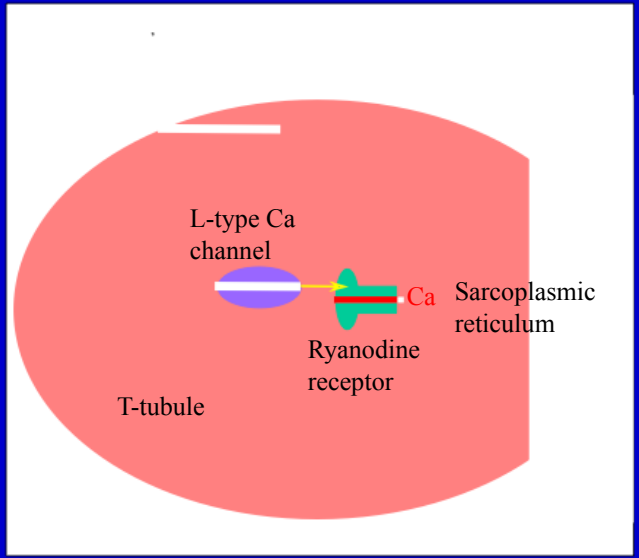
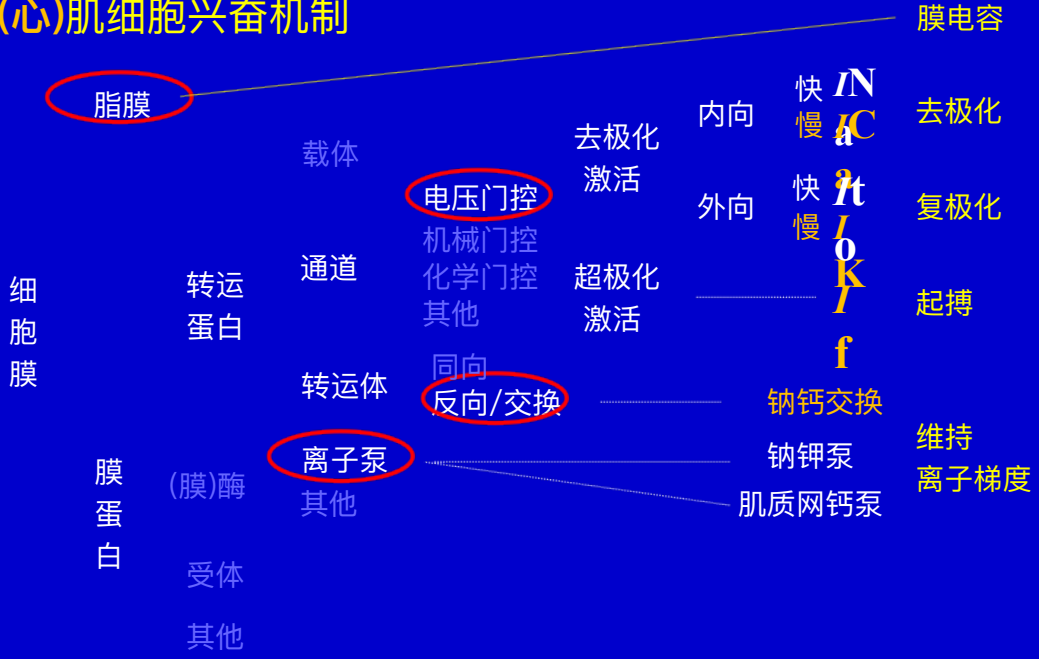
心肌和骨骼肌细胞的兴奋与收缩



(心)肌细胞兴奋机制


膜电容
脂膜
细胞膜
转运蛋白
载体
通道
转运体
离子泵
其他
膜蛋白
(膜)酶
受体
其他
电压门控
机械门控
化学门控
其他
同向
反向/交换
去极化激活
超极化激活
内向
外向
快
慢
快
慢
INa
Ica
If
钠钙交换
钠钾泵
肌质网钙泵
去极化
复极化
起搏
维持离子梯度

