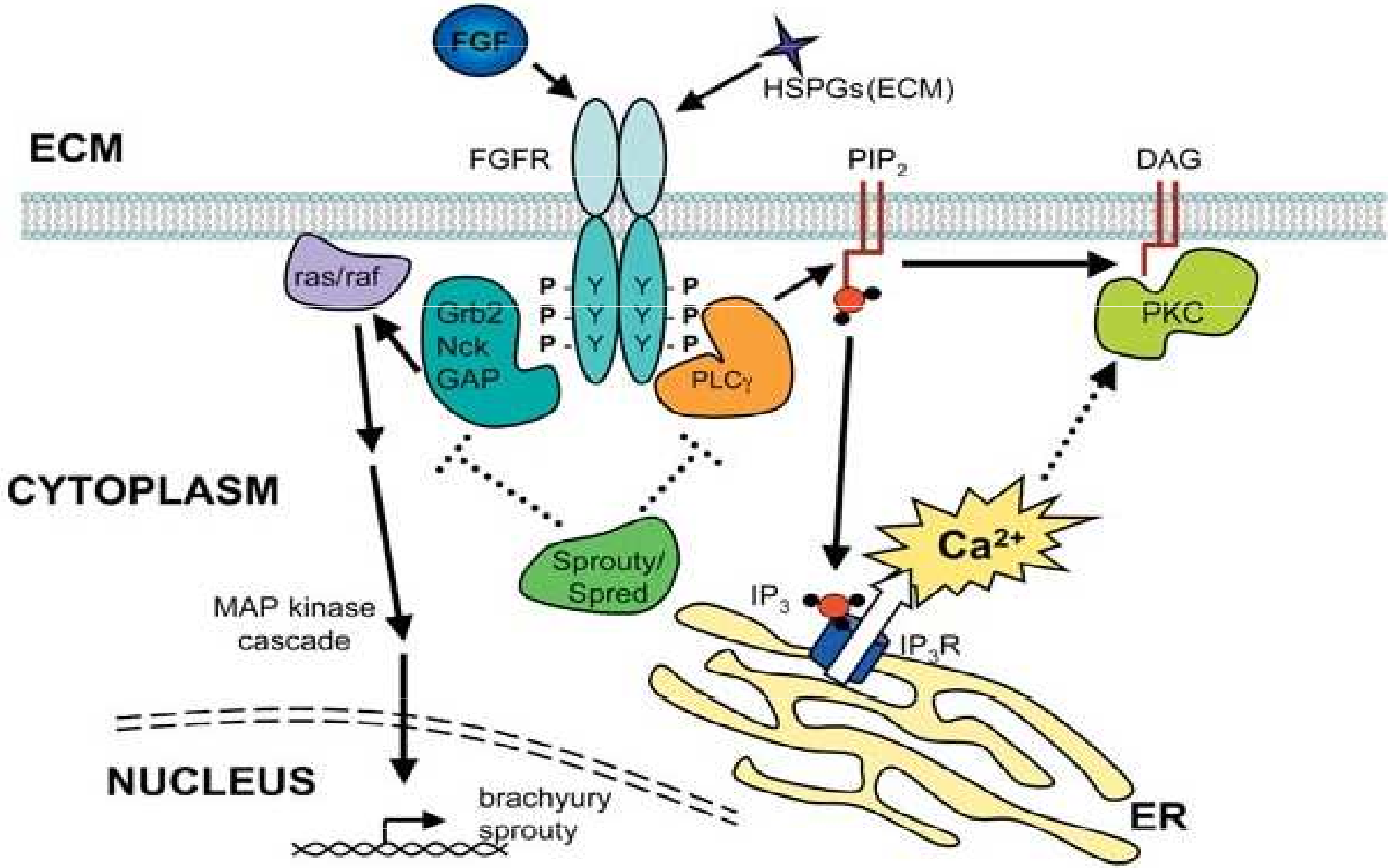
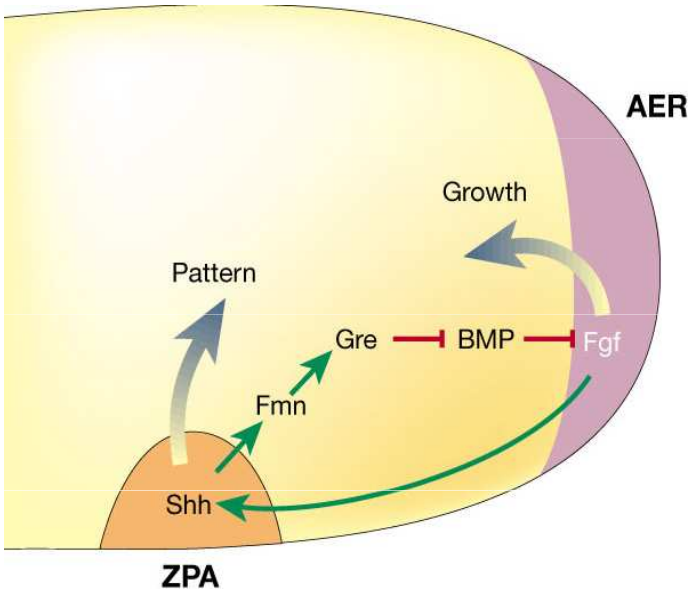
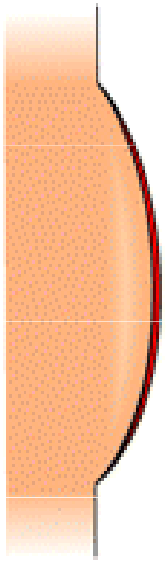
9. MECHANISMS OF DEVELOPMENT I – REGULATION OF LIMB DEVELOPMENT BY FIBROBLAST GROWTH FACTORS (FGF)

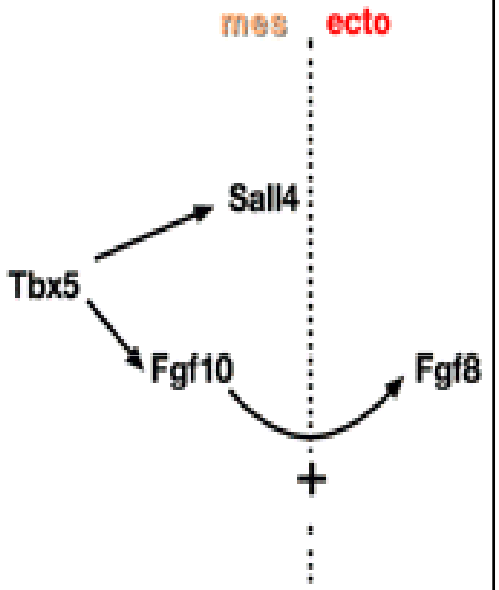
4 receptors: FGFR1-4
22 ligands: FGF1-23

