG, Conquer JS, Corby N, Connor RE, David R, Davies J, Davis C, Davis J, Delgado O, Deshazo D, Dhami P, Ding Y, Dinh H, Dodsworth S, Draper H, Dugan-Rocha S, Dunham A, Dunn M, Durbin KJ, Dutta I, Eades T, Ellwood M, Emery-Cohen A, Errington H, Evans KL, Faulkner L, Francis F, Frankland J, Fraser AE, Galgoczy P, Gilbert J, Gill R, Glöckner G, Gregory SG, Gribble S, Griffiths C, Grocock R, Gu Y, Gwilliam R, Hamilton C, Hart EA, Hawes A, Heath PD, Heitmann K, Hennig S, Hernandez J, Hinzmann B, Ho S, Hoffmann M, Howden PJ, Huckle EJ, Hume J, Hunt PJ, Hunt AR, Isherwood J, Jacob L, Johnson D, Jones S, de Jong PJ, Joseph SS, Keenan S, Kelly S, Kershaw JK, Khan Z, Kioschis P, Klages S, Knights AJ, Kosiura A, Kovar-Smith C, Laird GK, Langford C, Lawlor S, Leversha M, Lewis L, Liu W, Lloyd C, Lloyd DM, Louseged H, Loveland JE, Lovell JD, Lozado R, Lu J, Lyne R, Ma J, Maheshwari M, Matthews LH, McDowall J, McLaren S, McMurray A, Meidl P, Meitinger T, Milne S, Miner G, Mistry SL, Morgan M, Morris S, Müller I, Mullikin JC, Nguyen N, Nordsiek G, Nyakatura G, O'Dell CN, Okwuonu G, Palmer S, Pandian R, Parker D, Parrish J, Pasternak S, Patel D, Pearce AV, Pearson DM, Pelan SE, Perez L, Porter KM, Ramsey Y, Reichwald K, Rhodes S, Ridler KA, Schlessinger D, Schueler MG, Sehra HK, Shaw-Smith C, Shen H, Sheridan EM, Shownkeen R, Skuce CD, Smith ML, Sotheran EC, Steingruber HE, Steward CA, Storey R, Swann RM, Swarbreck D, Tabor PE, Taudien S, Taylor T, Teague B, Thomas K, Thorpe A, Timms K, Tracey A, Trevanion S, Tromans AC, d'Urso M, Verduzco D, Villasana D, Waldron L, Wall M, Wang Q, Warren J, Warry GL, Wei X, West A, Whitehead SL, Whiteley MN, Wilkinson JE, Willey DL, Williams G, Williams L, Williamson A, Williamson H, Wilming L, Woodmansey RL, Wray PW, Yen J, Zhang J, Zhou J, Zoghbi H, Zorilla S, Buck D, Reinhardt R, Poustka A, Rosenthal A, Lehrach H, Meindl A, Minx PJ, Hillier LW, Willard HF, Wilson RK, Waterston RH, Rice CM, Vaudin M, Coulson A, Nelson DL, Weinstock G, Sulston JE, Durbin R, Hubbard T, Gibbs RA, Beck S, Rogers J, Bentley DR. The DNA sequence of the human X chromosome. *Nature*. 2005 Mar 17;434(7031):325-37.  
*Citation on PubMed:* <https://www.ncbi.nlm.nih.gov/pubmed/15772651>  
*Free article on PubMed Central:* <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2665286/>
- Schaffner SF. The X chromosome in population genetics. *Nat Rev Genet*. 2004 Jan;5(1):43-51. Review.  
*Citation on PubMed:* <https://www.ncbi.nlm.nih.gov/pubmed/14708015>
- Tartaglia N, Davis S, Hench A, Nimishakavi S, Beauregard R, Reynolds A, Fenton L, Albrecht L, Ross J, Visootsak J, Hansen R, Hagerman R. A new look at XYY syndrome: medical and psychological features. *Am J Med Genet A*. 2008 Jun 15;146A(12):1509-22. doi: 10.1002/ajmg.a.32366.  
*Citation on PubMed:* <https://www.ncbi.nlm.nih.gov/pubmed/18481271>  
*Free article on PubMed Central:* <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3056496/>