快通道

钠通道: I_{Na}

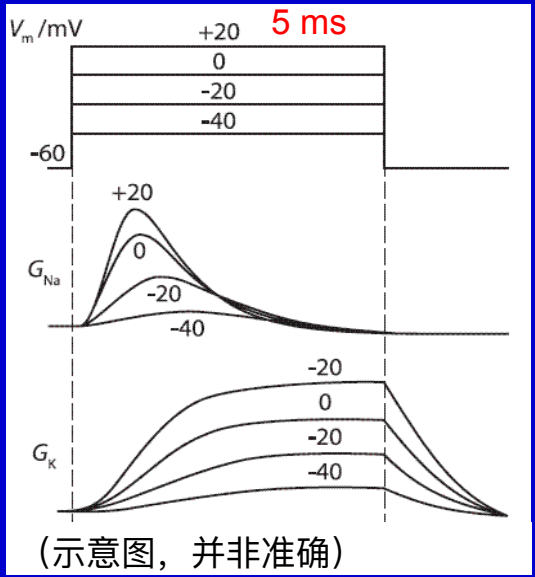
激活快 (~10-3 s)　阈电位：－70 mV (心脏)
－50 mV (神经)

失活快 (~10-3s，静息后才恢复)

钾通道: I_{to} (transient outward)

激活较快（10-3 ~ 10-2 s)　阈电位：~－40mV

失活慢（10-2 ~ 10-1 s)