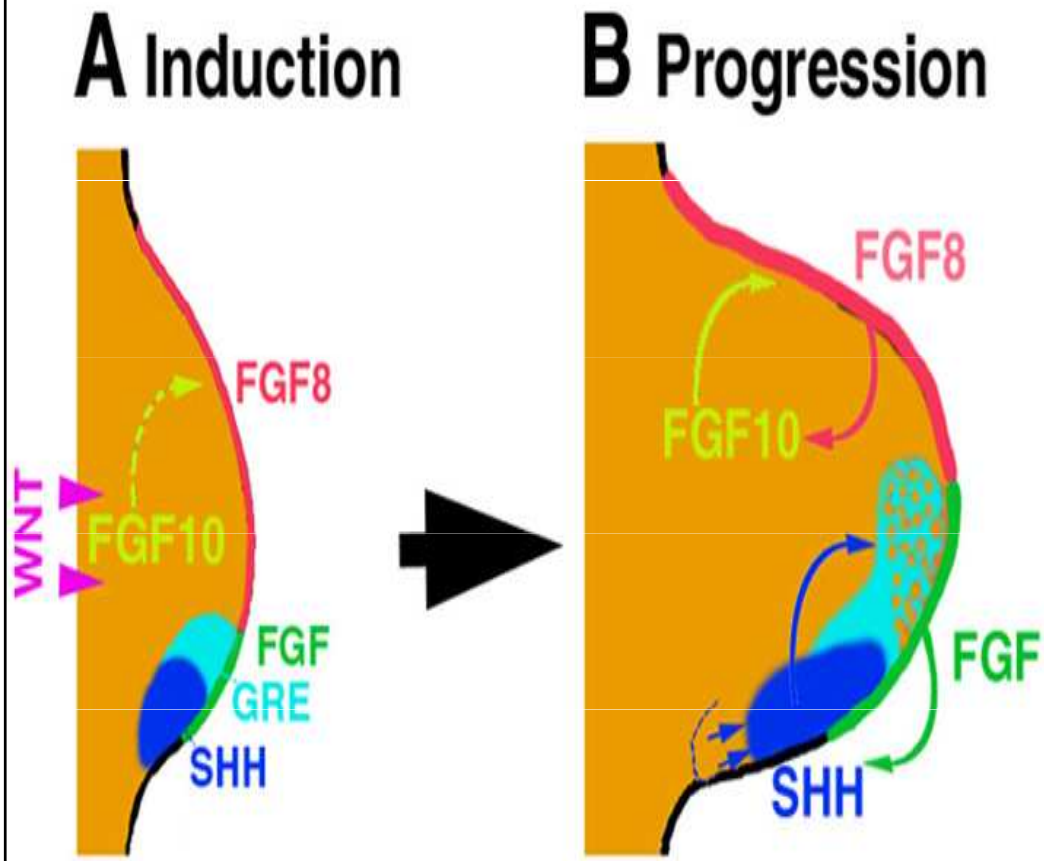


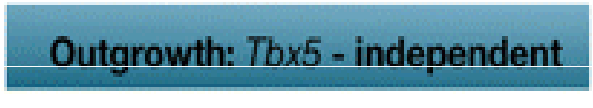

AER
Growth
Pattern
Gre
BMP
Fgf
Fmn
Shh
ZPA

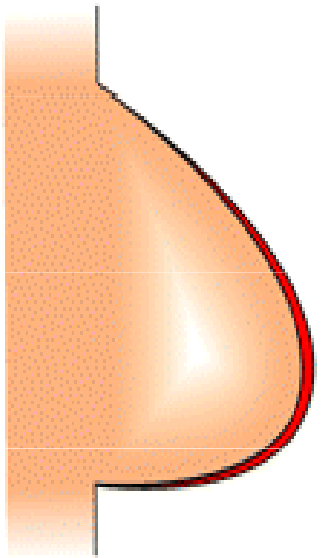

Initiation: Tbx5 - dependent

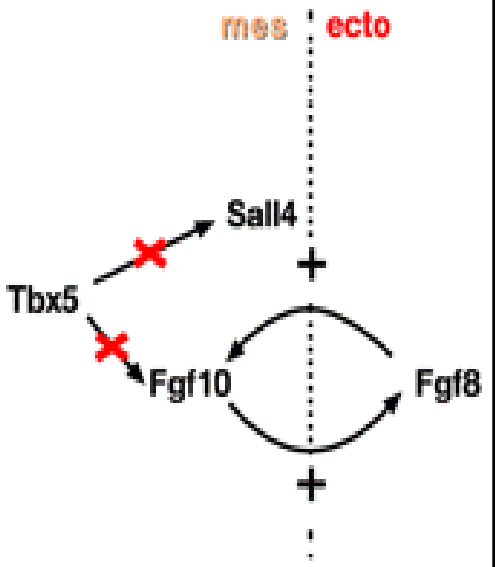



mes
ecto
Sall4
Tbx5
Fgf10
Fgf8


A Induction
B Progression
FGF8
WNT
FGF10
FGF
GRE
SHH
FGF8
FGF10
FGF
SHH


Outgrowth: Tbx5 - independent



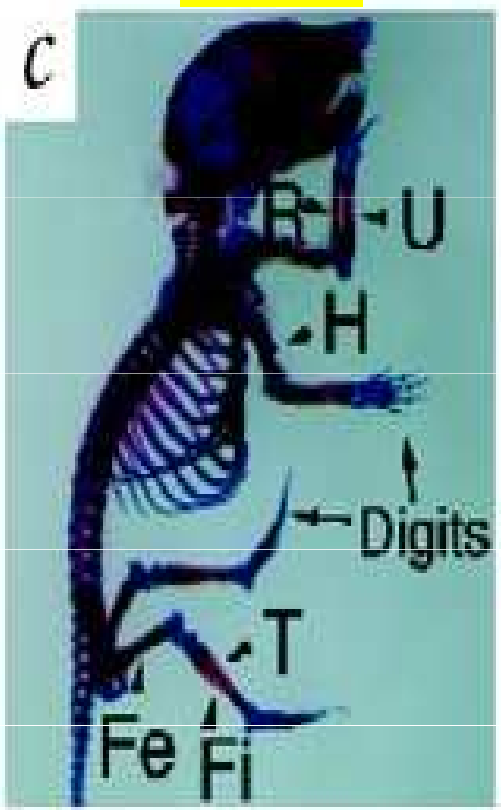

mes
ecto
Sall4
Tbx5
Fgf10
Fgf8

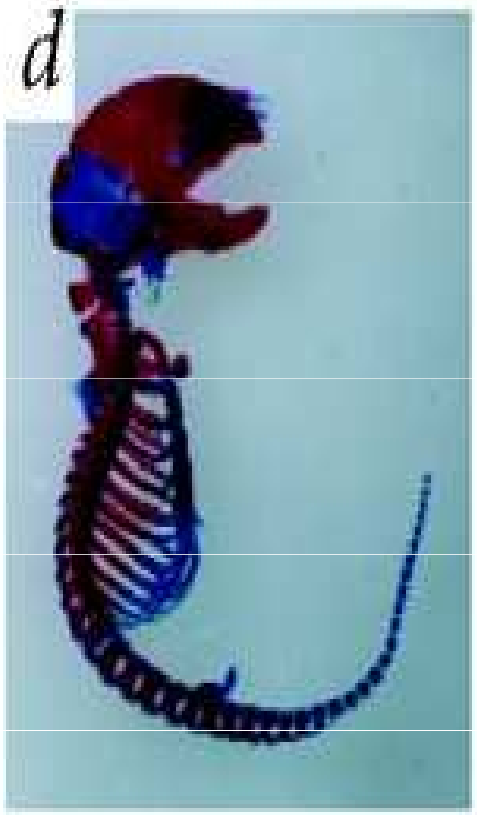
wt

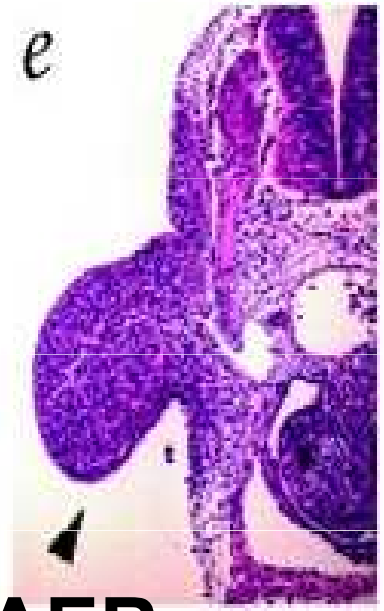
Fgf10-/-

wt

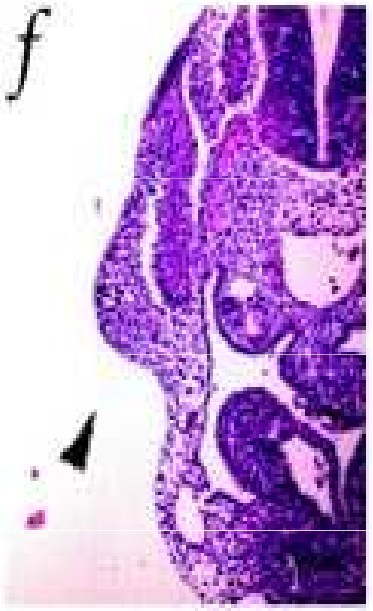
Fgf10-/-

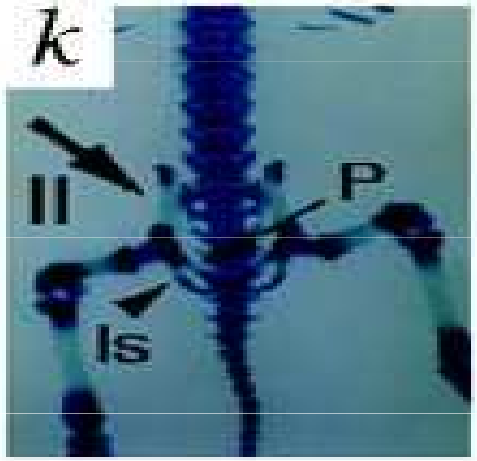


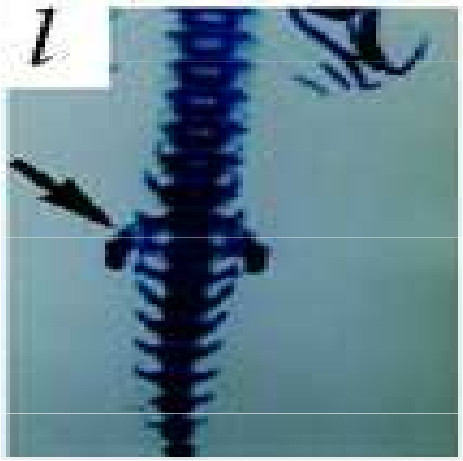




AER



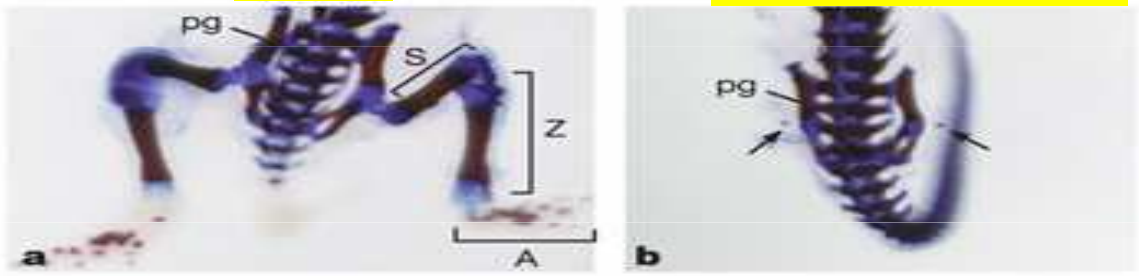




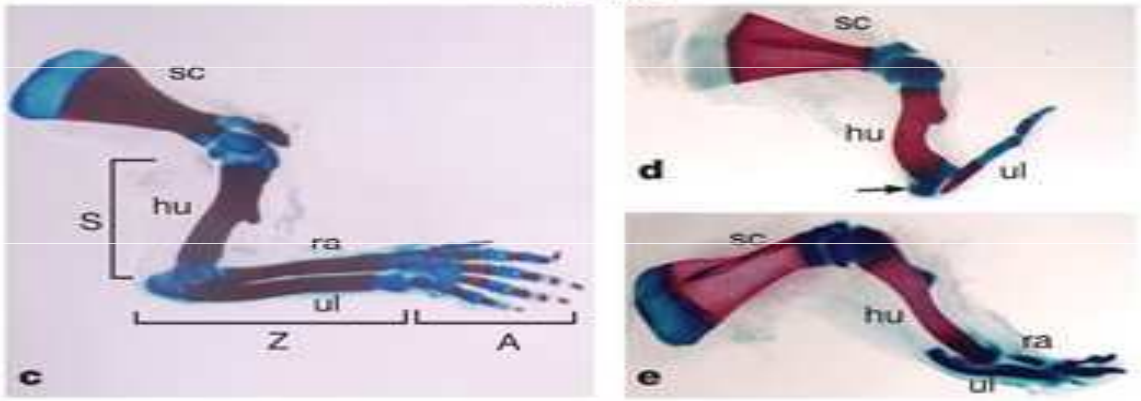
wt

Hindlimb

Fgf8/Fgf4$^{-/-}$



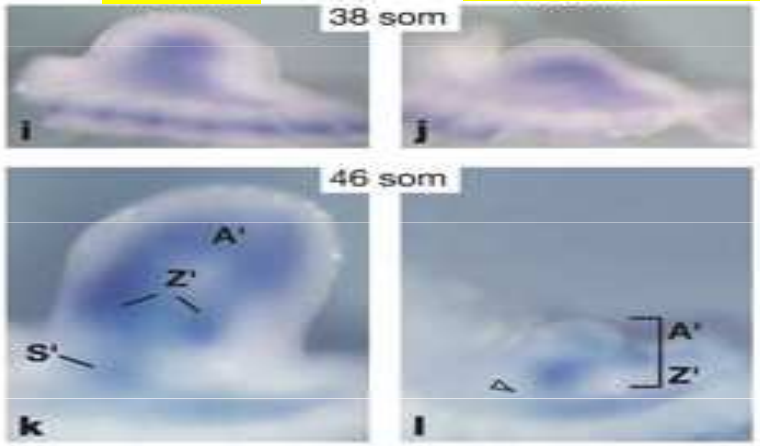
Forelimb



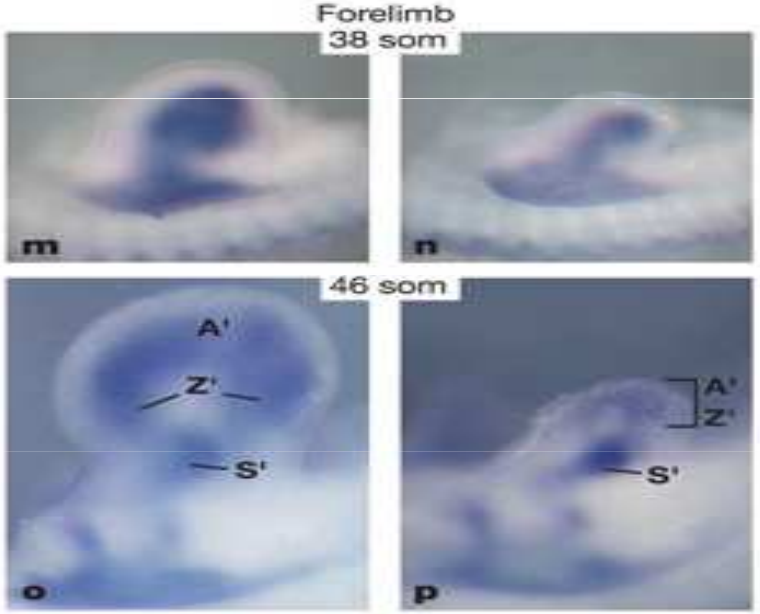
wt

Hindlimb

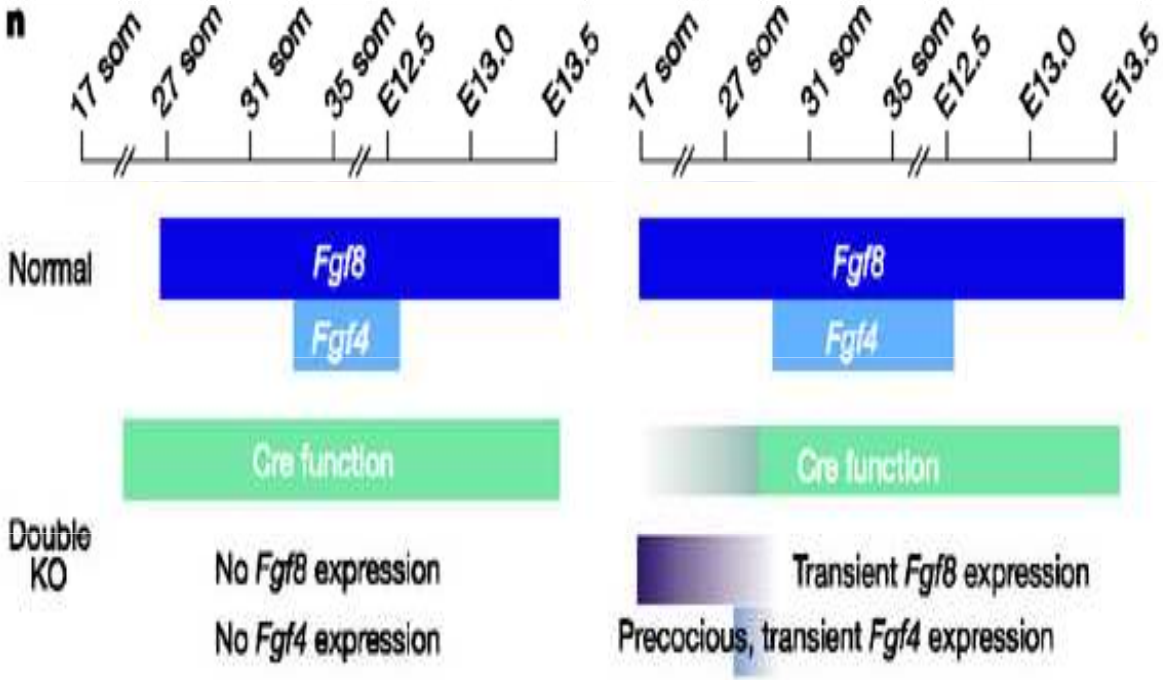
Fgf8/Fgf4$^{-/-}$

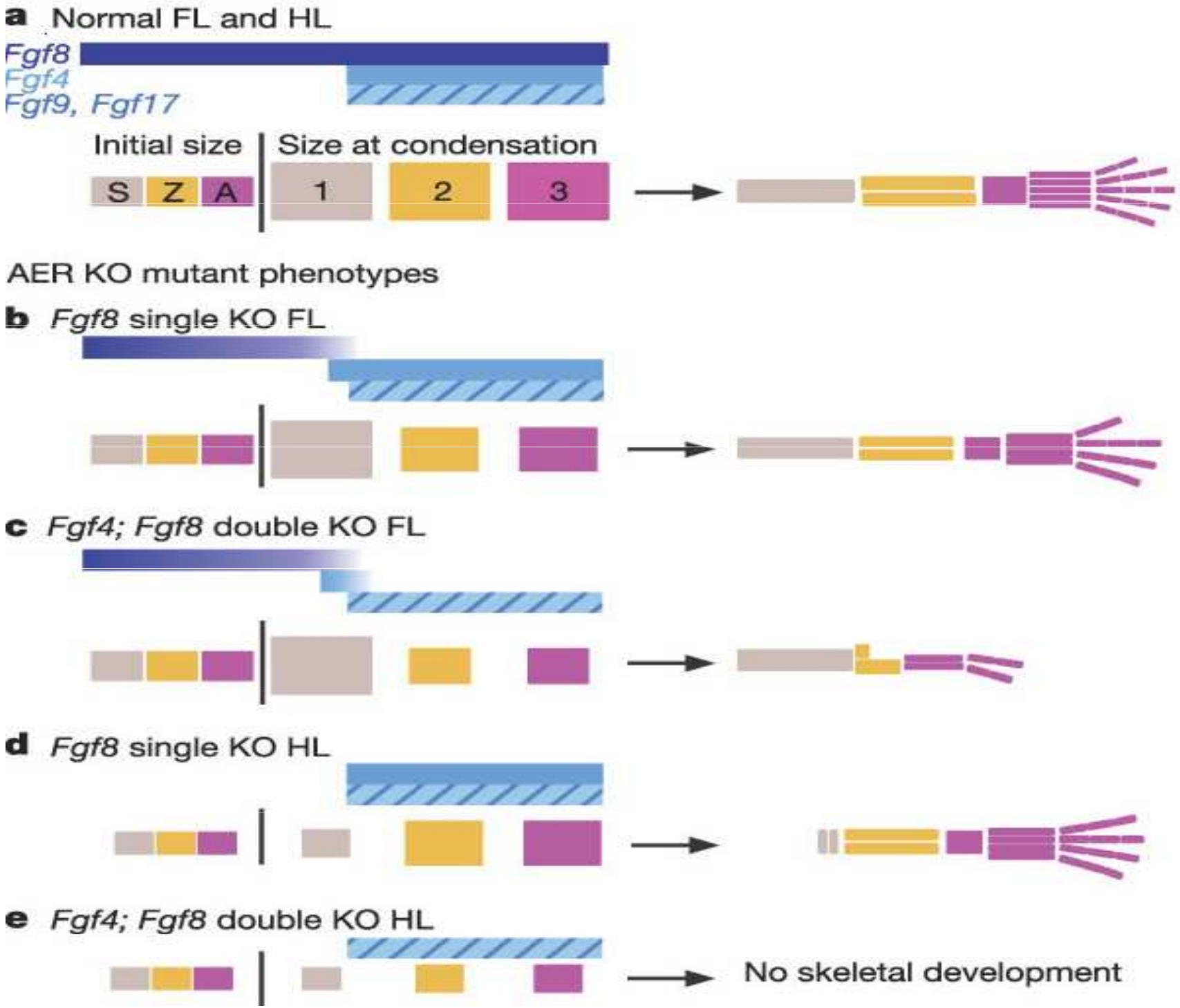


Forelimb

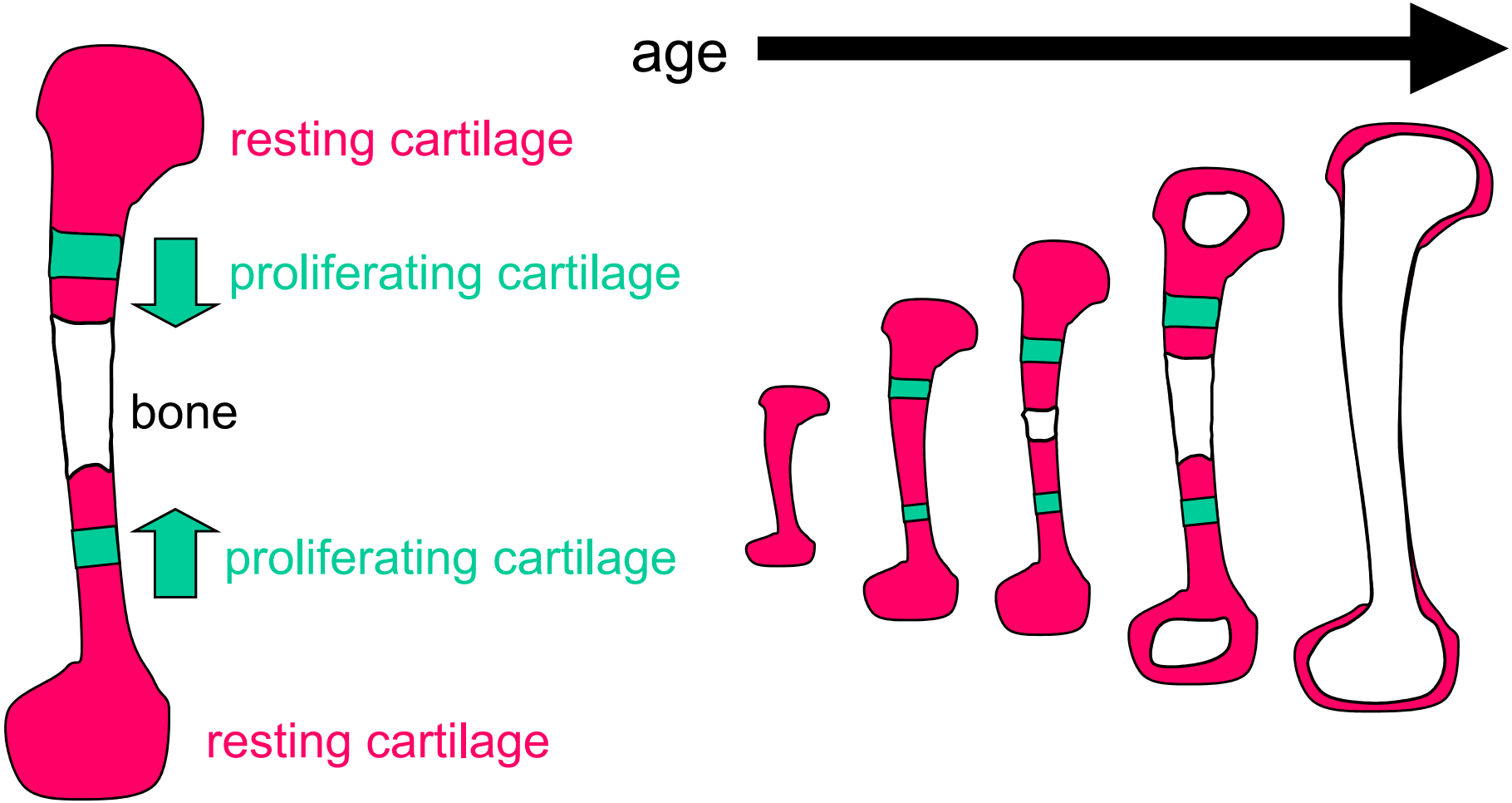


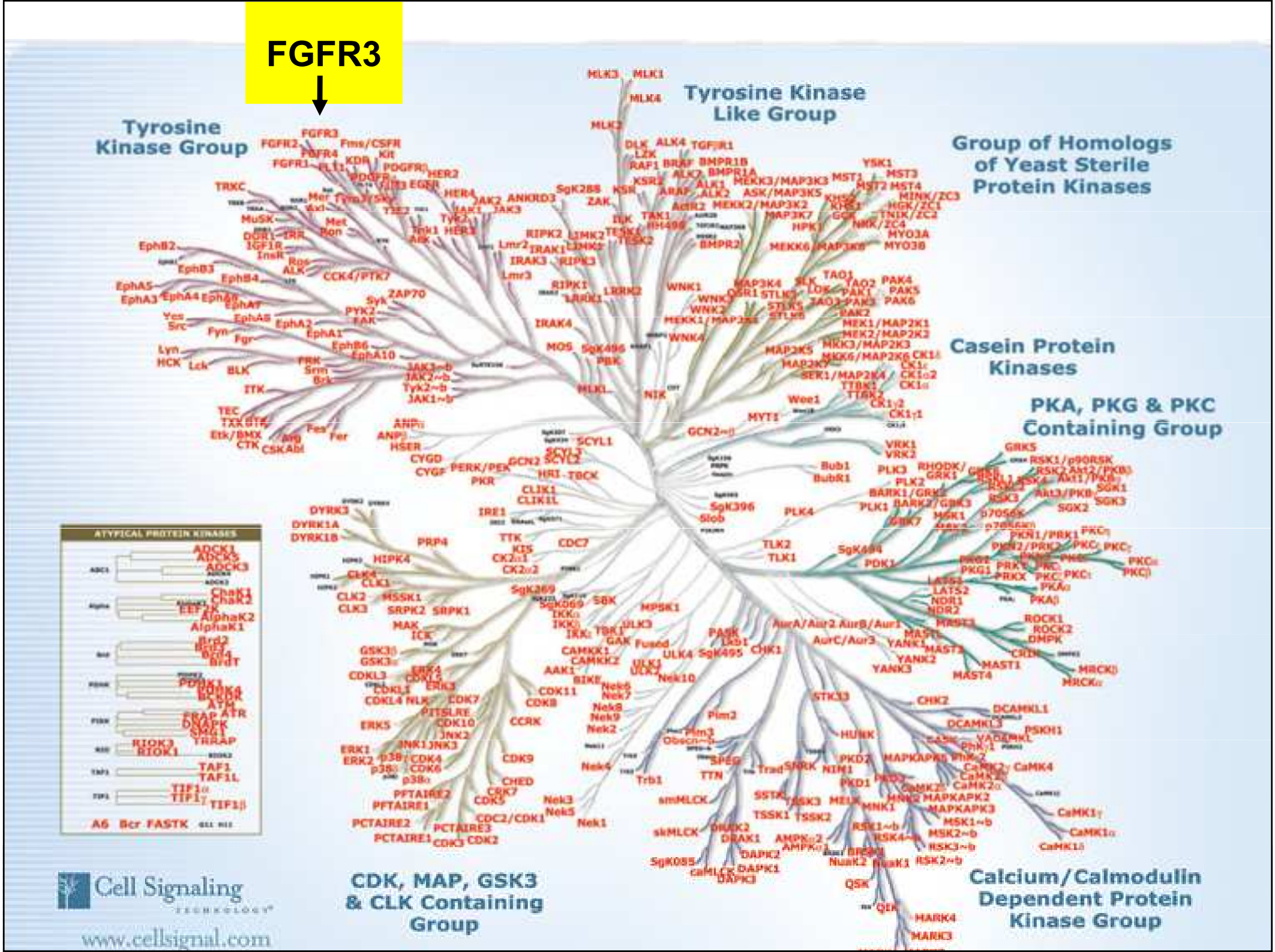
n

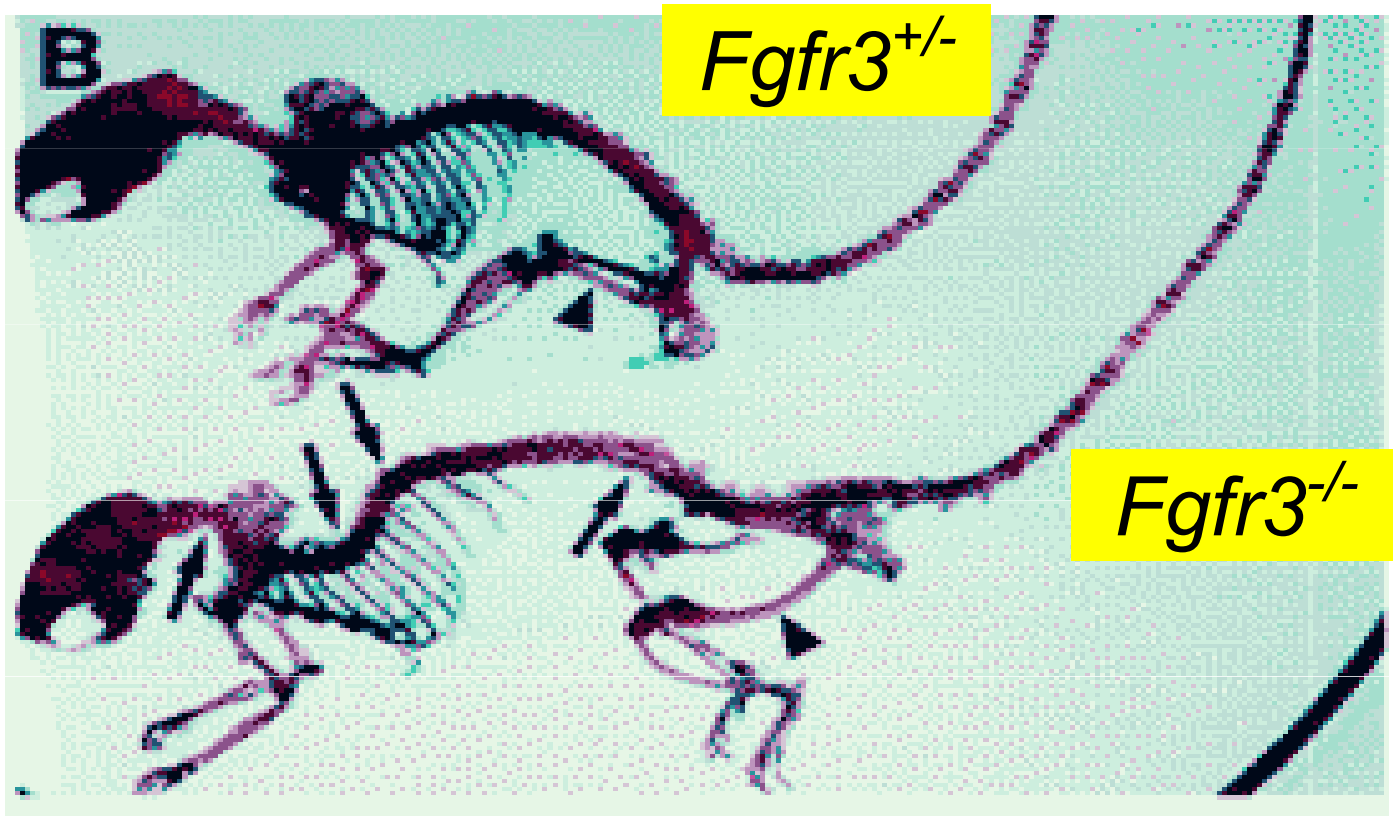



a Normal FL and HL
Fgf8
Fgf4
Fgf9, Fgf17
Initial size
Size at condensation
S
Z
A
1
2
3
AER KO mutant phenotypes
b Fgf8 single KO FL
c Fgf4; Fgf8 double KO FL
d Fgf8 single KO HL
e Fgf4; Fgf8 double KO HL
No skeletal development

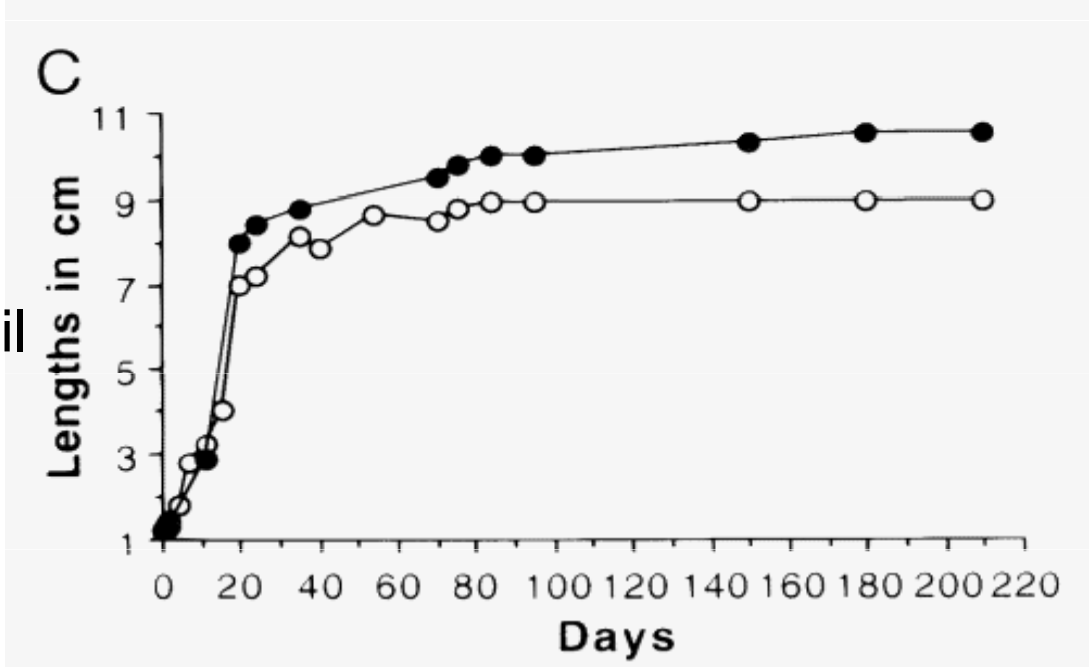
How do the limbs grow?




