

Intermolecular disulfide bonds between nucleoporins regulate karyopherin-dependent nuclear transport

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Summary

Disulfide (S–S) bonds play important roles in the regulation of protein function and cellular stress responses. In this study, we demonstrate that distinct sets of nucleoporins (Nups), components of the nuclear pore complex (NPC), form S–S bonds and regulate nuclear transport through the NPC. Kinetic analysis of importin β demonstrated that the permeability of the NPC was increased by dithiothreitol treatment and reduced by oxidative stress. The permeability of small proteins such as GFP was not affected by either oxidative stress or a reducing reagent. Immunoblot analysis revealed that the oxidative stress significantly induced S–S bond formation in Nups 358, 155, 153 and 62 but not 88 and 160. The direct involvement of cysteine residues in the formation of S–S bonds was confirmed by mutating conserved cysteine residues in Nup62, which abolished the formation of S–S bonds and enhanced the permeability of the NPC. Knocking down Nup62 reduced the stress-inducible S–S bonds of Nup155, suggesting that Nup62 and Nup155 are covalently coupled via S–S bonds. From these results, we propose that the inner channel of the NPC is somehow insulated from the cytoplasm and is more sensitive than the cytoplasm to the intracellular redox state.

Key words: Disulfide bridge, Importin β , Nuclear pore, Nucleocytoplasmonic transport, Oxidative stress

Introduction

Disulfide (S–S) bond formation within and between proteins plays an important role in protein folding, stability, function, and protein–protein interaction. Reactive oxygen species (ROS) directly or indirectly oxidize the thiol group in cysteine residues, and thereby alter enzymatic functions (Kobayashi et al., 2006; Motohashi and Yamamoto, 2004; Pekovic et al., 2011; Rhee et al., 2005; Spickett et al., 2006; Winterbourn, 2008). The cytoplasm is normally maintained in a reducing state due to ubiquitous reducing reagents such as glutathione. However, ROS have been known to oxidize proteins in the cytoplasm. In the case of protein tyrosine phosphatase, one of the cysteine residues in the reactive center is oxidized by hydrogen peroxide (H_2O_2) and forms an intramolecular S–S bond, which results in the inhibition of phosphatase activity (Rhee et al., 2005). The transcription factor Nrf2 is also regulated by oxidative stress. Under non-stressed conditions, Nrf2 is ubiquitinated in a Keap1-dependent manner and subject to proteasome-dependent degradation. Under oxidative stress, however, specific cysteine residues in Keap1 are modified (Kobayashi et al., 2006). The modifications are thought to block Keap1 from binding to Nrf2, and thus increase the intracellular level of Nrf2, which results in the transcriptional activation of a series of genes related to oxidative responses (Motohashi and Yamamoto, 2004).

Macromolecular transport between the cytoplasm and the nucleoplasm is mediated by a large protein complex, the nuclear pore complex (NPC), which is composed of ~30 different kinds

of subunits called nucleoporins (Nups) (Brohawn et al., 2009). The NPC is a selective barrier that blocks the diffusion of large proteins (>40 kDa), but allows that of small proteins (<40 kDa) (Görlich and Kutay, 1999). The transport of large proteins is achieved by a number of transport mediators (karyopherins, also called importin α/β -family proteins) and the RanGDP-RanGTP gradient across the nuclear envelope (Mosammaparast and Pemberton, 2004; Weis, 2003). The importin α/β pathway is the best known route for transporting nuclear localization signal (NLS)-containing proteins from the cytoplasm to the nucleoplasm (Mattaj and Englmeier, 1998). It has been reported that oxidative stress inhibits macromolecular transport through the NPC (Crampton et al., 2009; Kodiha et al., 2004; Kodiha et al., 2009; Kodiha et al., 2008; Miyamoto et al., 2004; Patel et al., 2012; Stochaj et al., 2000; Yasuda et al., 2006). Oxidative stress influences the intracellular distribution of Ran and transport mediators, which in turn affects the intracellular localization of the cargo proteins (Kodiha et al., 2004; Kodiha et al., 2008; Yasuda et al., 2006). Oxidative stress also alters the modifications of Nups (phosphorylation and glycosylation), which might affect the passage of proteins through the NPC (Crampton et al., 2009; Kodiha et al., 2009).