（示意图，并非准确）

慢通道

钙通道: I_{Ca}（L型）

激活较慢 (~ 10-2 s)　　阈电位：－40 mV

失活慢 (~10-1s

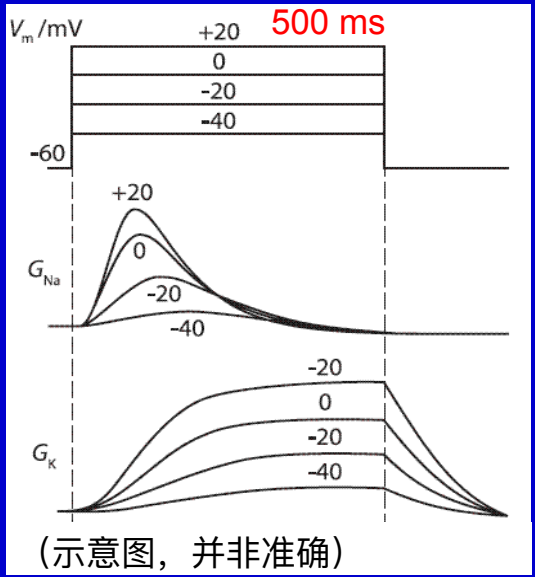
阻断剂: 二价阳离子，如 Mn2+

二氢吡啶, 如 x x 地平

钾通道: I_K

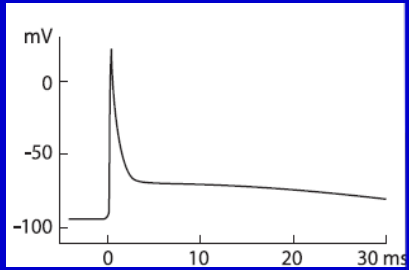
激活慢（~ 10-1 s)　　阈电位：~－20mV

无明显失活

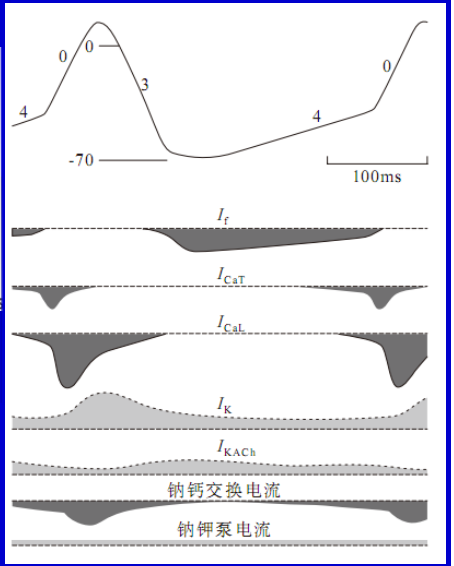


（示意图，并非准确）

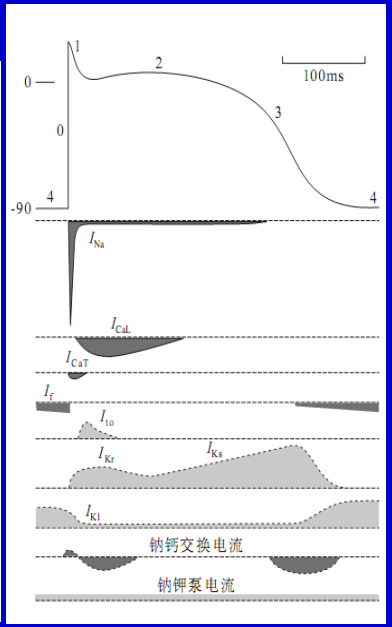
肌细胞兴奋的发生



骨骼肌细胞



窦房结细胞



心室肌细胞

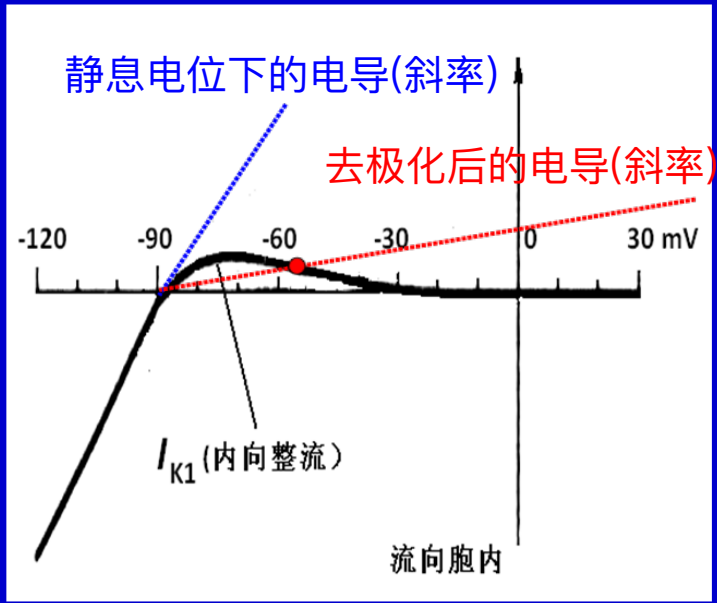
I_{K1}——内向整流钾电流

在心肌细胞舒张期

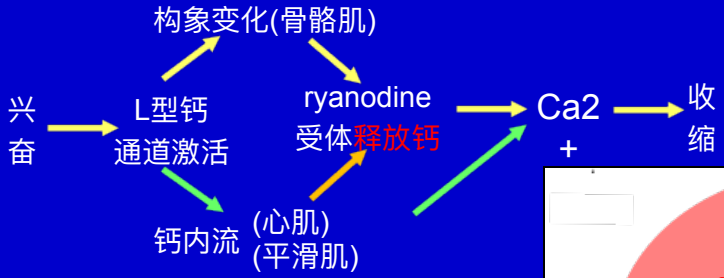
维持一定的钾离子通透性

从而稳定静息膜电位