FGFR3
Tyrosine Kinase Group
Tyrosine Kinase Like Group
Group of Homologs of Yeast Sterile Protein Kinases
Casein Protein Kinases
PKA, PKG & PKC Containing Group
CDK, MAP, GSK3 & CLK Containing Group
Calcium/Calmodulin Dependent Protein Kinase Group
ATYPICAL PROTEIN KINASES
Cell Signaling TECHNOLOGY
www.cellsignal.com



Tail

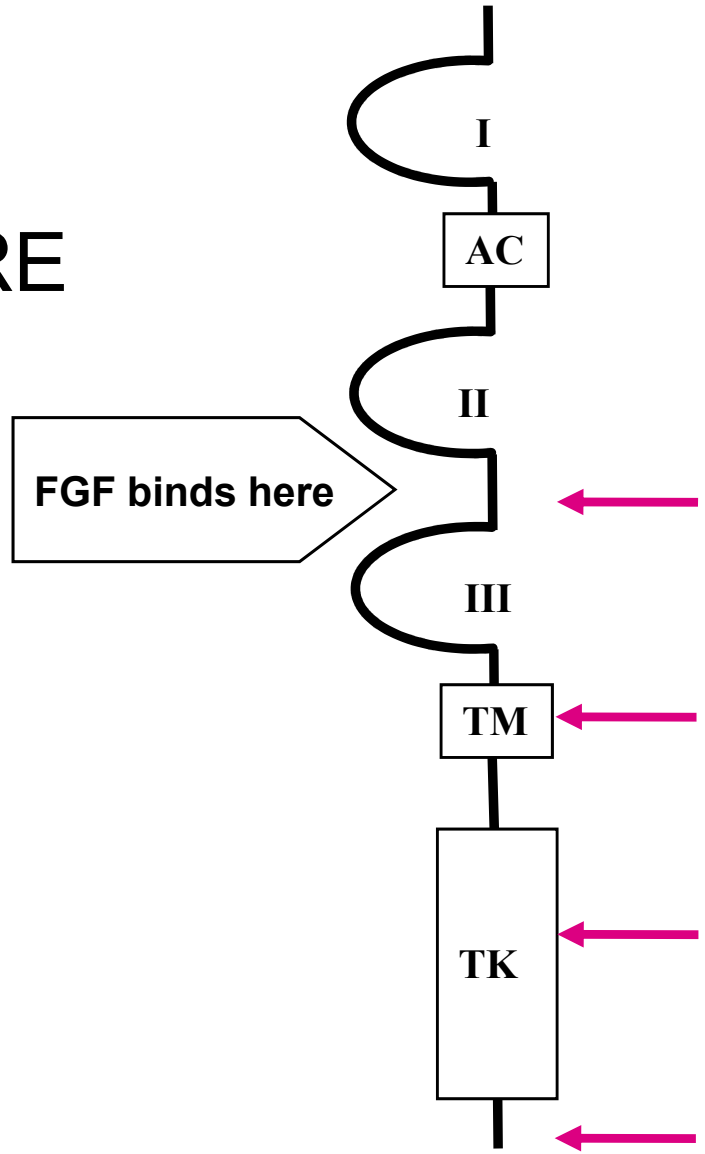


Fgfr3+/-
Fgfr3-/-

FGFR3-related skeletal dysplasia

STATURE

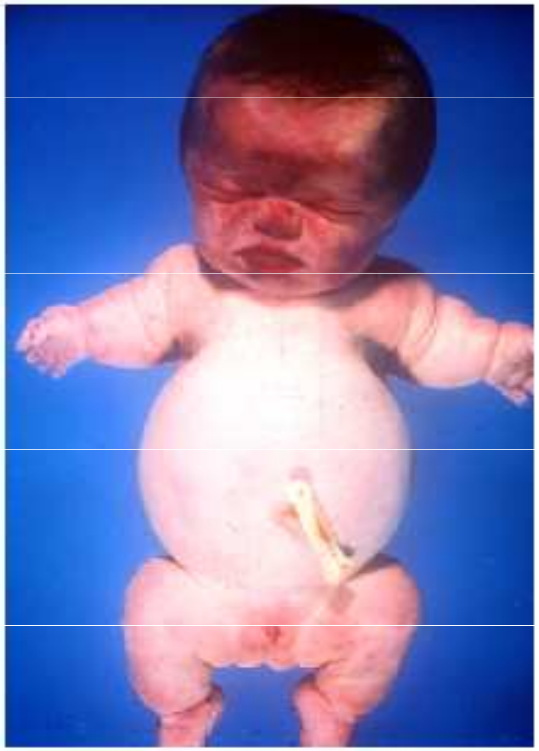
Hypochondroplasia
Achondroplasia
SADDAN
Thanatophoric Dysplasia