- Trivellin G, Daly AF, Faucz FR, Yuan B, Rostomyan L, Larco DO, Scherthaner-Reiter MH, Szarek E, Leal LF, Caberg JH, Castermans E, Villa C, Dimopoulos A, Chittiboina P, Xekouki P, Shah N, Metzger D, Lysy PA, Ferrante E, Strebkova N, Mazerkina N, Zatelli MC, Lodish M, Horvath A, de Alexandre RB, Manning AD, Levy I, Keil MF, Sierra Mde L, Palmeira L, Coppieters W, Georges M, Naves LA, Jamar M, Bours V, Wu TJ, Choong CS, Bertherat J, Chanson P, Kamenický P, Farrell WE, Barlier A, Quezado M, Bjelobaba I, Stojilkovic SS, Wess J, Costanzi S, Liu P, Lupski JR, Beckers A, Stratakis CA. Gigantism and acromegaly due to Xq26 microduplications and GPR101 mutation. *N Engl J Med*. 2014 Dec 18;371(25):2363-74. doi: 10.1056/NEJMoa1408028. Epub 2014 Dec 3.  
*Citation on PubMed:* <https://www.ncbi.nlm.nih.gov/pubmed/25470569>  
*Free article on PubMed Central:* <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4291174/>
- UCSC Genome Browser: Statistics  
<http://genome.cse.ucsc.edu/goldenPath/stats.html>
- Vallender EJ, Pearson NM, Lahn BT. The X chromosome: not just her brother's keeper. *Nat Genet*. 2005 Apr;37(4):343-5.  
*Citation on PubMed:* <https://www.ncbi.nlm.nih.gov/pubmed/15800647>
- Visootsak J, Aylstock M, Graham JM Jr. Klinefelter syndrome and its variants: an update and review for the primary pediatrician. *Clin Pediatr (Phila)*. 2001 Dec;40(12):639-51. Review.  
*Citation on PubMed:* <https://www.ncbi.nlm.nih.gov/pubmed/11771918>
- Visootsak J, Graham JM Jr. Klinefelter syndrome and other sex chromosomal aneuploidies. *Orphanet J Rare Dis*. 2006 Oct 24;1:42. Review.  
*Citation on PubMed:* <https://www.ncbi.nlm.nih.gov/pubmed/17062147>  
*Free article on PubMed Central:* <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1634840/>
- Visootsak J, Rosner B, Dykens E, Tartaglia N, Graham JM Jr. Behavioral phenotype of sex chromosome aneuploidies: 48,XXYY, 48,XXXYY, and 49,XXXXY. *Am J Med Genet A*. 2007 Jun 1; 143A(11):1198-203.  
*Citation on PubMed:* <https://www.ncbi.nlm.nih.gov/pubmed/17497714>
- Wimplinger I, Rauch A, Orth U, Schwarzer U, Trautmann U, Kutsche K. Mother and daughter with a terminal Xp deletion: implication of chromosomal mosaicism and X-inactivation in the high clinical variability of the microphthalmia with linear skin defects (MLS) syndrome. *Eur J Med Genet*. 2007 Nov-Dec;50(6):421-31. Epub 2007 Aug 6.  
*Citation on PubMed:* <https://www.ncbi.nlm.nih.gov/pubmed/17845869>

Reprinted from Genetics Home Reference:  
<https://ghr.nlm.nih.gov/chromosome/X.pdf>

Reviewed: December 2017  
Published: June 12, 2018

Lister Hill National Center for Biomedical Communications  
U.S. National Library of Medicine  
National Institutes of Health  
Department of Health & Human Services