（想一想原理是什么？）

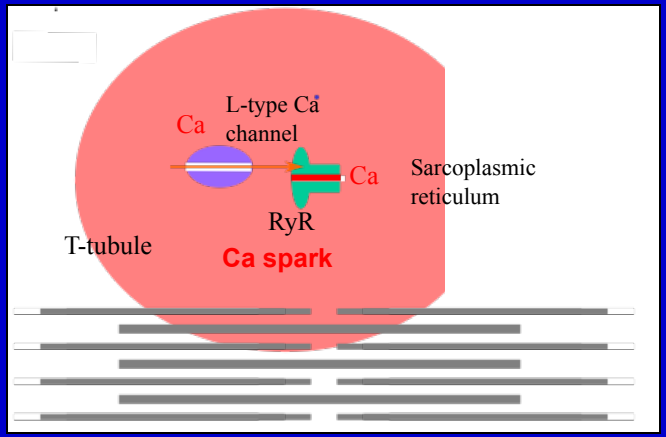


兴奋收缩耦联过程

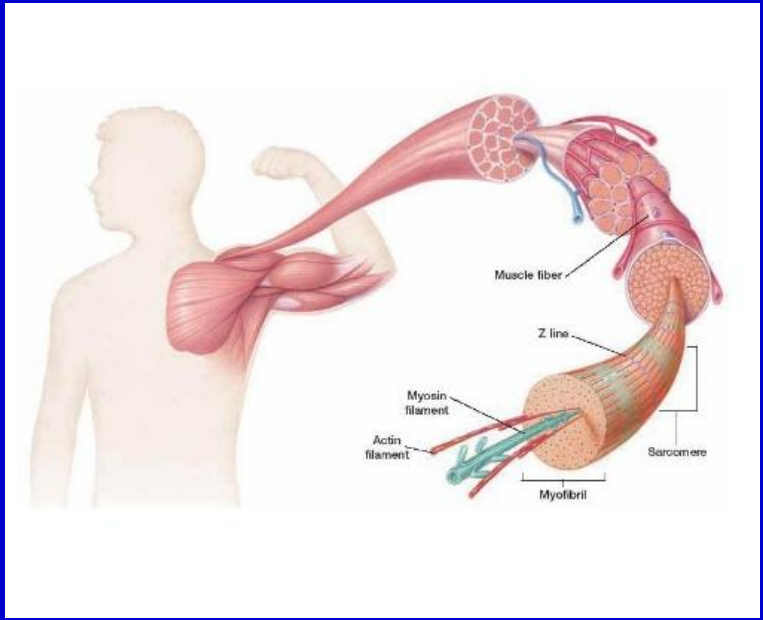


钙致钙释放

(Ca-induced Ca release)



肌肉收缩的机制


Muscle fiber
Z line
Myosin filament
Actin filament
Sarcomere
Myofibril

肌纤维结构功能

肌 膜

肌腱

细胞器

肌肉

肌纤维

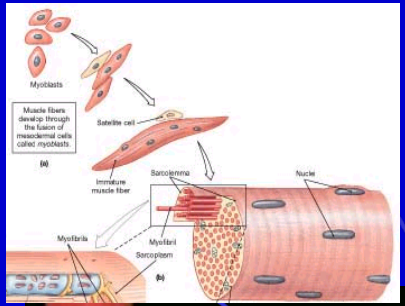
细胞核

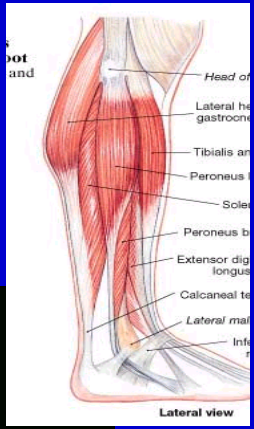
肌腹

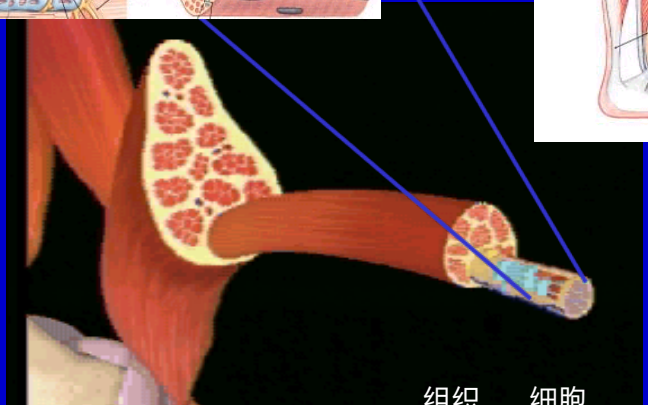
肌原纤维

肌 质

结缔组织膜







组织 细胞

肌纤维结构功能

肌 膜

肌腱

肌肉

肌纤维

肌腹

细胞器

细胞核

肌原纤维

肌 质

结

表面膜

横管(Transverse管)

肌质网

...