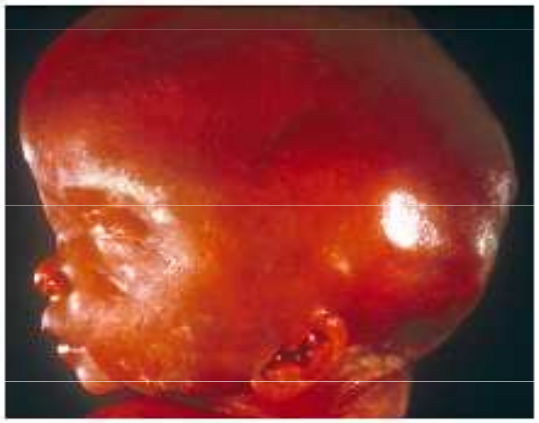


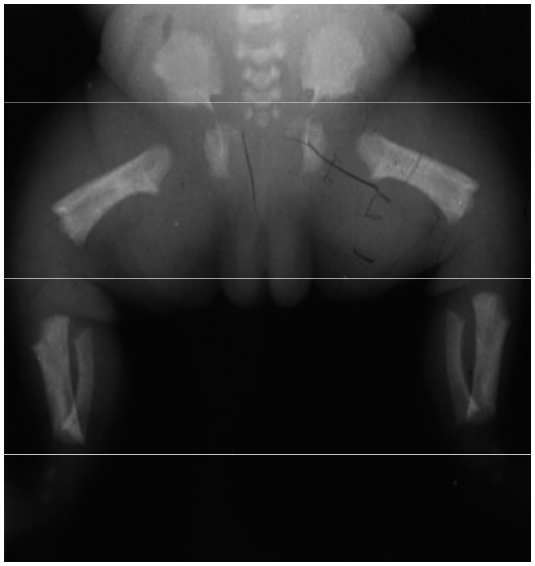
FGFR3-related skeletal dysplasia

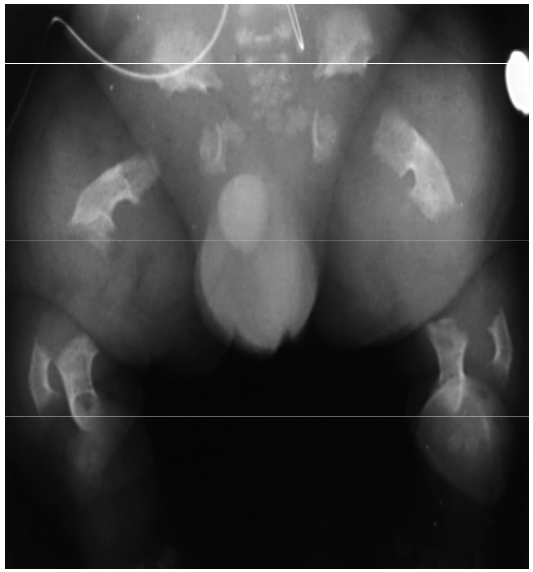
Achondroplasia

Thanatophoric Dysplasia





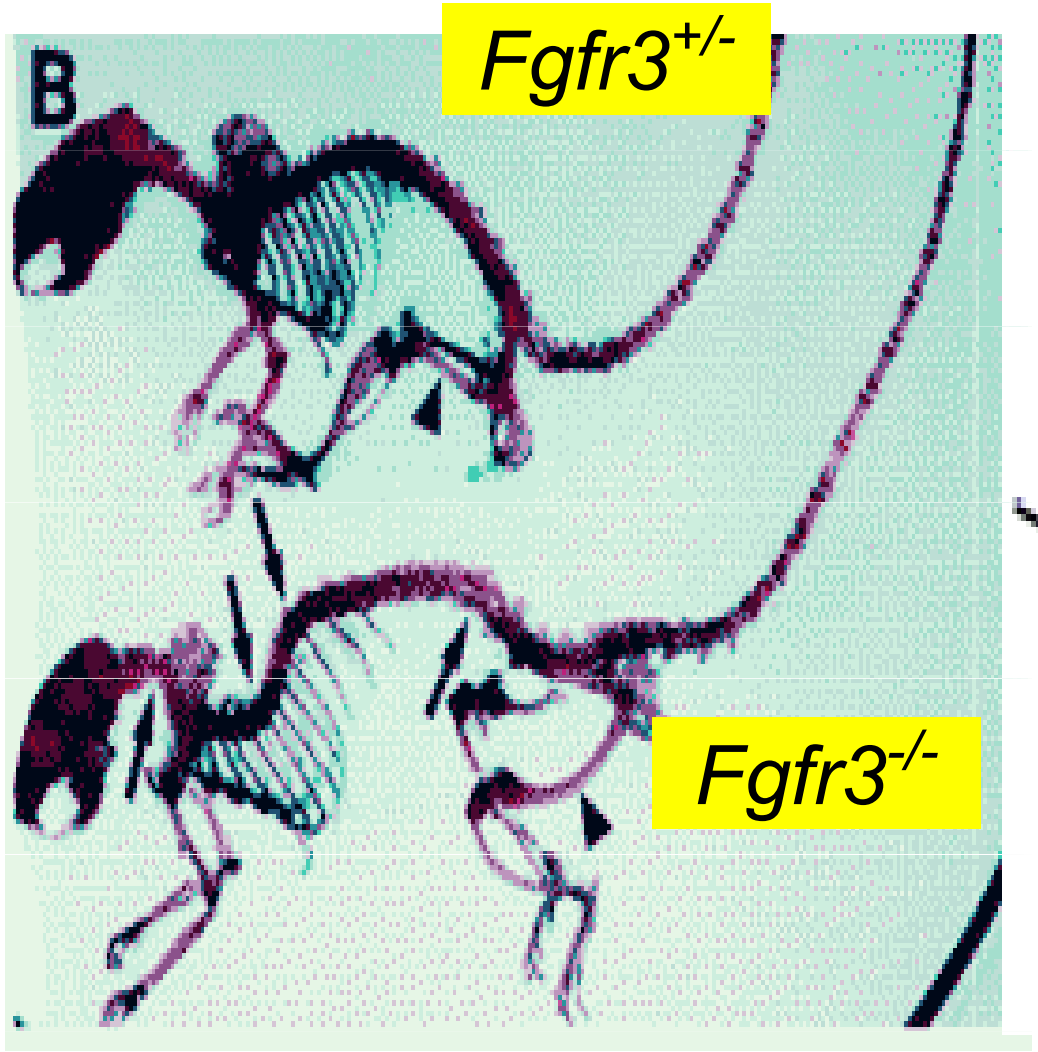


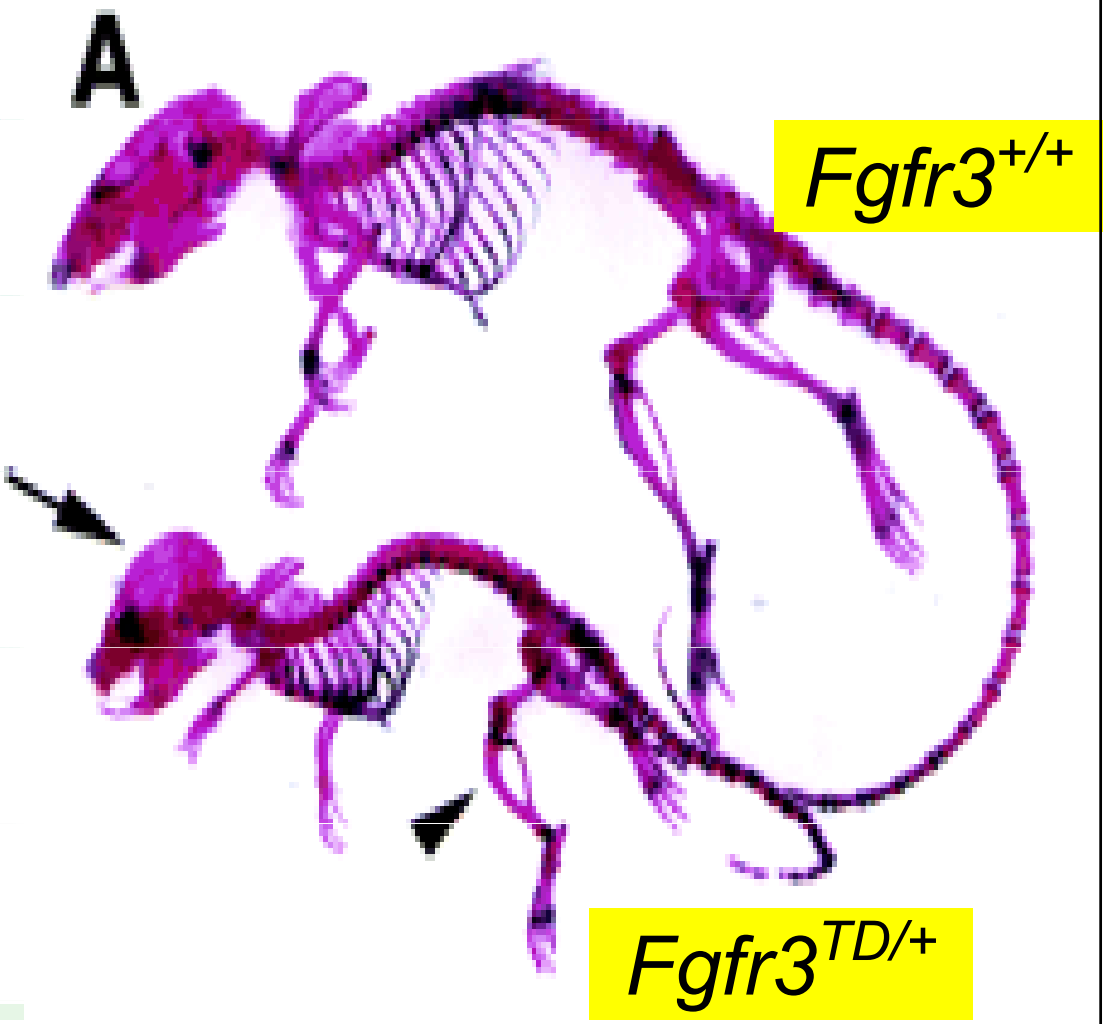


healthy

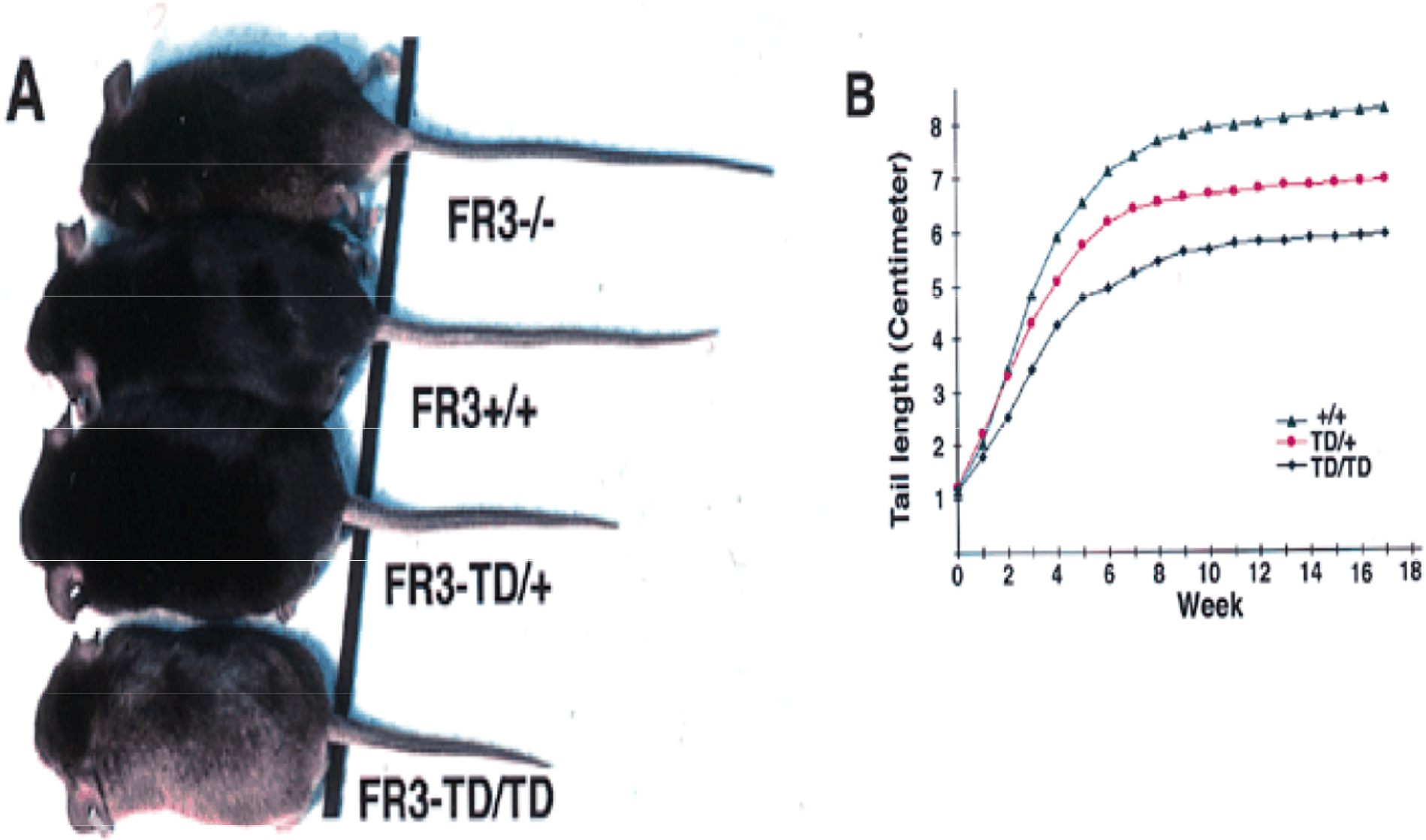
TD

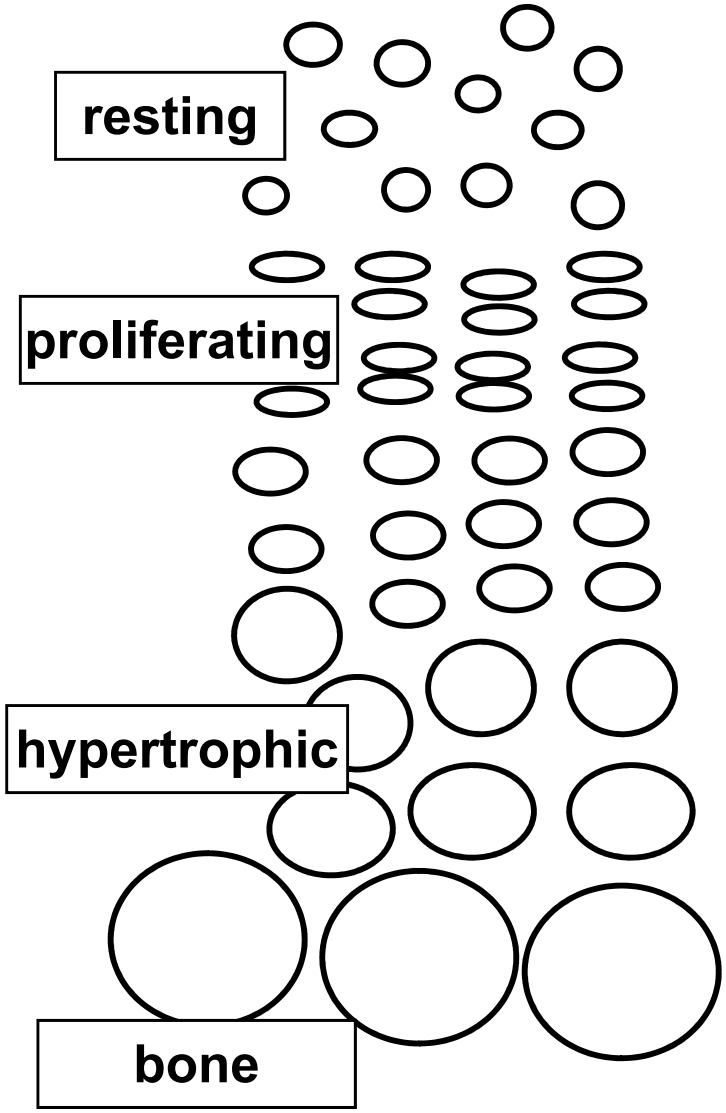
- short long bones
- brachydactyly
- macrocephaly
- low nasal bridge
- spinal stenosis
- temporal lobe malformations

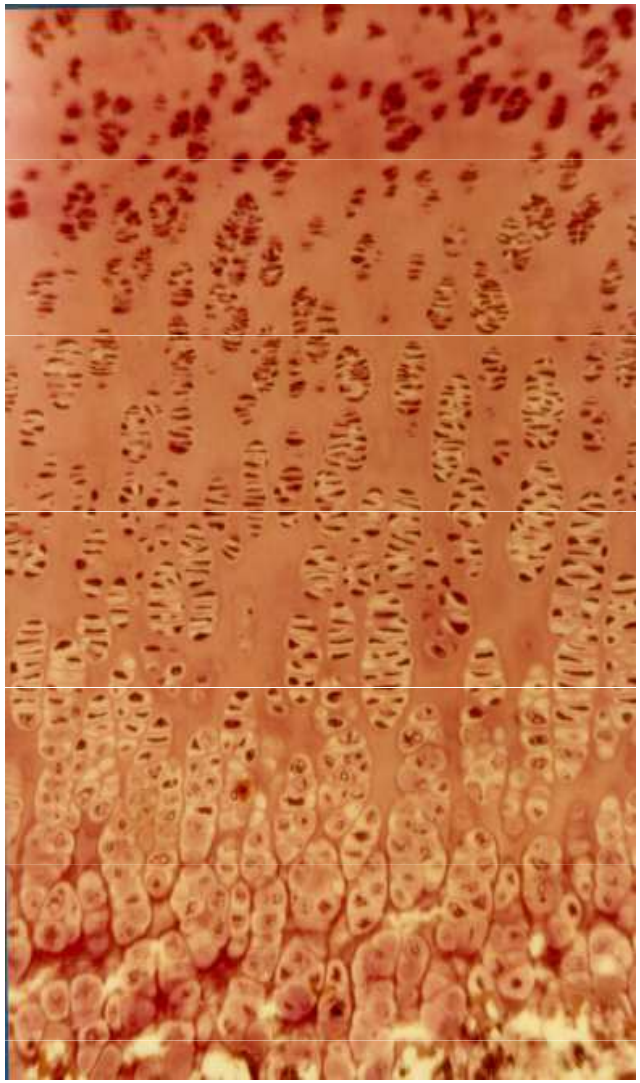




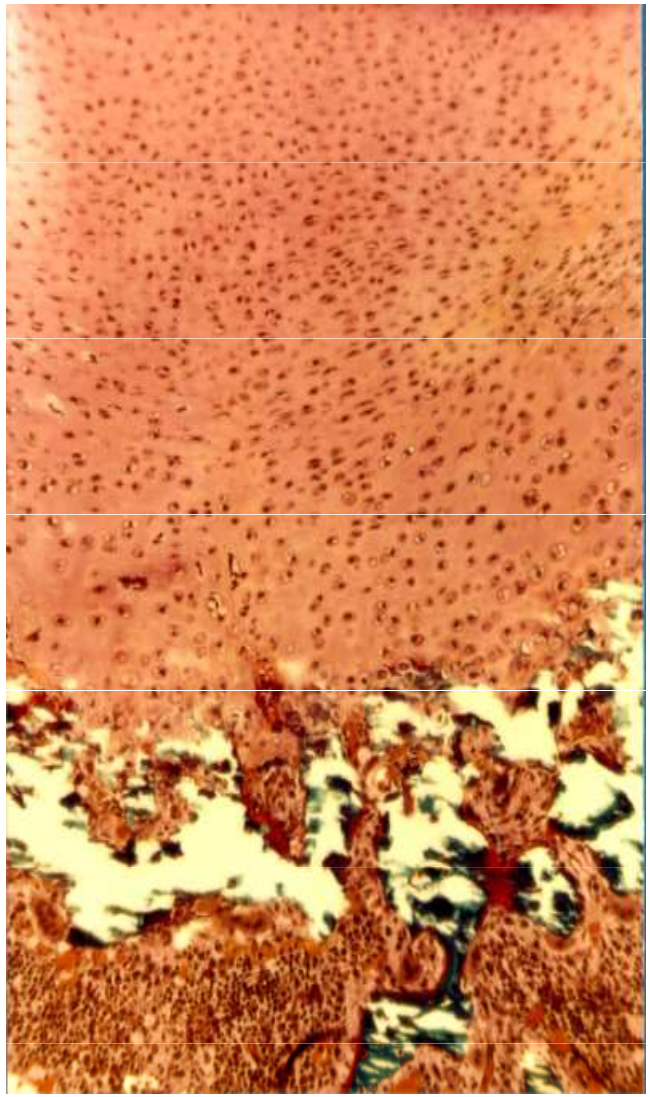
Loss-of-function vs. Gain-of-function


A
FR3-/-
FR3+/+
FR3-TD/+
FR3-TD/TD
B
Tail length (Centimeter)
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
Week
+/+
TD/+
TD/TD



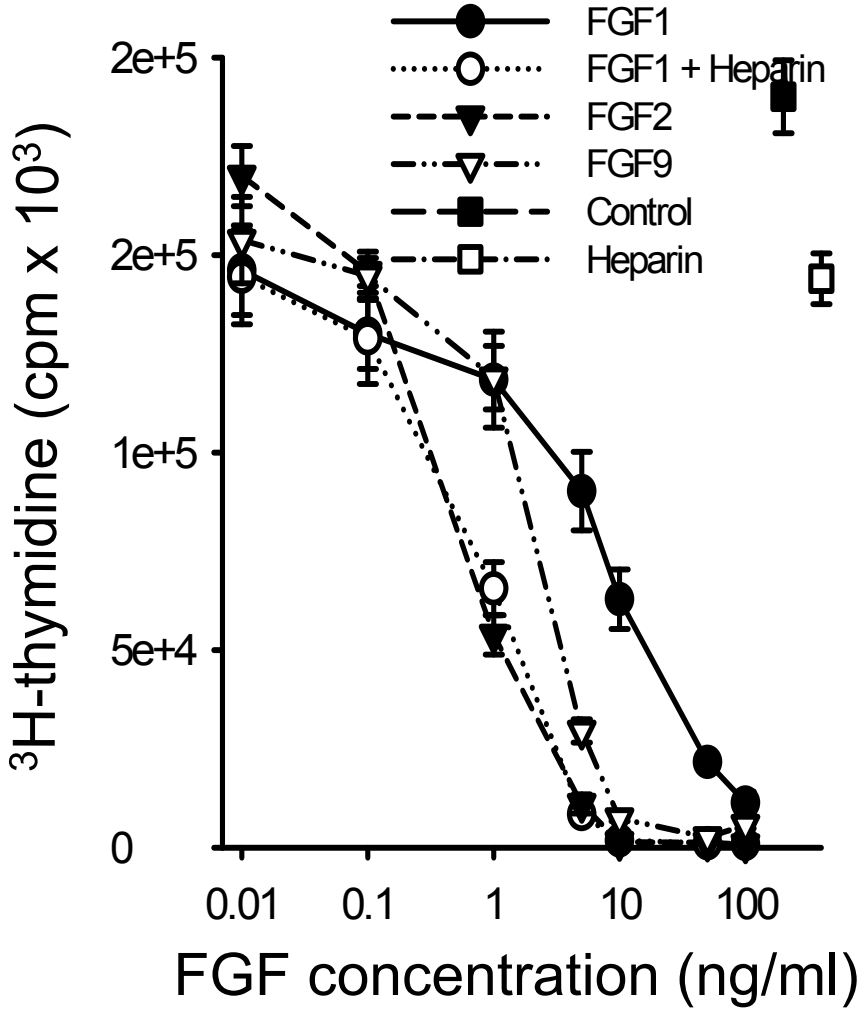


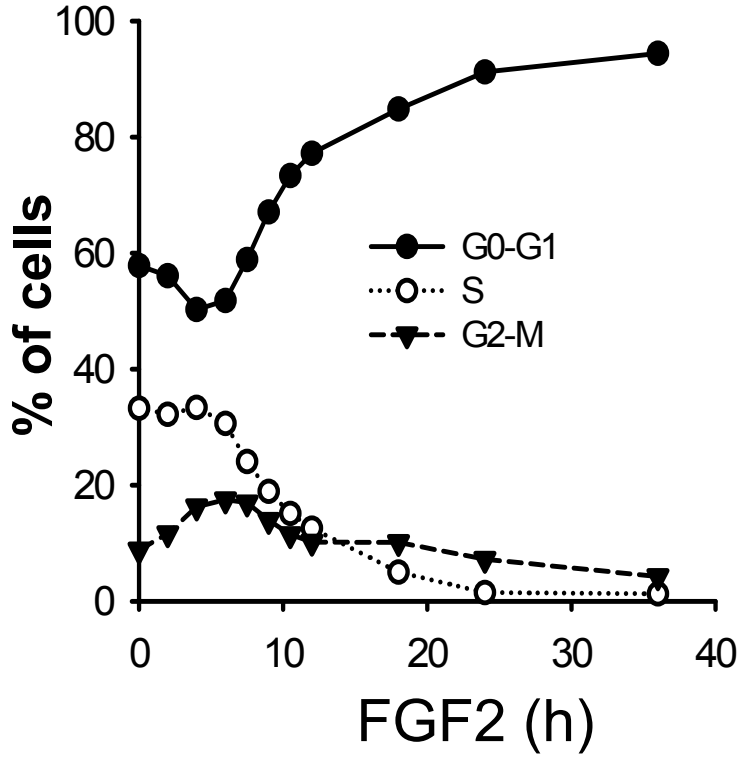
healthy



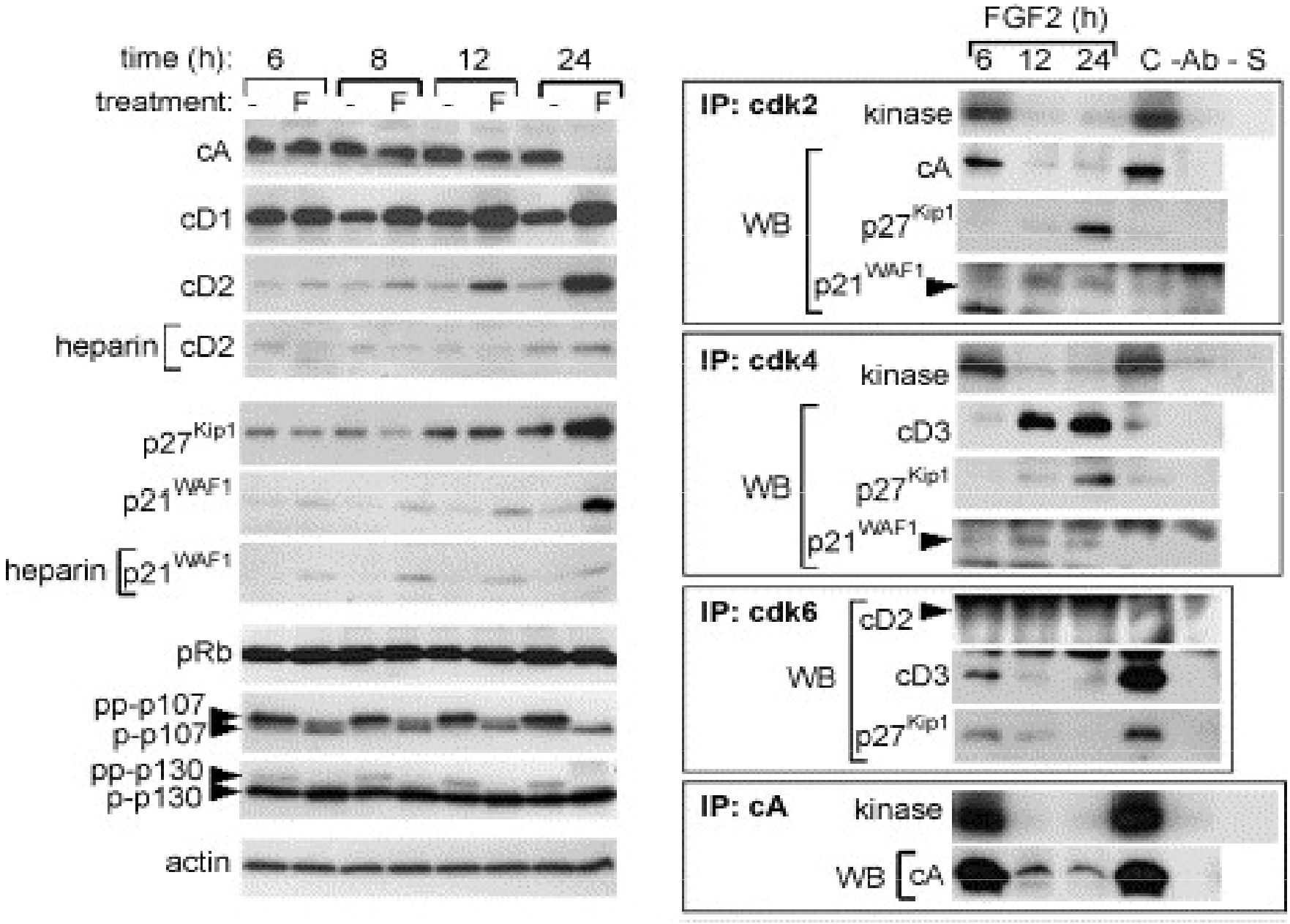
TD

FGFR3 inhibits chondrocyte proliferation by arresting their cell cycle in G1 phase