In this study, we investigated the possibility of cysteine modifications of Nups, and their involvement in the regulation of nuclear transport. We found that several Nups form intermolecular S–S bonds, and that oxidative stress enhances such S–S bond formation and directly affects the transport of importin β through the NPC.

Results

Oxidative stress and reducing reagents alter importin β -dependent cargo transport

We first examined how oxidizing and reducing reagents affect protein transport through the NPC. HeLa cells were treated with digitonin at 4°C to remove the plasma membrane and the cytosolic proteins. The exposed nuclei were further incubated at 37°C to remove small soluble proteins from the nuclei. Immunofluorescence microscopic observation revealed that this treatment removed most of the intracellular Ran; no signal was seen in the cytoplasm and only weak signal was detected in the nucleoplasm (5% of the intact cells) (Fig. 1A). Immunoblot analysis also showed that 96% of Ran was removed by this treatment (Fig. 1B).

A mixture of recombinant transport mediators (importin α and β), fluorescently labeled cargo protein (glutathione S-transferase (GST)-NLS-GFP), and RanGDP was incubated with these nuclei in the presence of an ATP-regeneration system. Microscopic observation revealed that the fluorescent cargo was imported into

the nucleus from the external medium (Fig. 1C). When the same type of experiment was performed with the cells pre-exposed to oxidative stress (H_2O_2) for 1 hour, the nuclear cargo level decreased up to 0.43-fold as the H_2O_2 concentration increased (Fig. 1C,D), indicating that the permeability of the NPC is somehow affected by oxidative stress. On the other hand, pre-treatment of nuclei with dithiothreitol (DTT) increased the nuclear cargo level of both non-stressed and stressed cells by ~1.3-fold (Fig. 1E).

The intracellular ROS was quantified by a ROS-reactive fluorescence probe (carboxy-H₂DCFDA). As shown in Fig. 1F,G, the intracellular amount of ROS increased by oxidative stress. The pre-treatment of the cells by a ROS scavenger, *N*-acetyl cysteine (NAC, 10 mM), could reduce the ROS generation (Fig. 1G), and restore the stress-induced inhibition of nuclear import of NLS cargo (Fig. 1D). These results demonstrate that the stress-induced inhibition of nuclear transport results from the increase of the intracellular ROS level.