线粒体

肌小节

细肌丝

粗肌丝

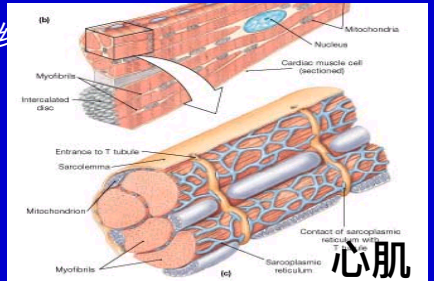
钠通道　钾～　钠钾泵　钙通道　钠钙交换　兴奋

三联管　构象/Ca

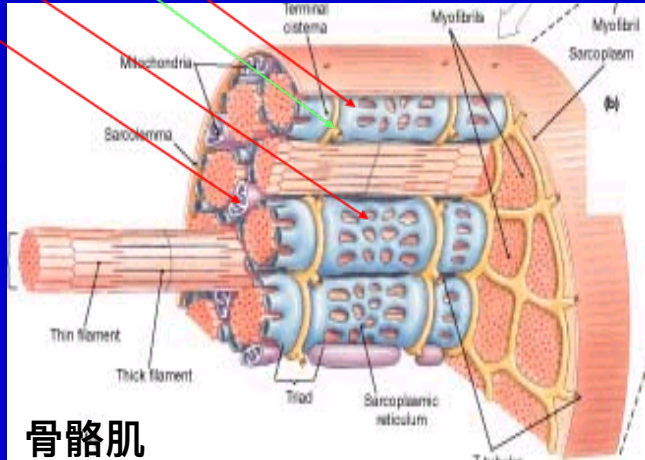
连接～(侧囊)　钙释放通道　钙释放

纵行～　Ca　钙泵　钙摄取

ATP　供能



心肌



骨骼肌

肌纤维结构功能

肌 膜

表面膜

横管(Transverse管)

钠通道　钾～　钠钾泵　钙通道　钠钙交换

兴奋

三联管　构象/Ca

肌腱

肌质网　连接～(侧囊)

钙释放通道

钙释放

钙摄取

细胞器　…　纵行～

Ca　钙泵

ATP

供能

钙受体

肌肉

肌纤维

细胞核

线粒体

肌钙蛋白

细肌丝　原肌球蛋白　位移

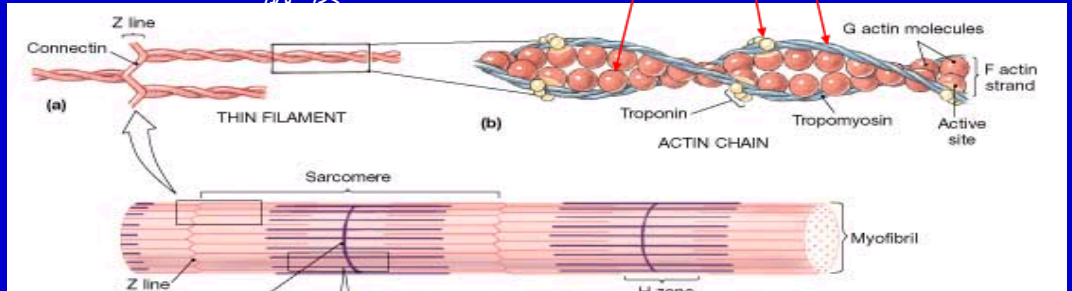
肌动蛋白

肌腹

肌原纤维　肌小节

粗肌丝　肌球蛋白

肌 质



肌纤维结构功能

肌 膜

表面膜

横管(Transverse管)

钠通道 钾～ 钠钾泵

钙通道 钠钙交换

兴奋

三联管

构象/Ca

肌腱

肌质网

连接～(侧囊)

钙释放通道

钙释放

钙摄取

细胞器

纵行～

Ca

钙泵

ATP

供能

肌肉

肌纤维

细胞核

肌钙蛋白

钙受体

细肌丝

原肌球蛋白

位移

肌动蛋白

肌

肌原纤维

肌小节

肌丝滑行

粗肌丝

肌球蛋白

轻链(X4)

横桥

重链(X2)