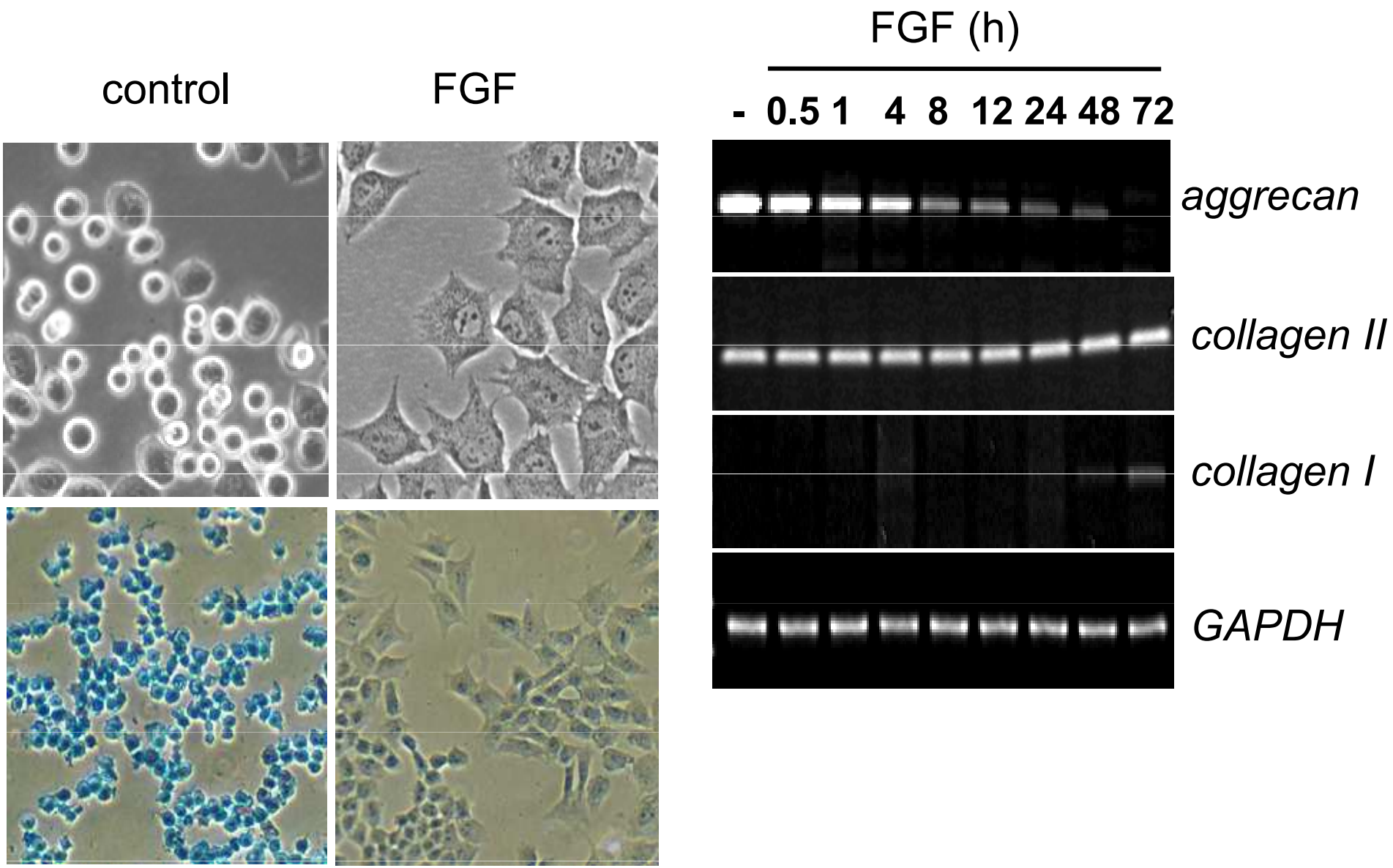




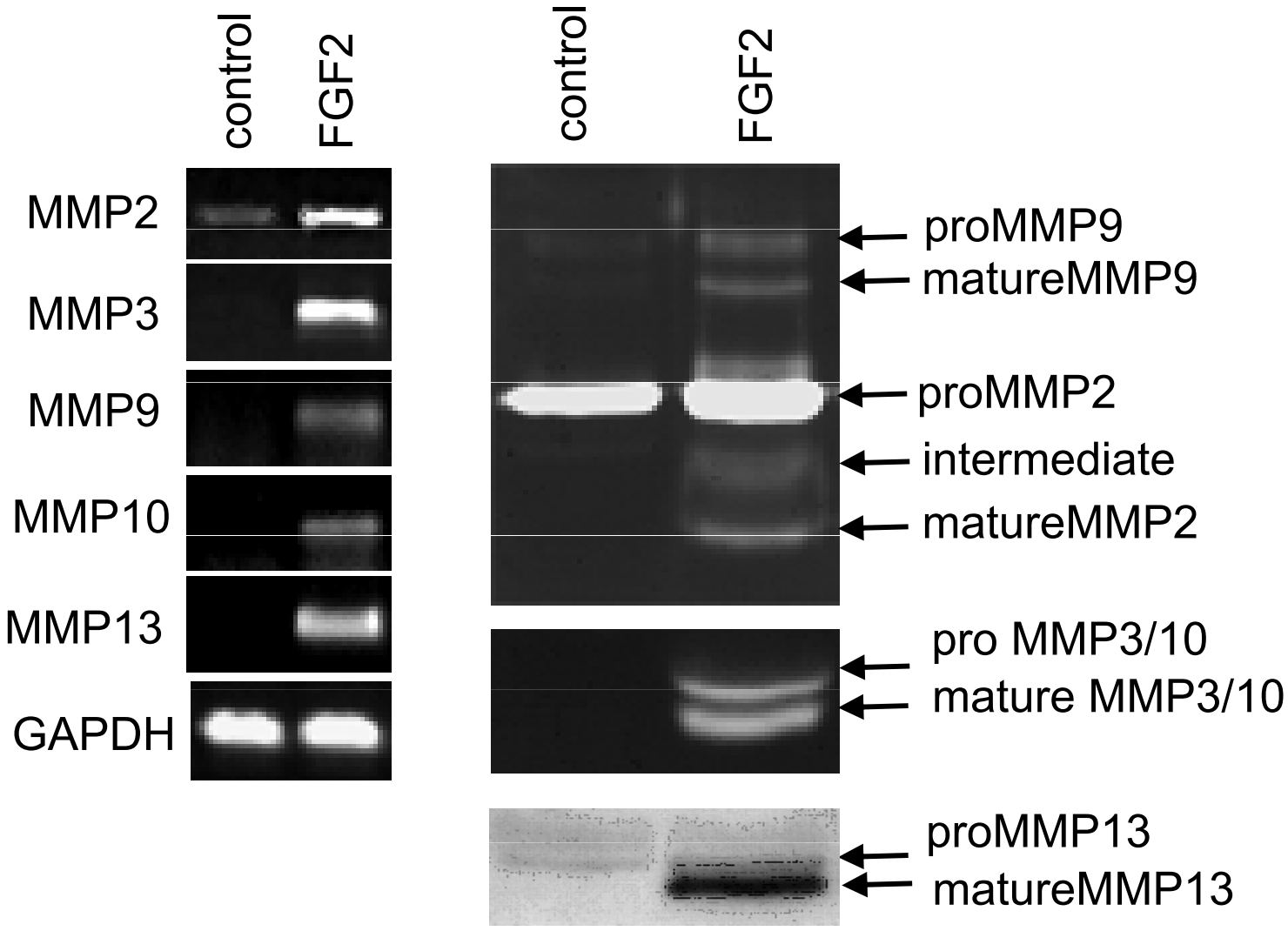
….via inhibition of cdk activity necessary for progression through the G1 phase of a cell cycle



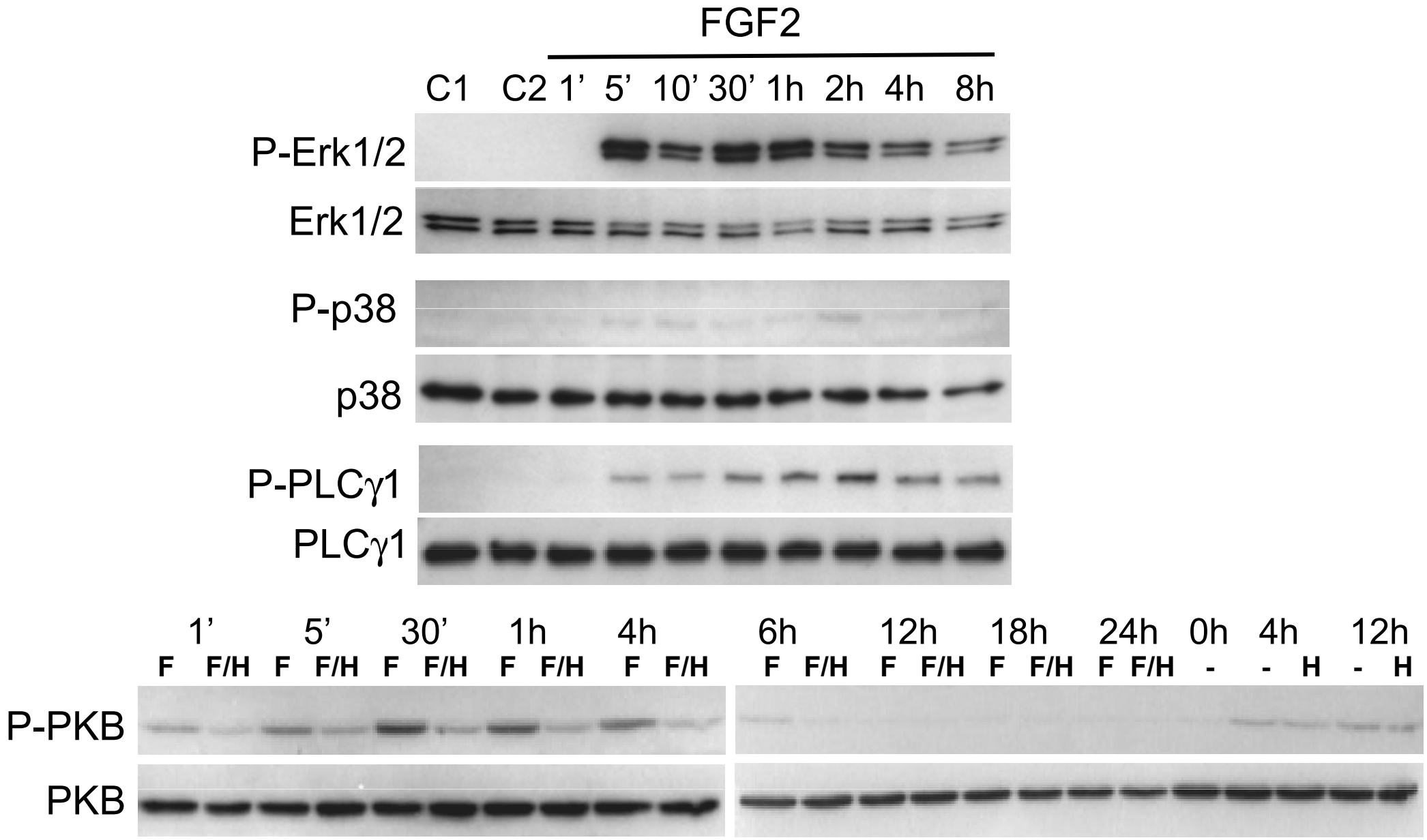
FGF alters the cartilage-like phenotype of chondrocytes



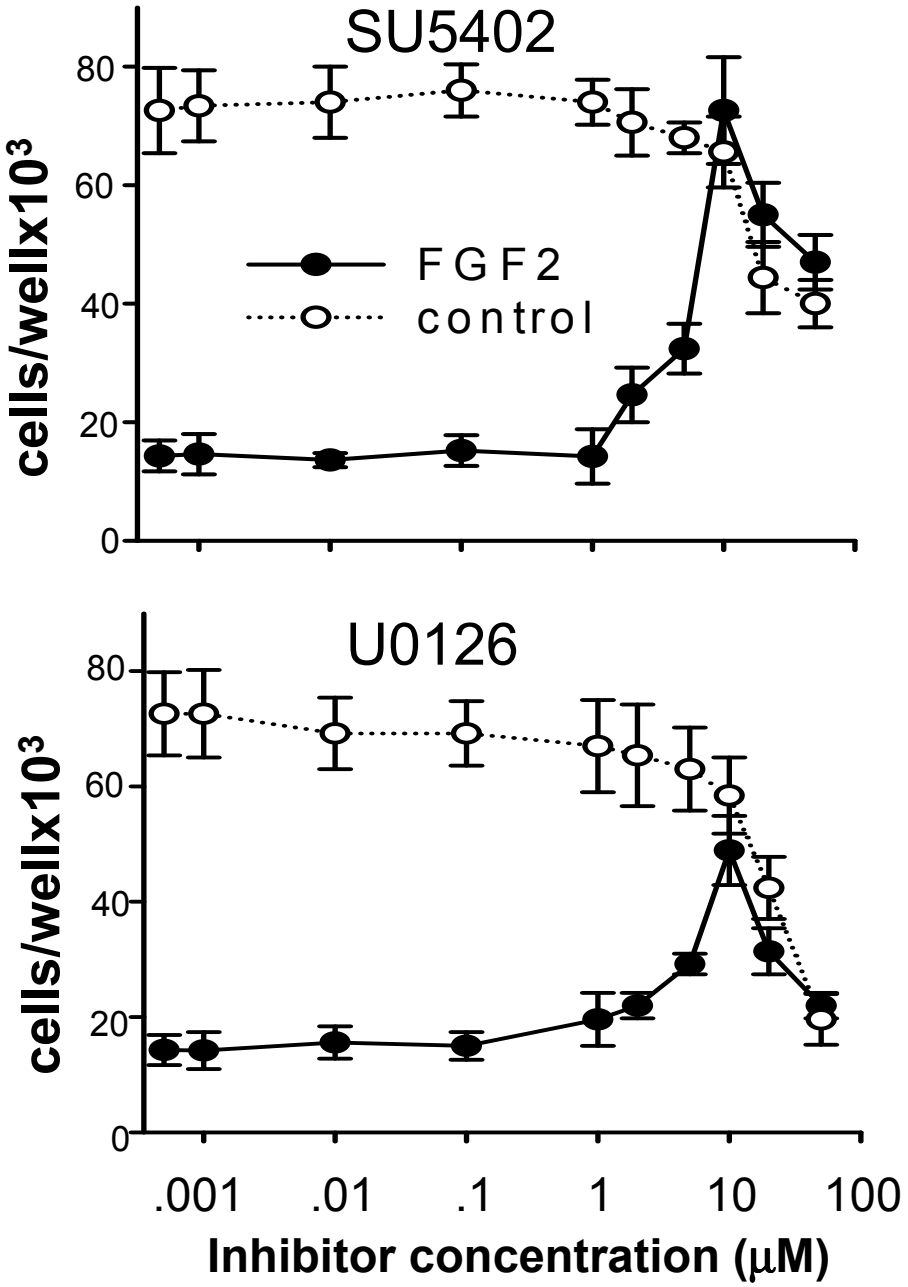
……via MMP-mediated degradation of extracellular matrix

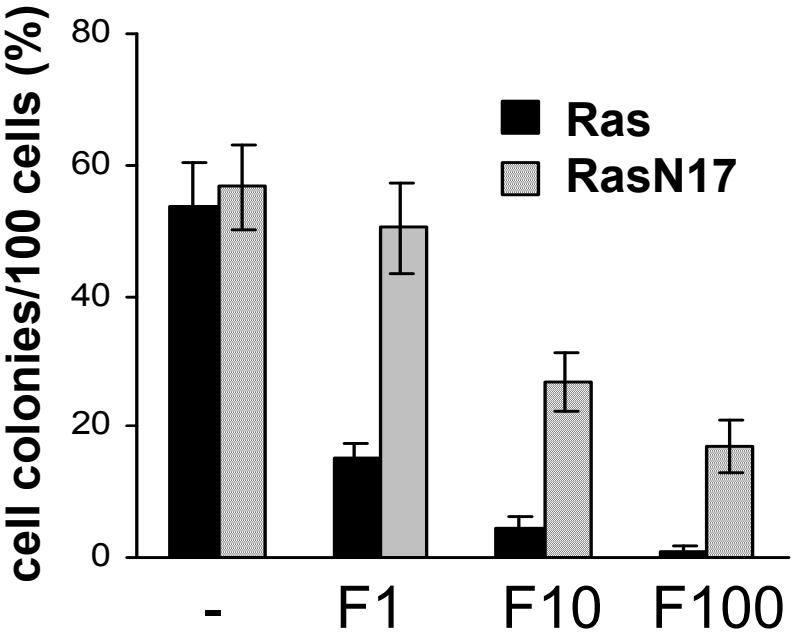


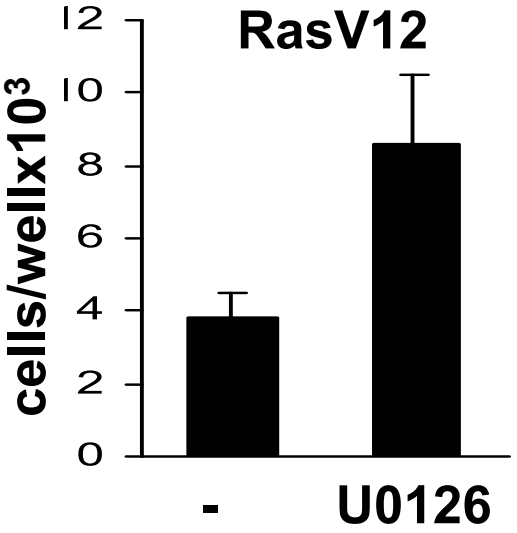
FGF2 activates Erk and p38 MAPK, PLCγ and PKB in chondrocytes