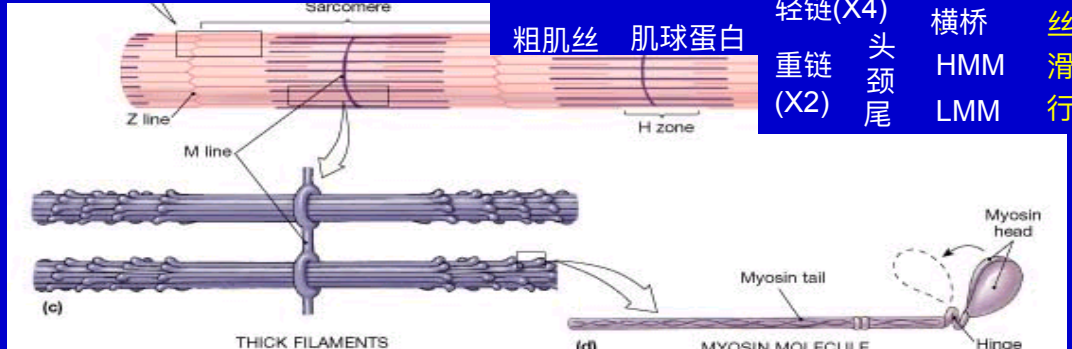
头

HMM

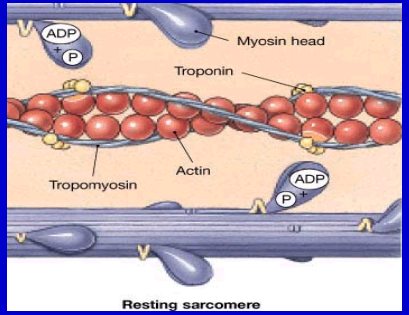
颈

尾

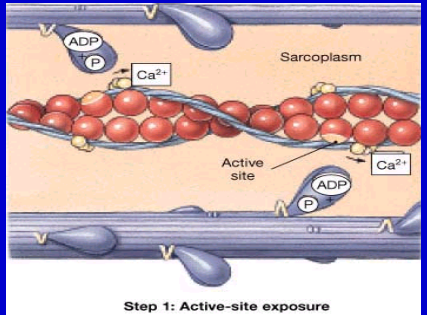
LMM



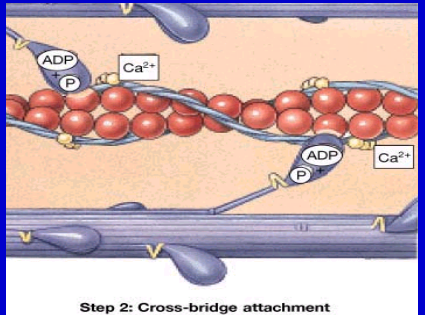
肌丝滑行过程（一步一动）



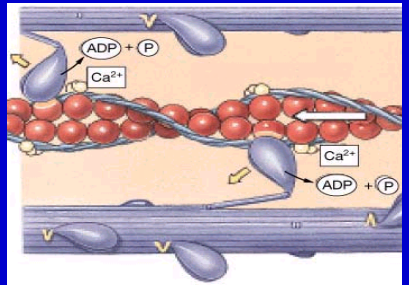
Resting sarcomere



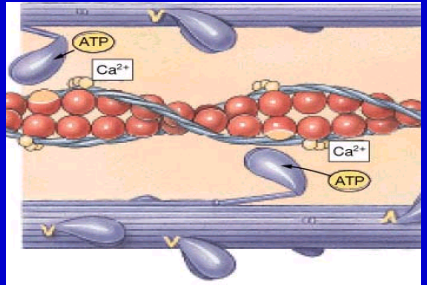
Step 1: Active-site exposure



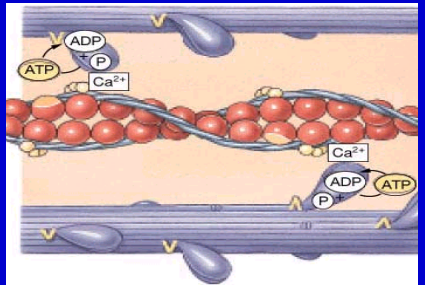
Step 2: Cross-bridge attachment



Step 3: Pivoting of myosin head

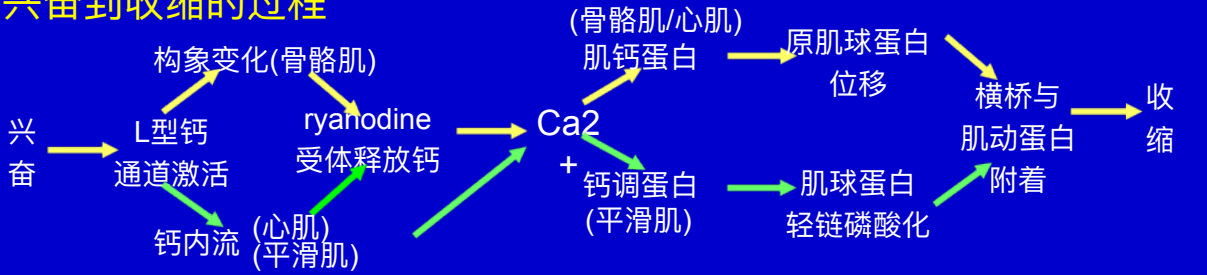


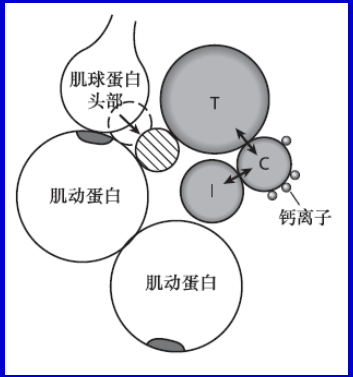
Step 4: Cross-bridge detachment

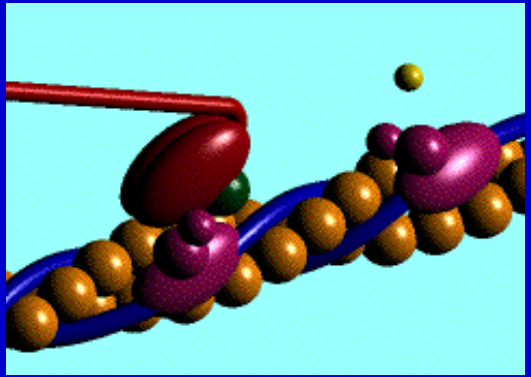


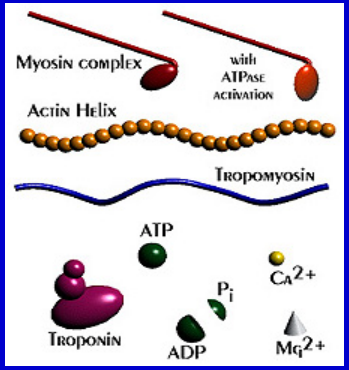
Step 5: Myosin reactivation

兴奋到收缩的过程


兴奋
L型钙通道激活
构象变化(骨骼肌)
钙内流
(心肌)
(平滑肌)
ryanodine受体释放钙
Ca2+
(骨骼肌/心肌)肌钙蛋白
钙调蛋白(平滑肌)
原肌球蛋白位移
肌球蛋白轻链磷酸化
横桥与肌动蛋白附着
收缩

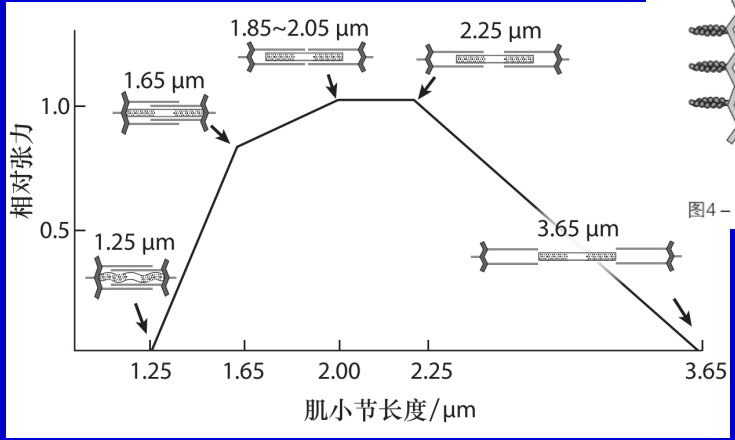

肌球蛋白头部
T
C
I
肌动蛋白
钙离子
肌动蛋白




Myosin complex
with ATPase activation
Actin Helix
Tropomyosin
ATP
Troponin
ADP
Pi
Ca2+
Mg2+

肌丝滑行理论的证据

1. 明带和暗带的消长



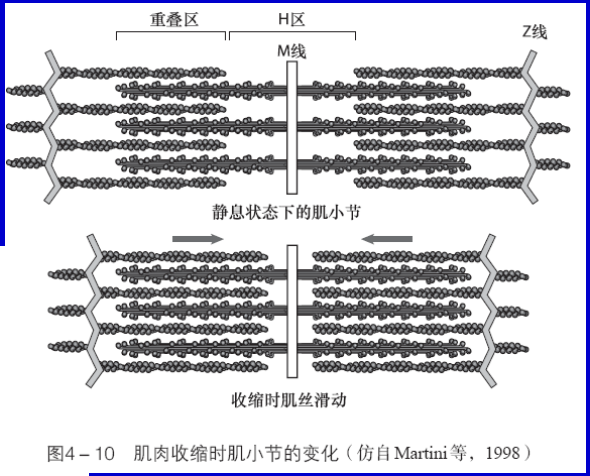
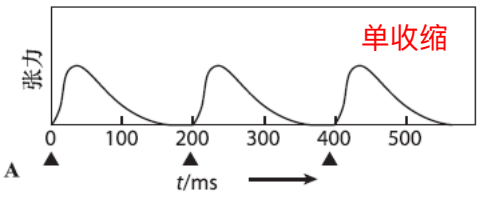
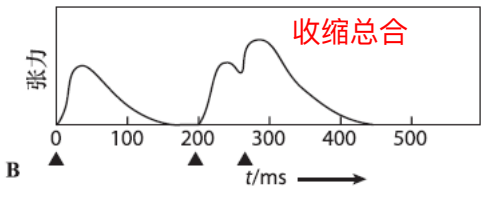
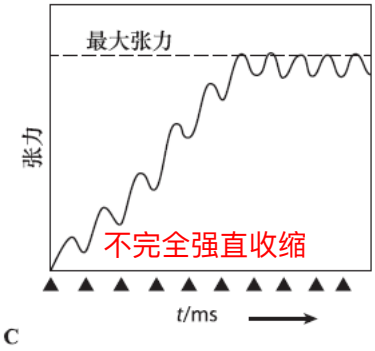