……but only Ras/Erk activity is involved in FGF-induced growth arrest



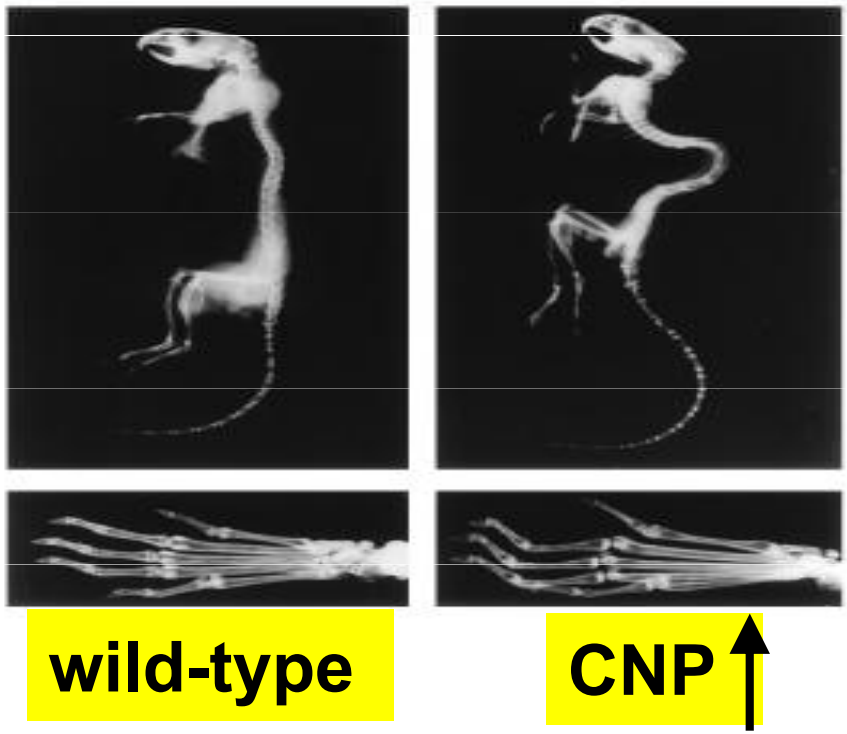


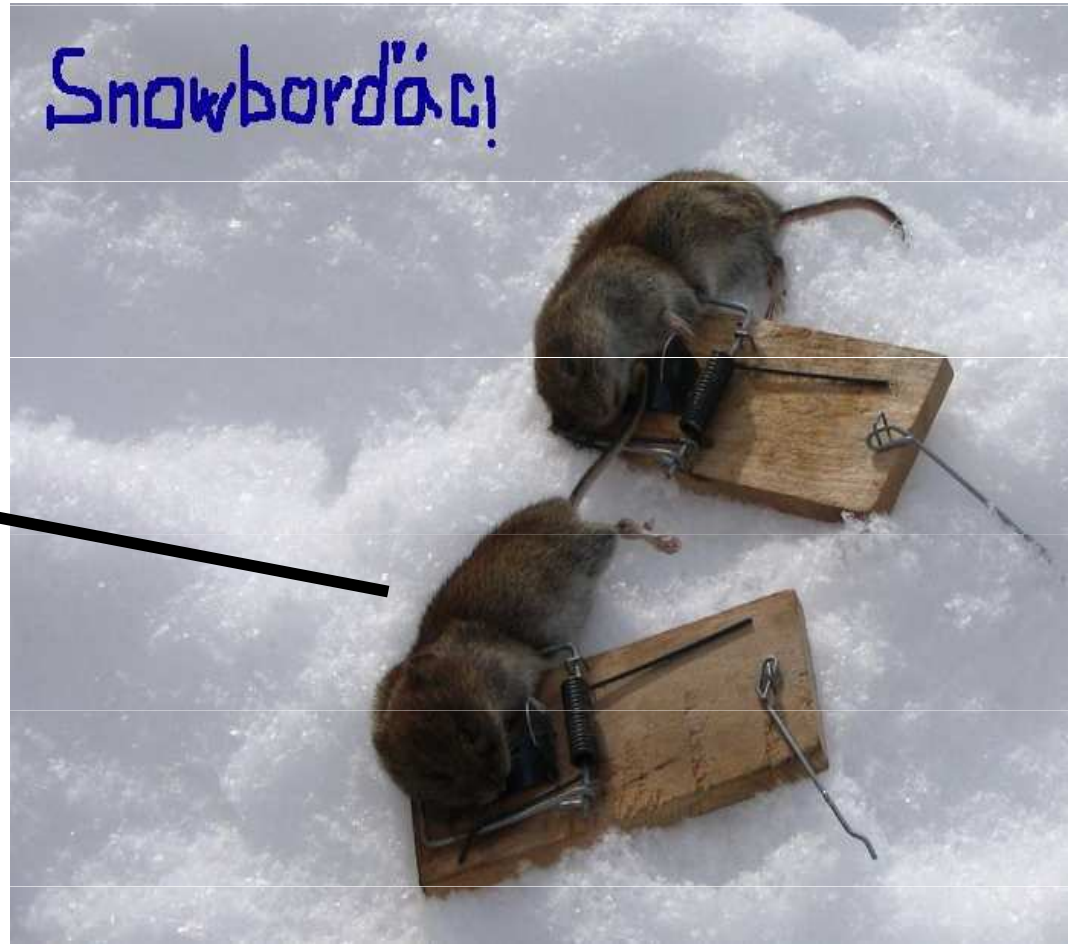


Erk MAP kinase activity is necessary for FGFR3 phenotype in cartilage

FGF2
↓
FGFR3
↓
FRS2
↓
Ras
↓
Raf-1
↓
MEK
↓
Erk →

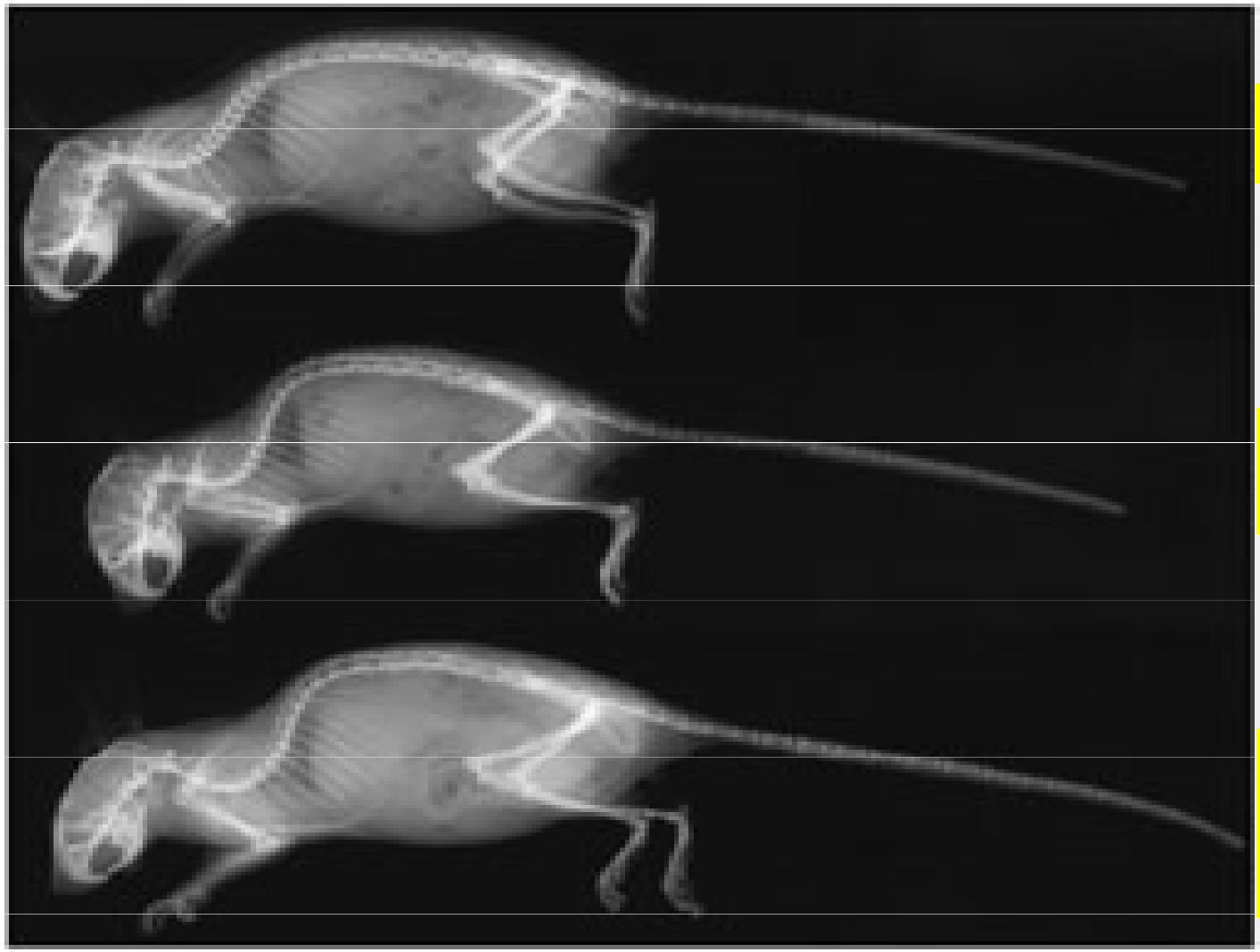
C-type Natriuretic Peptide (CNP) over-expression results in skeleton overgrowth in mice





CNP over-expression???

CNP rescues dwarfism caused by ACH mutation in FGFR3

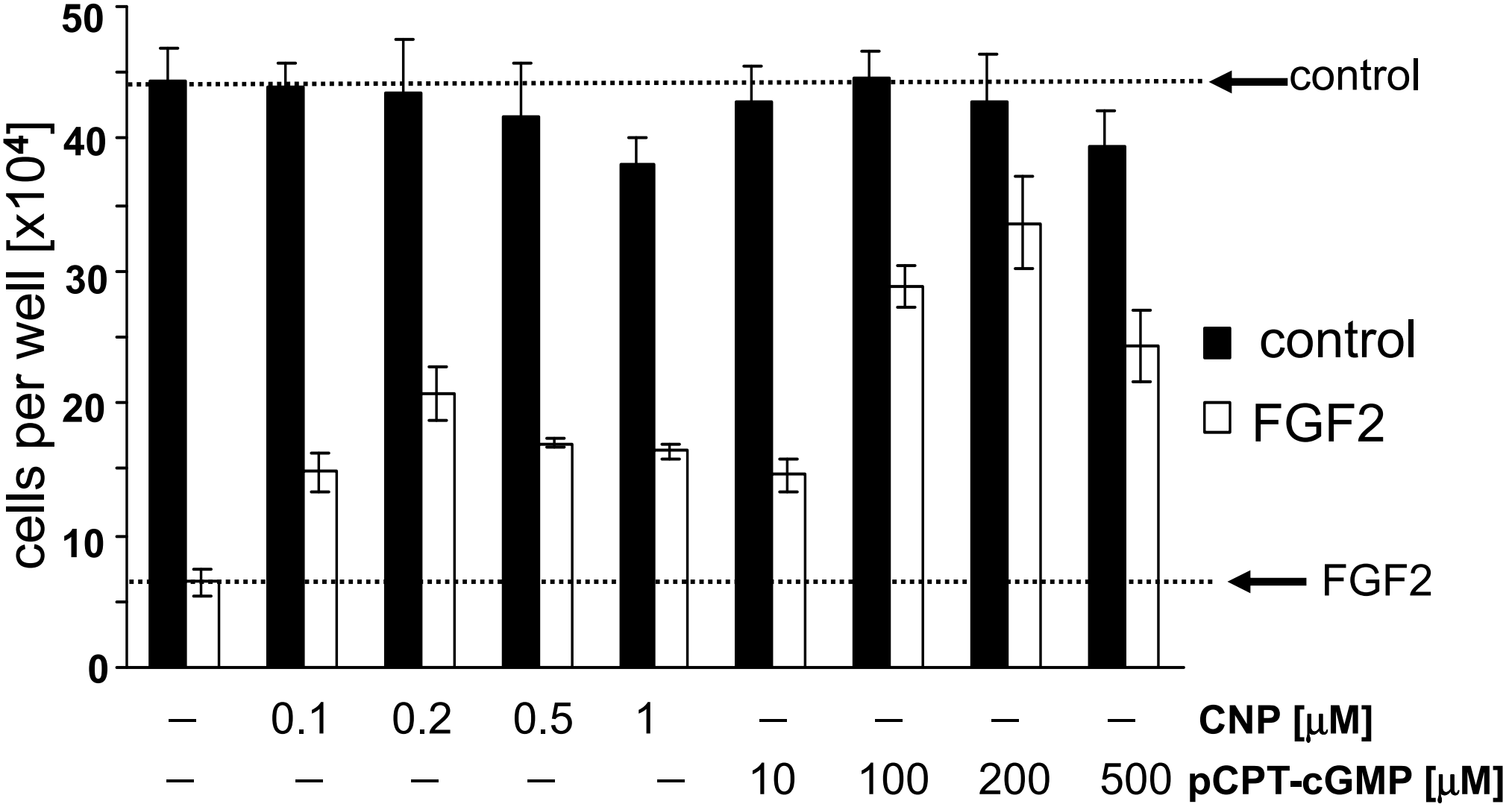


wild-type

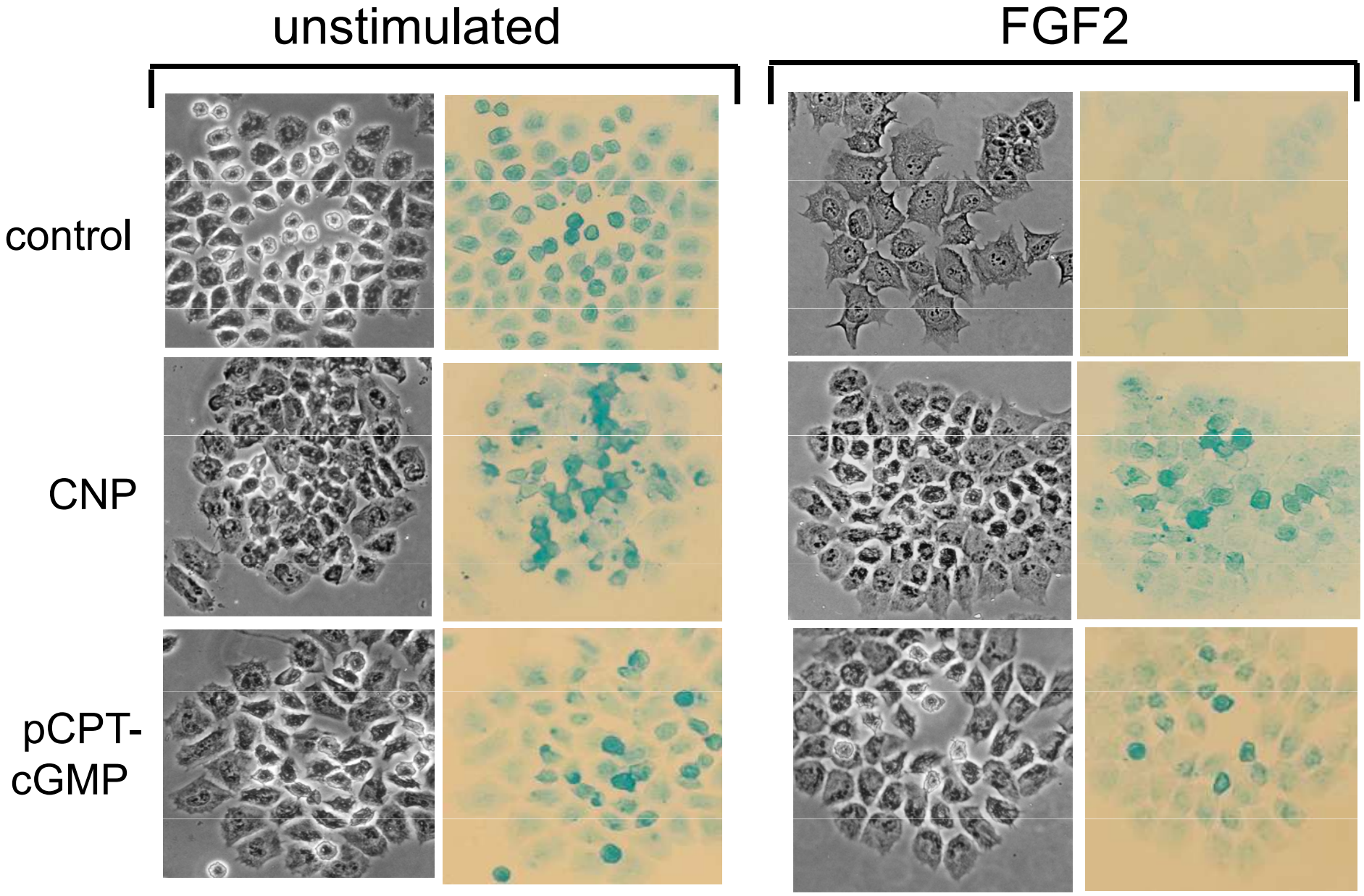
Fgfr3^{Ach}

Fgfr3$^{Ach/CNP}$ ↑

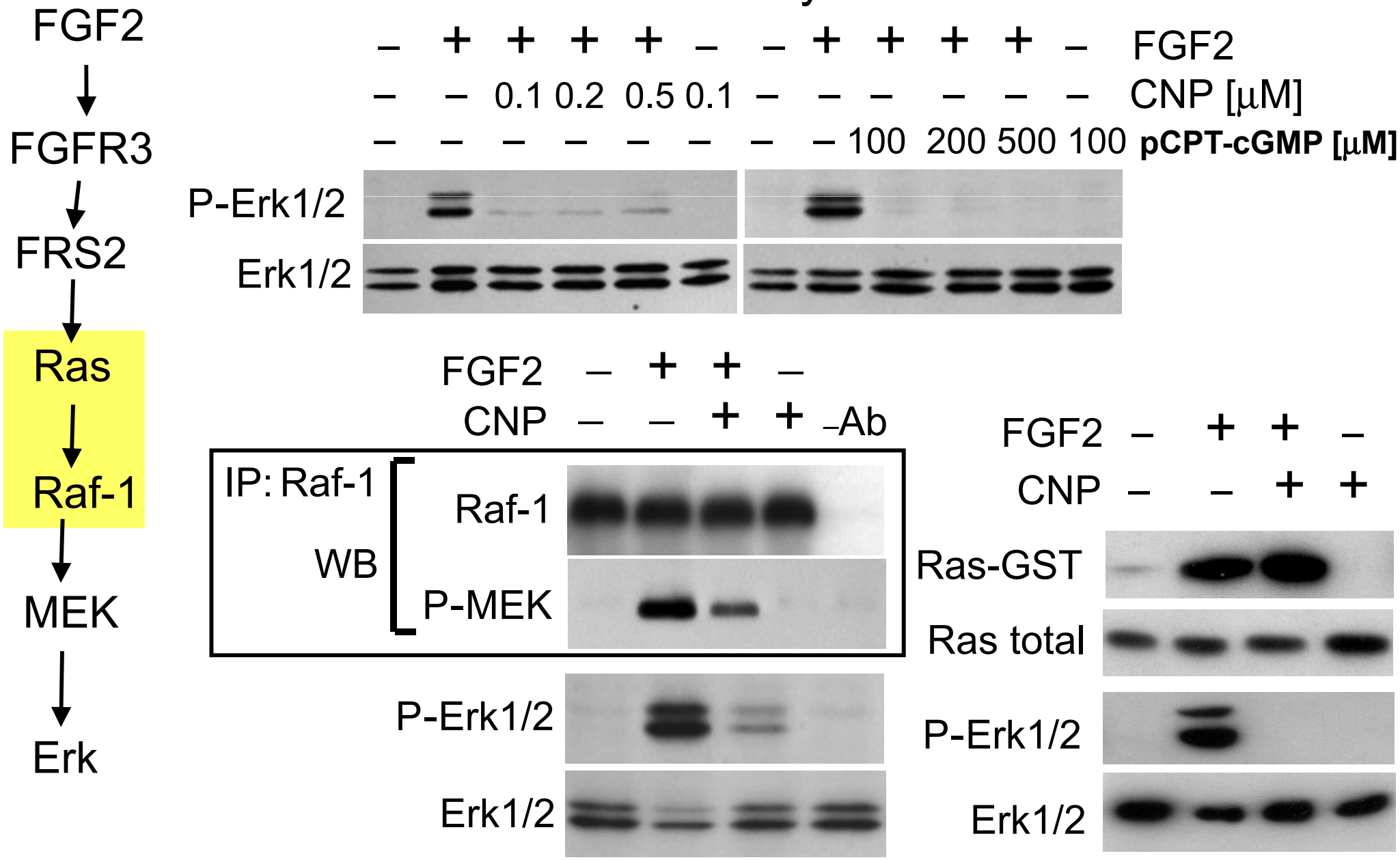
CNP counteracts FGF2-mediated chondrocyte growth arrest through cGMP-dependent pathway



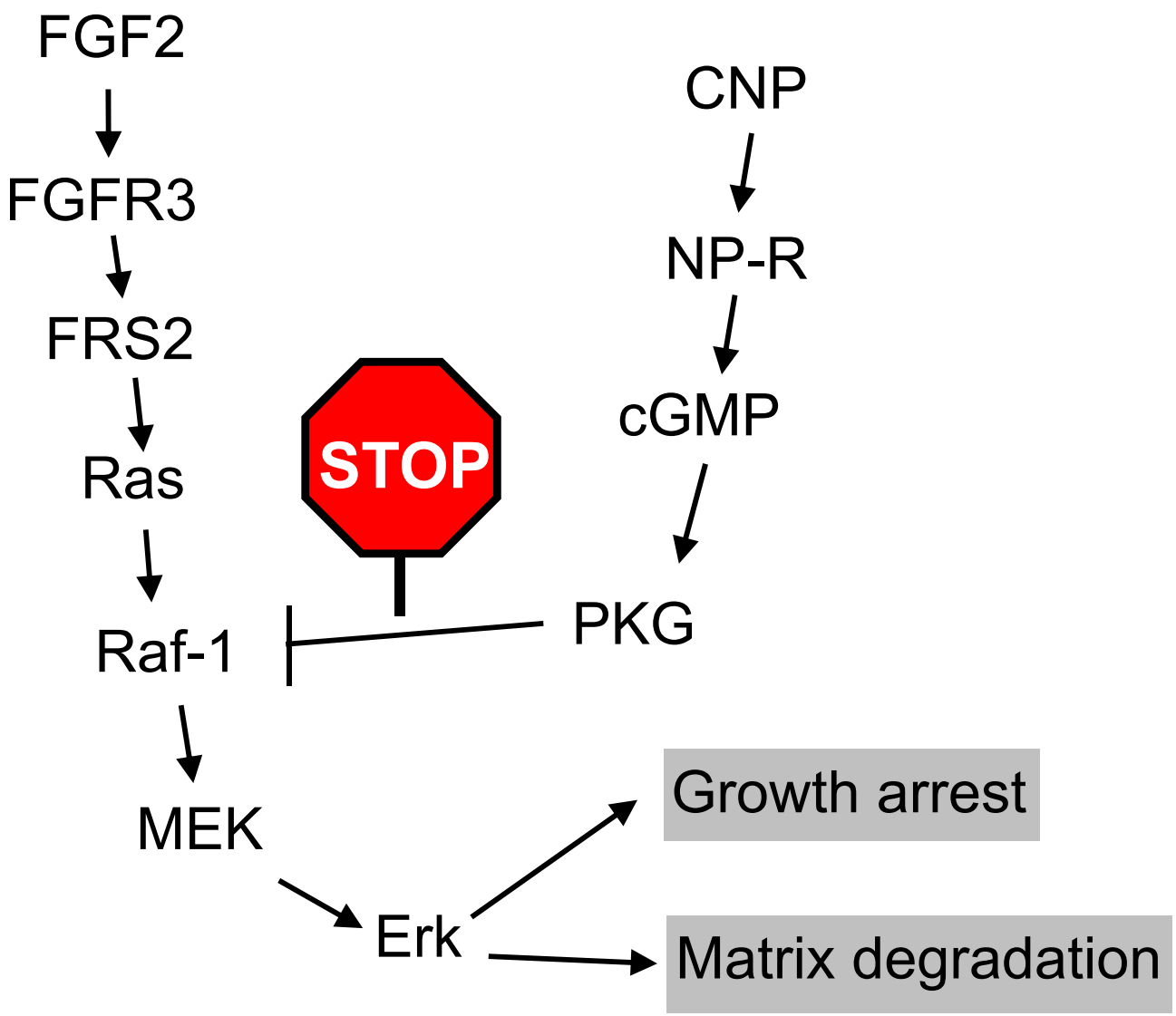
CNP antagonizes FGF2-mediated loss of cartilage extracellular matrix in chondrocytes



CNP counteracts FGF2-mediated activation of Erk MAP kinase in chondrocytes

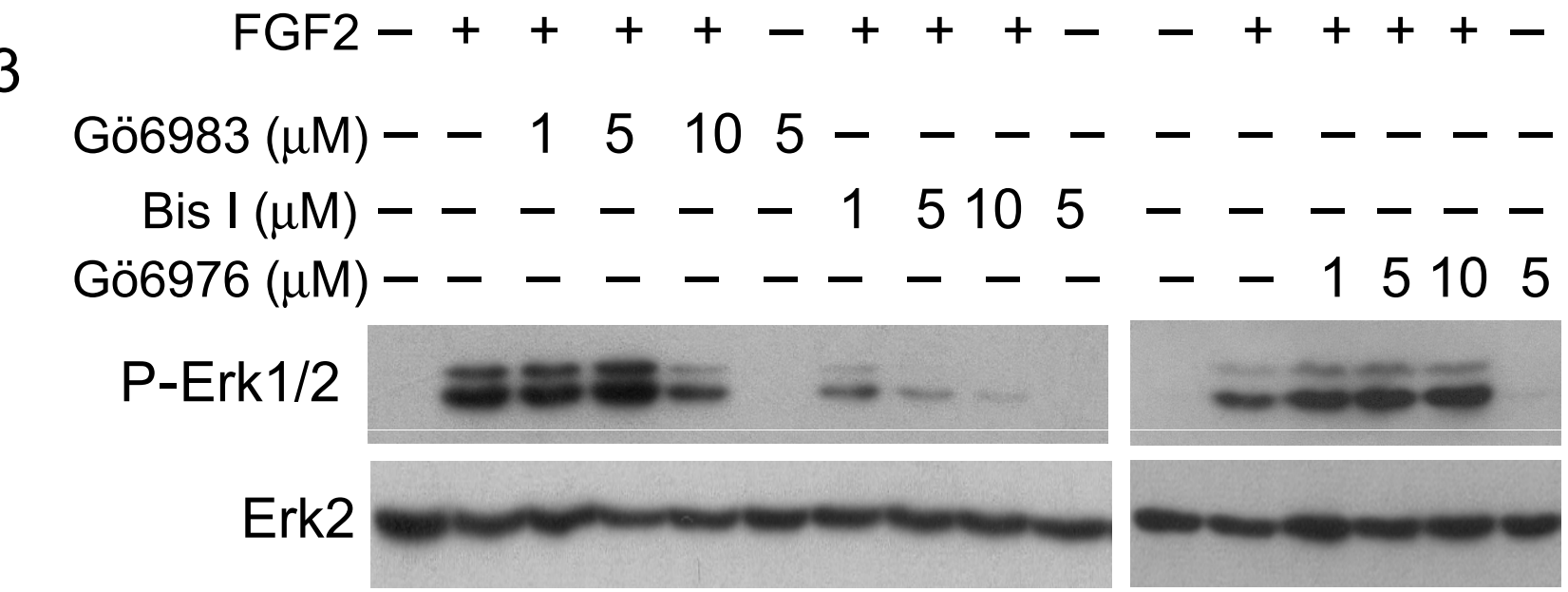


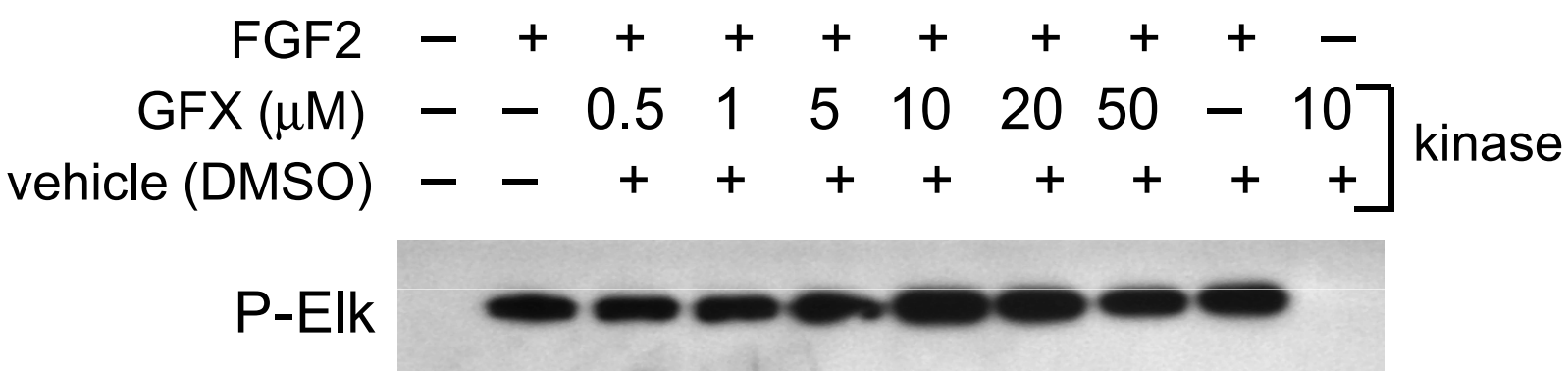
CNP inhibits Erk MAP kinase module at the Raf level

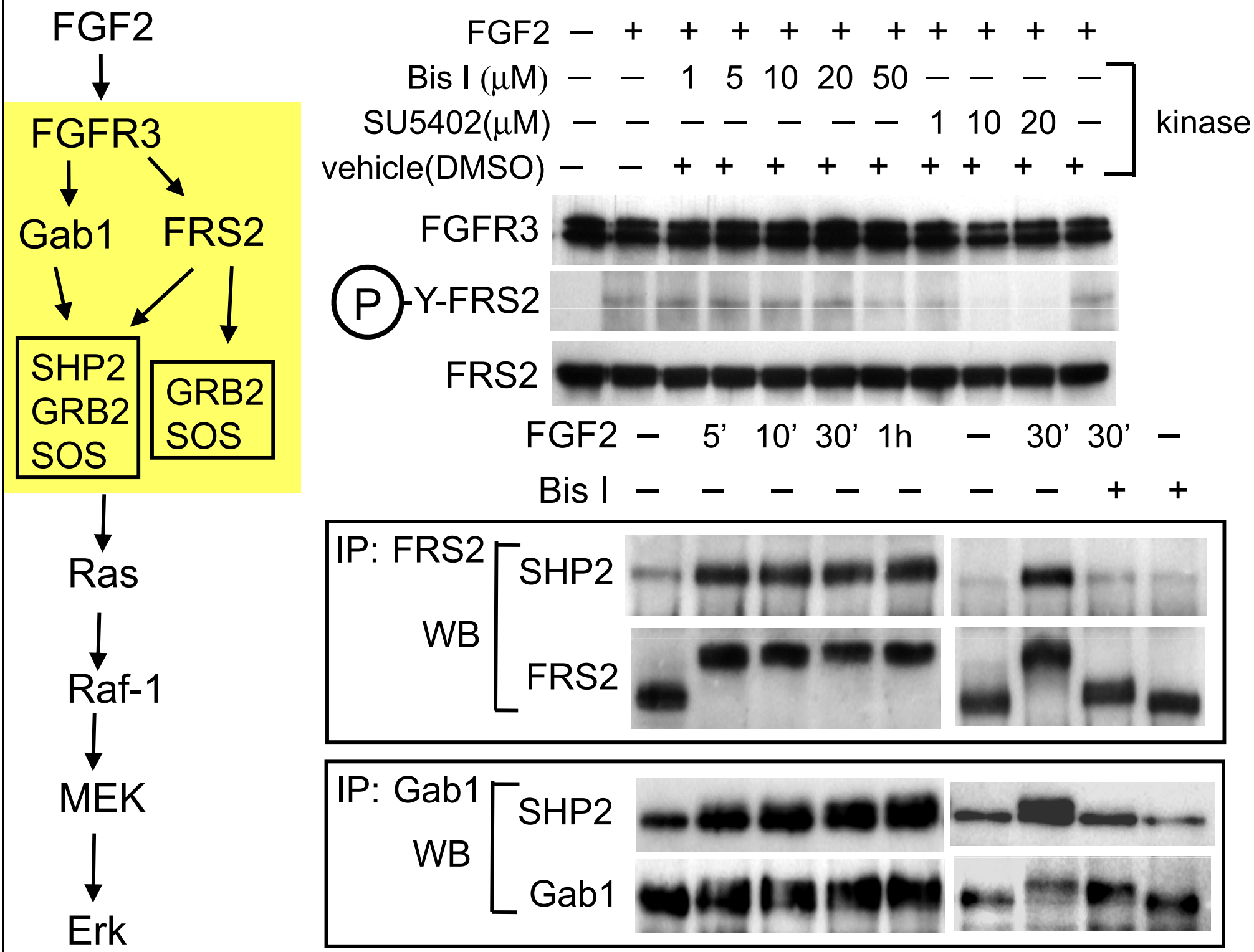


Is protein kinase C (PKC) involved in FGFR3-mediated activation of Erk in chondrocytes?

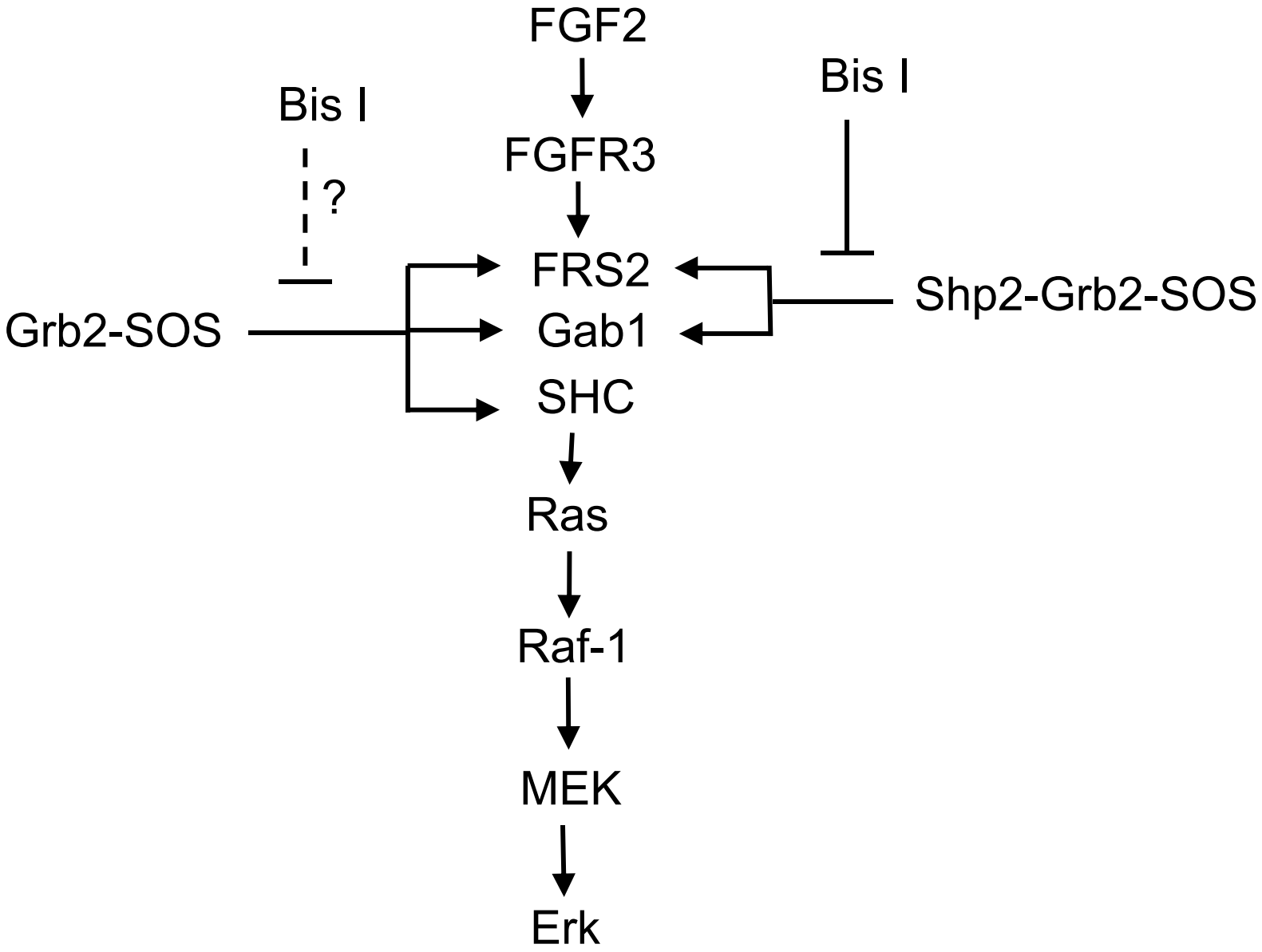
FGF2
↓
FGFR3
↓
FRS2
↓
Ras
↓
Raf-1
↓
MEK
↓
Erk



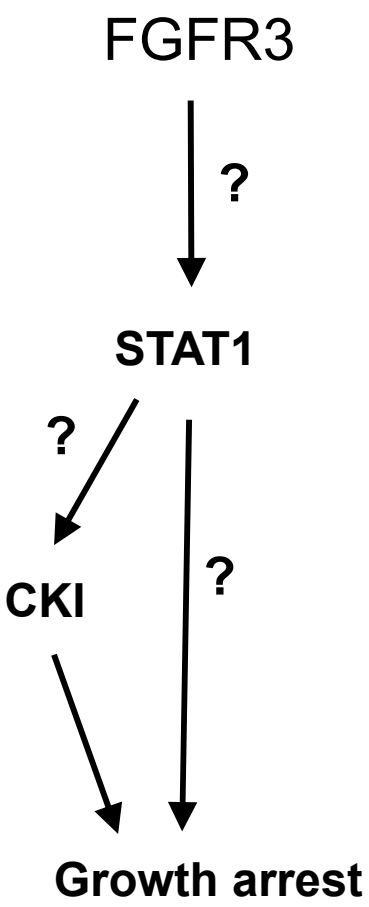


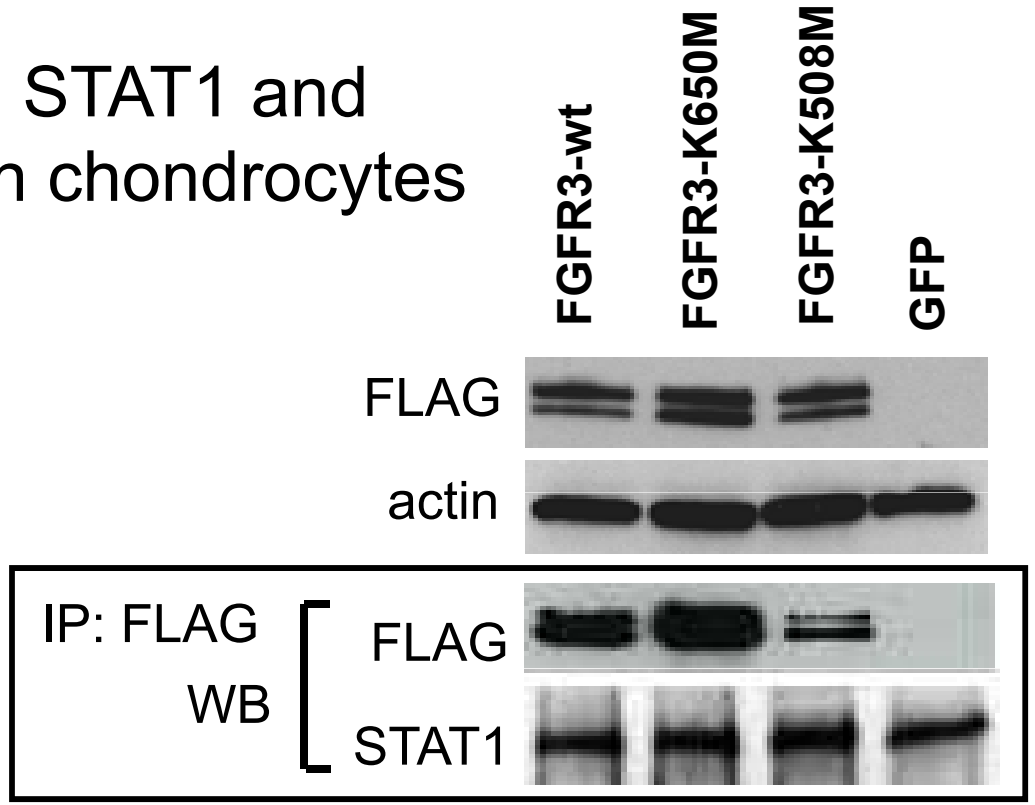

FGF2
FGFR3
Gab1
FRS2
SHP2
GRB2
SOS
GRB2
SOS
Ras
Raf-1
MEK
Erk
FGF2 – + + + + + + + + + +
Bis I (μM) – – 1 5 10 20 50 – – – –
SU5402(μM) – – – – – – – 1 10 20 –
vehicle(DMSO) – – + + + + + + + + +
kinase
FGFR3
P-Y-FRS2
FRS2
FGF2 – 5' 10' 30' 1h – 30' 30' –
Bis I – – – – – – – + +
IP: FRS2
WB
SHP2
FRS2
IP: Gab1
WB
SHP2
Gab1

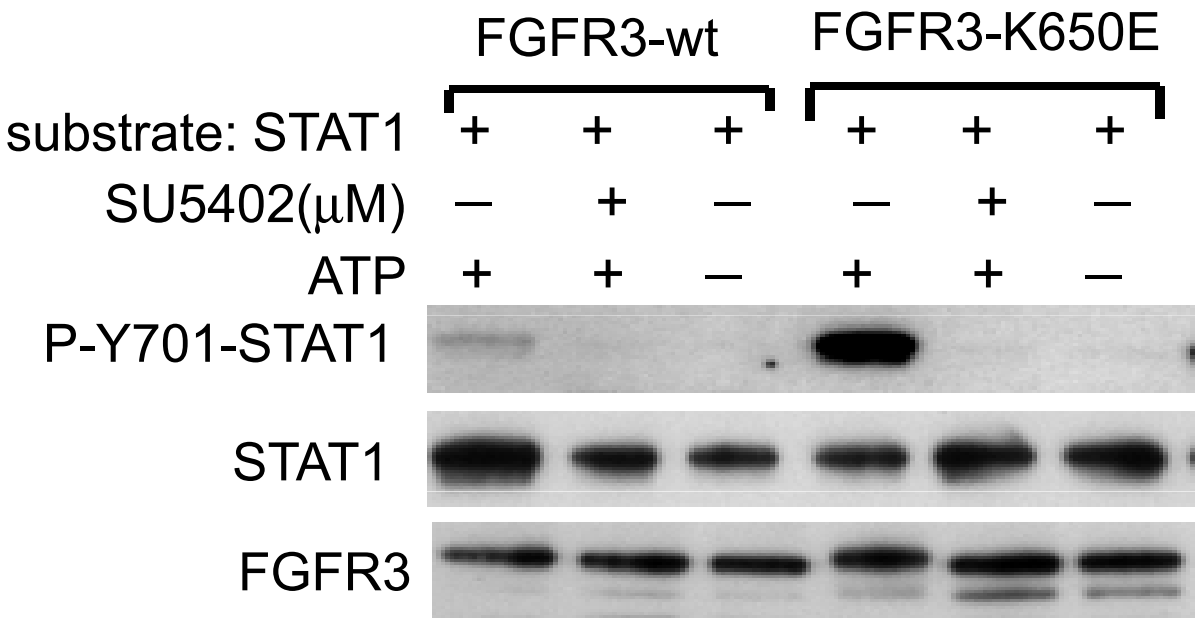
Protein kinase C inhibitor Bisindolylmaleimide I (Bis I)suppresses the FGF2-mediated activation of Erk MAP kinase pathway in chondrocytes by preventing the SHP2 association with FRS2 and Gab1 adaptor proteins



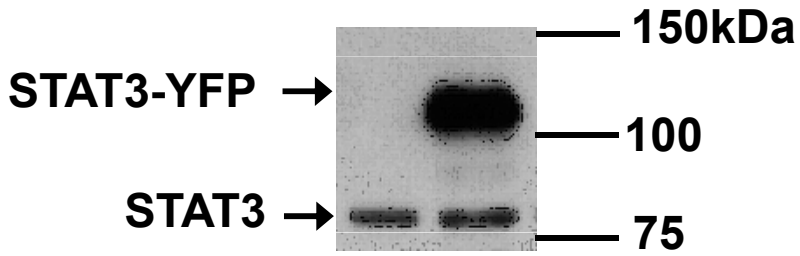
FGFR3 associates with STAT1 and acts as STAT1-kinase in chondrocytes