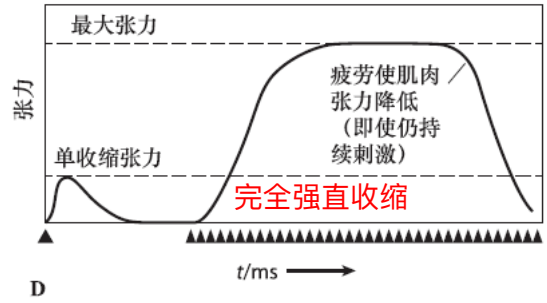
图4－10　肌肉收缩时肌小节的变化（仿自Martini等，1998）

收缩总合与强直收缩


单收缩
张力
0
100
200
300
400
500
t/ms
A


收缩总合
张力
0
100
200
300
400
500
t/ms
B


最大张力
张力
不完全强直收缩
t/ms
C

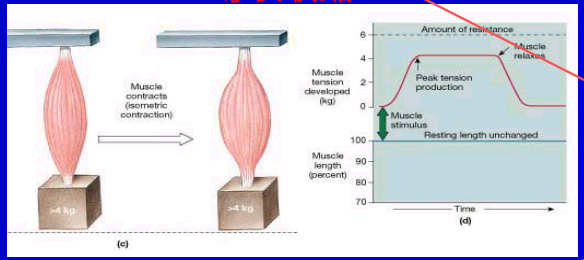

最大张力
张力
疲劳使肌肉
张力降低
（即使仍持
续刺激）
单收缩张力
完全强直收缩
t/ms
D

收缩的力学

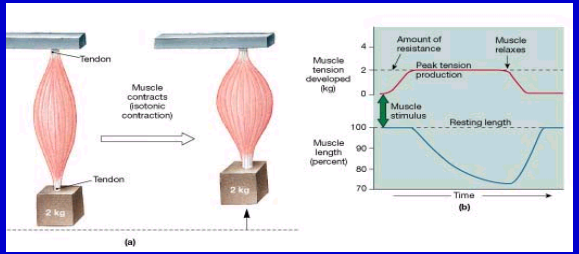
骨骼肌

心肌

等长收缩



等张收缩



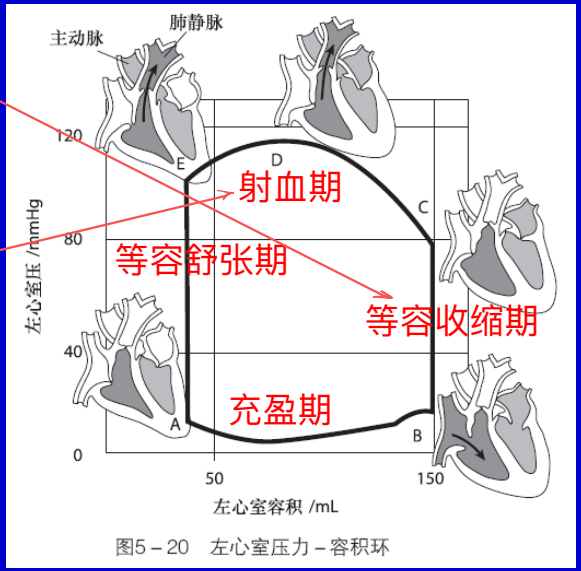


图5－20　左心室压力－容积环