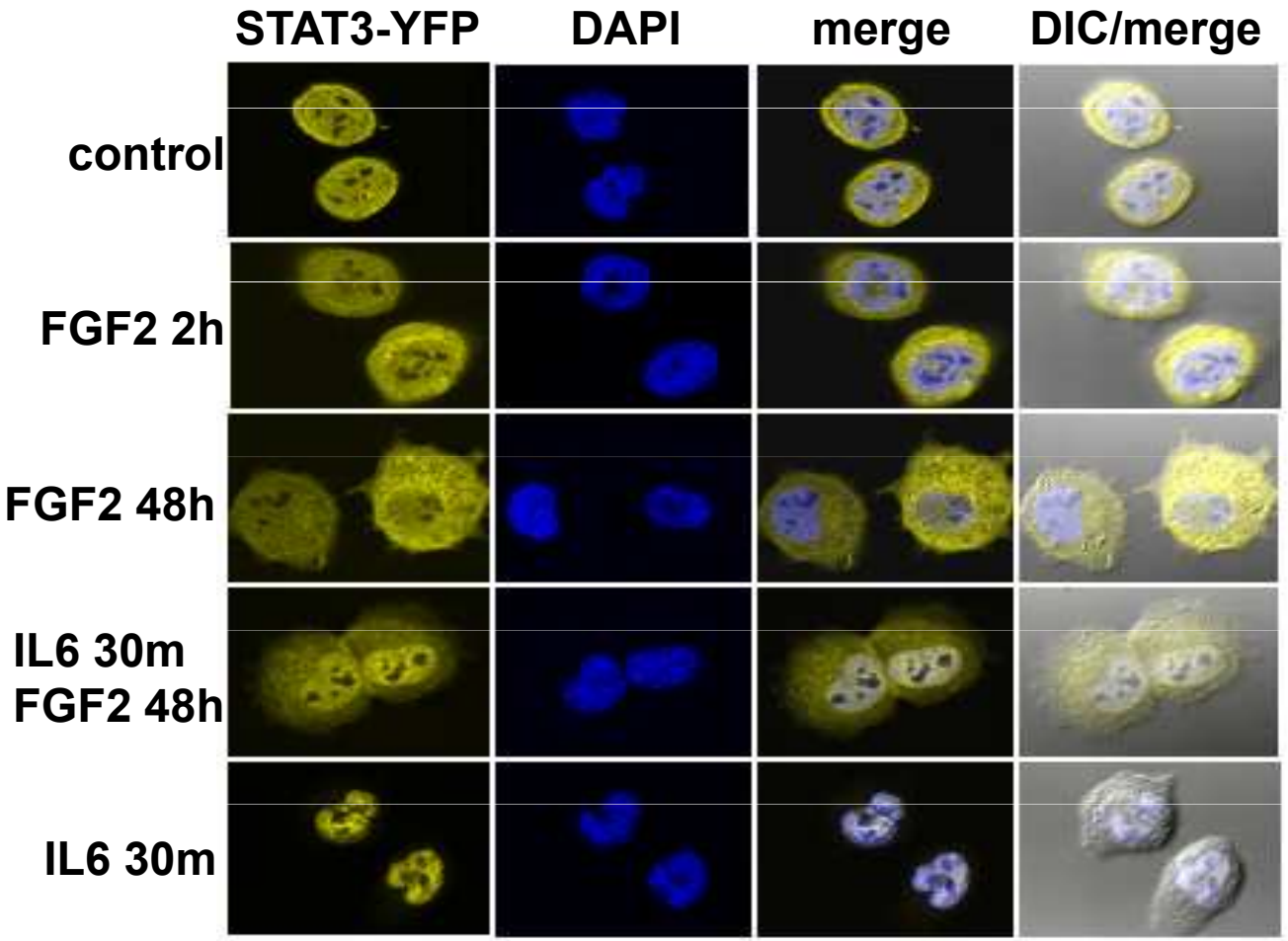




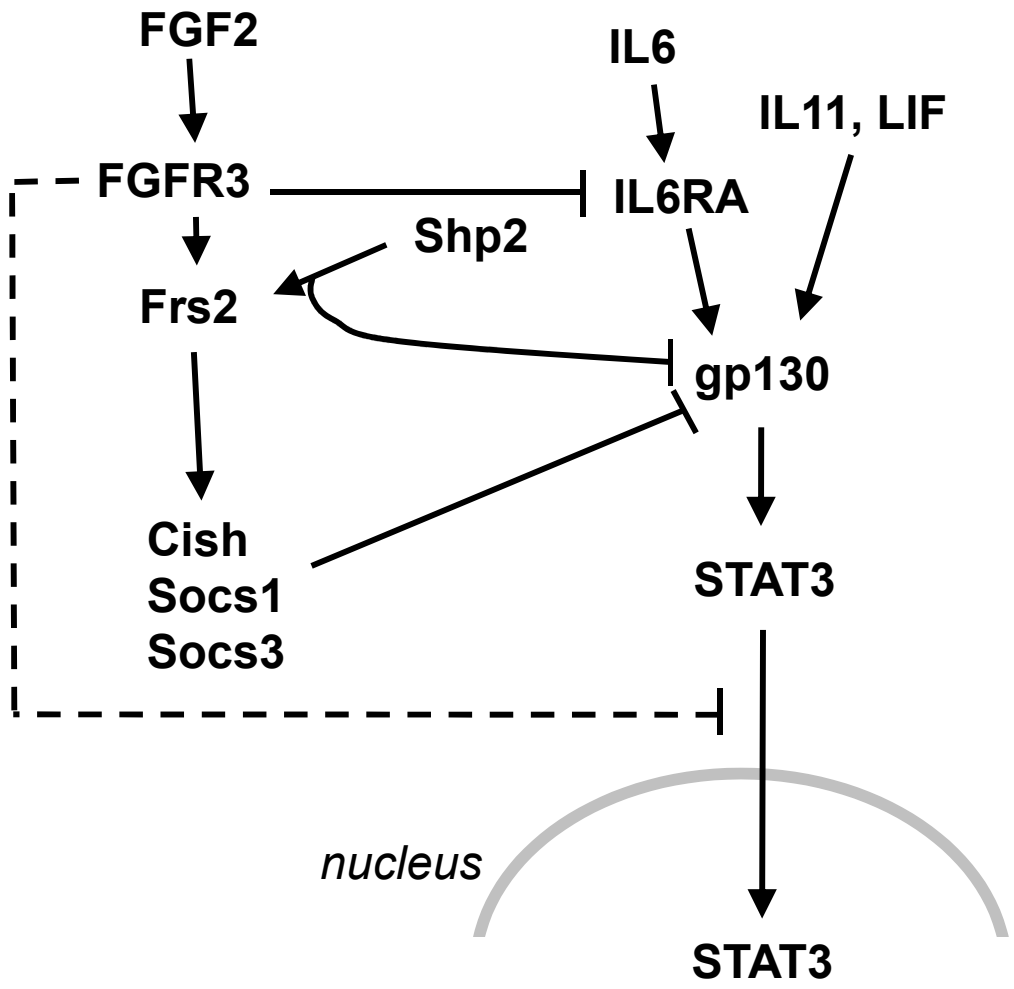


Chronic FGF stimulus inhibits cytokine/STAT signaling in chondrocytes

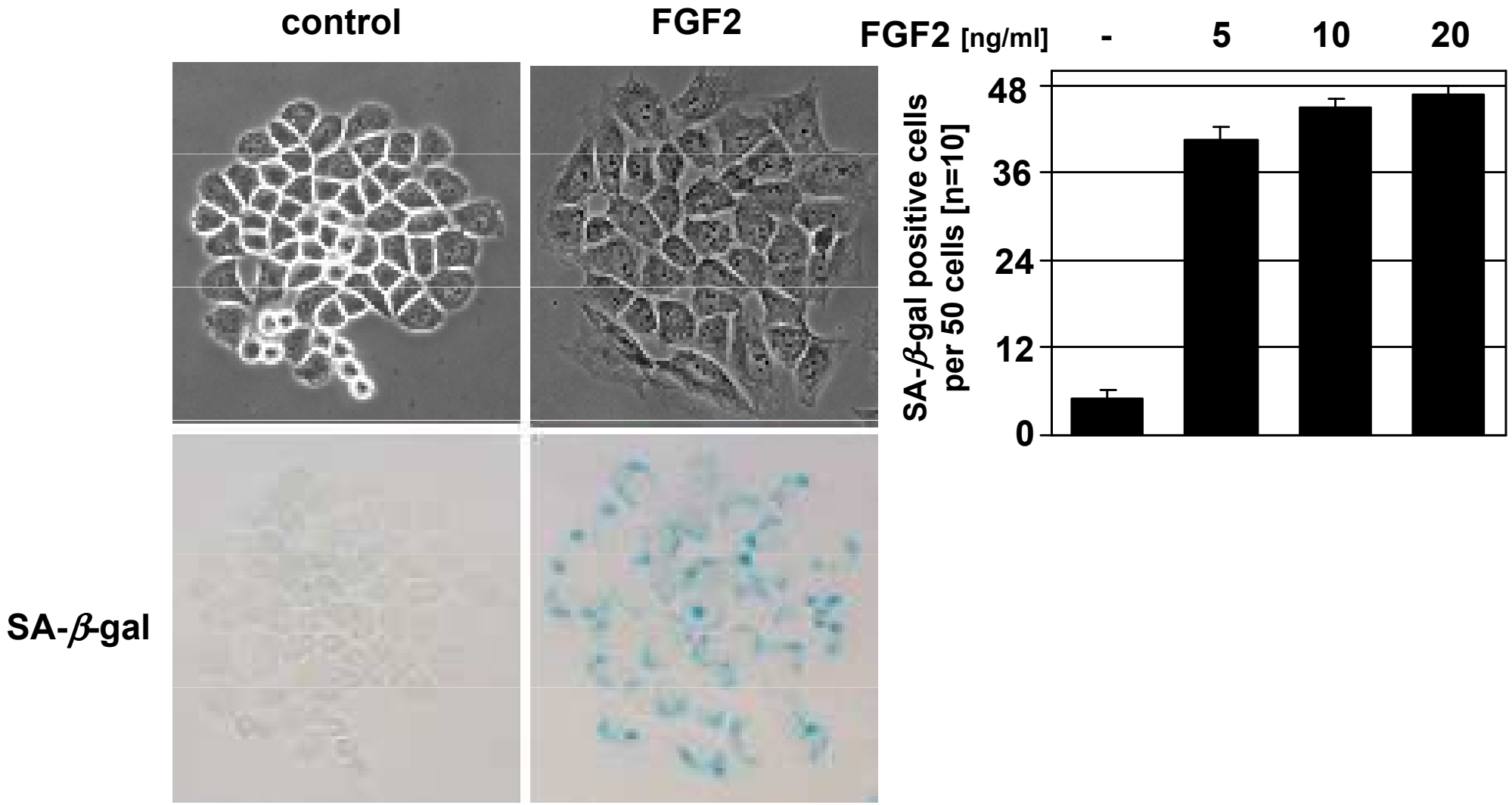




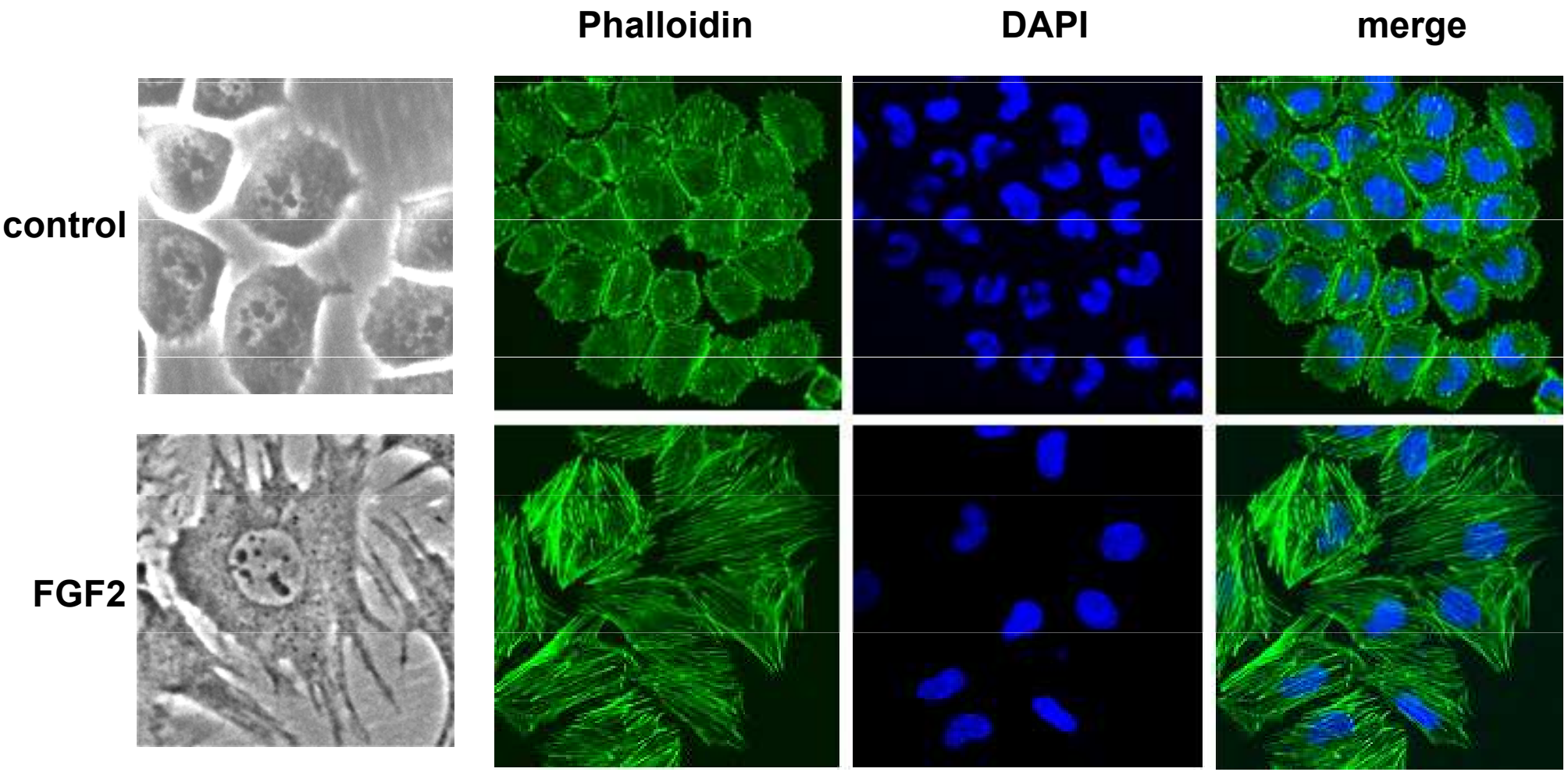
Chronic FGF stimulus inhibits cytokine/STAT signaling in chondrocytes



FGF2 causes premature senescence in chondrocytes

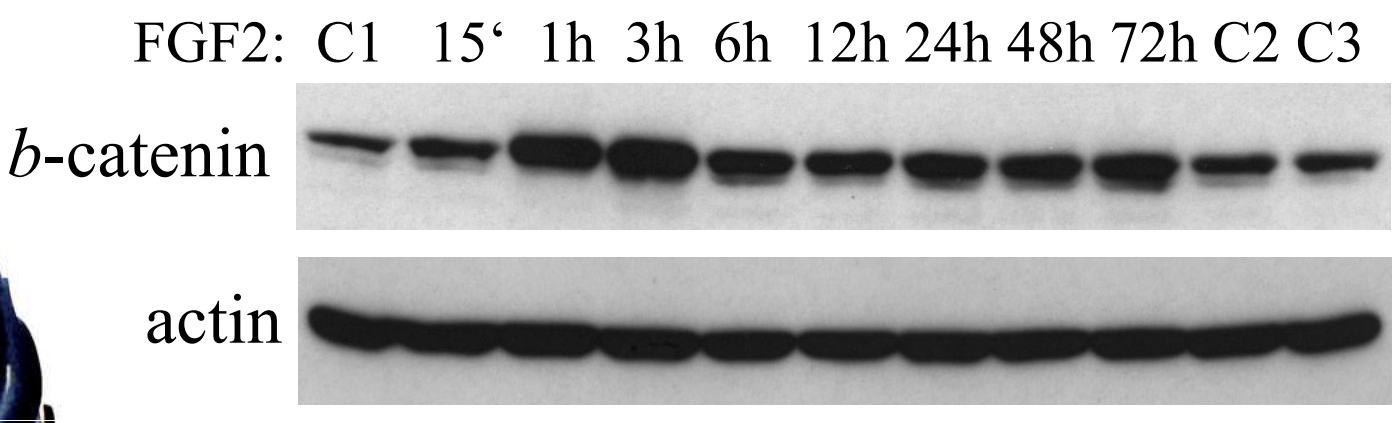


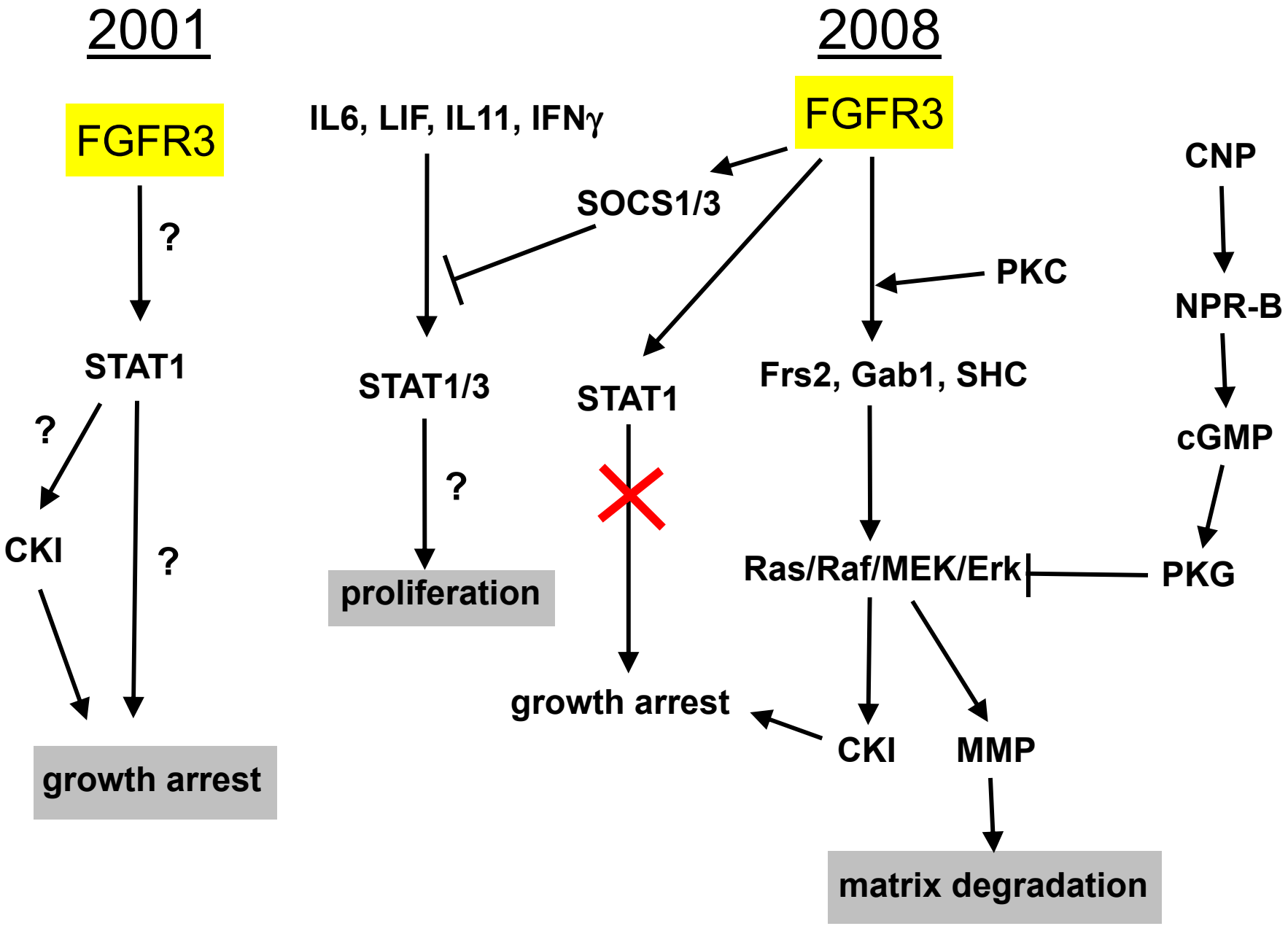
FGF2 signals towards the cytoskeleton in chondrocytes



Where is Wnt?


I Wnt YOU


FGF2: C1 15‘ 1h 3h 6h 12h 24h 48h 72h C2 C3
b-catenin
actin


2001
FGFR3
?
STAT1
?
CKI
?
growth arrest
2008
IL6, LIF, IL11, IFNγ
SOCS1/3
FGFR3
CNP
PKC
NPR-B
STAT1/3
?
proliferation
STAT1
Frs2, Gab1, SHC
cGMP
Ras/Raf/MEK/Erk
PKG
growth arrest
CKI
MMP
matrix degradation