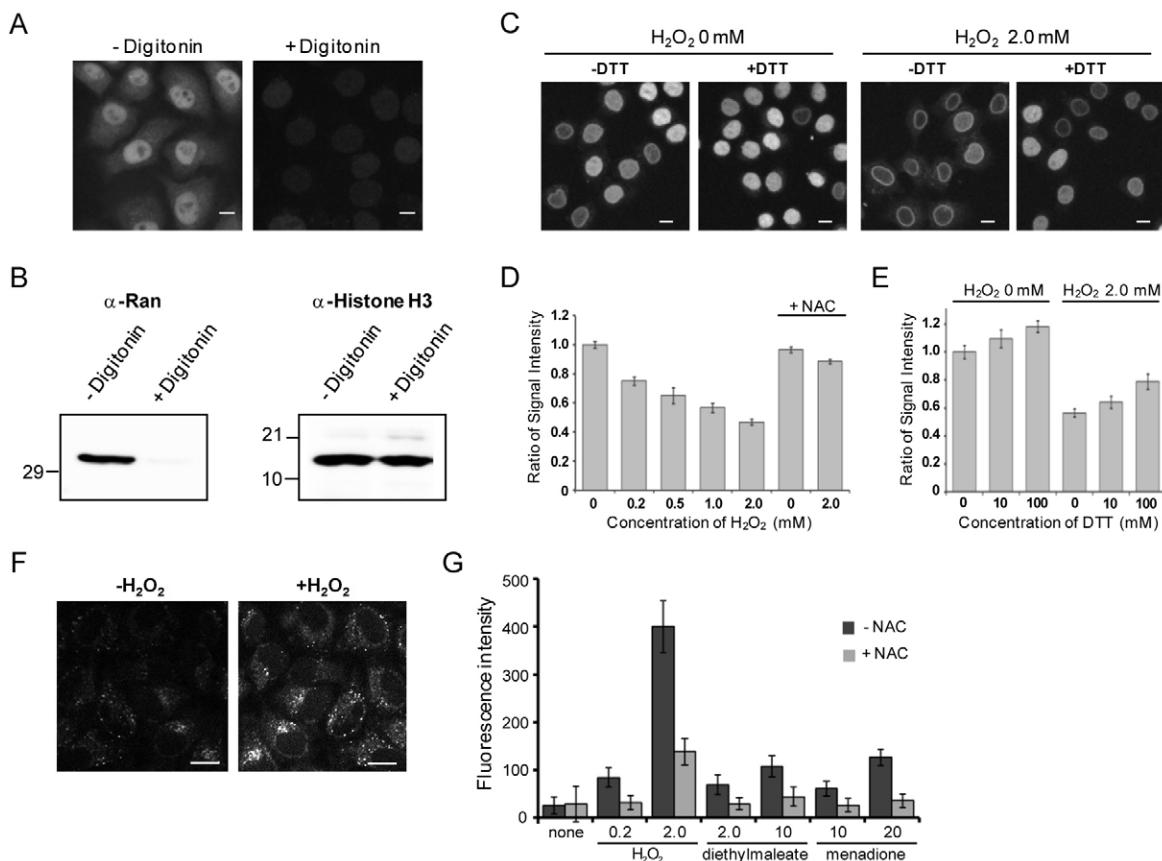


Fig. 1. Oxidative stress inhibits nuclear transport in permeabilized cells. (A,B) Digitonin treatment removes almost all endogenous Ran from the nucleus. (A) Digitonin-treated or non-treated HeLa cells were immunostained with anti-Ran antibody. (B) The digitonin-treated or non-treated HeLa cells were collected and subjected to SDS-PAGE and western blotting. Ran was detected using anti-Ran antibody. Histone H3 was also detected using anti-histone H3 antibody as a loading control. (C–E) HeLa cells were exposed to H_2O_2 for 1 hour. After washing, cells were permeabilized with digitonin, incubated with purified GST-NLS-GFP, importin α , importin β , Ran and ATP-regenerating system and observed by fluorescence microscopy (C). The signal intensity in the nucleus was quantified and represented in terms of its ratio to the signal from non-stressed cells (D). The same analysis was performed with permeabilized cells pre-treated with DTT before the addition of the import mixture (E). Error bars represent the s.e.m. of measurements from ~40 cells. (F,G) Oxidative stress increased the intracellular ROS level. A ROS-reactive fluorescence probe (carboxy-H₂DCFDA) was loaded to the cells before exposure to oxidative stress. To block ROS generation, the cells were pre-incubated with a ROS scavenger (NAC) before the addition of the stress. Fluorescence signal from the cells were either imaged by a confocal laser scanning microscopy (F), or quantified by a fluorometer (G) with an excitation wavelength at 488 nm. The effect of NAC on the NLS cargo transport is included in D. Scale bars: 10 μm.

Oxidative stress differentially regulates influx and efflux rate of importin β through the NPC

We then examined the flux rate of importin β through the NPC, since the accumulation of the cargo in the nucleus depends both on the concentration of RanGTP in the nucleus and on the flux rate of the import complex through the NPC. Purified GFP-fused importin β was incubated with digitonin-treated HeLa nuclei, and the accumulation of fluorescence signal in the nucleoplasm was monitored by time-lapse microscopy (Fig. 2A–C). A detailed kinetic analysis of the fluorescence signal provides both influx and efflux rate constants (k_{in} and k_{out} , respectively) (see also Materials and Methods). In this experimental system, we obtained a k_{out} value that was smaller than the k_{in} (0.15 seconds $^{-1}$ and 0.0088 seconds $^{-1}$ for k_{in} and k_{out} in non-stressed cells, respectively), probably because free importin β tends to firmly bind to immobile components within the nucleus (Paradise et al., 2007) and/or RanGTP is depleted from the nucleus, which reduces the apparent efflux rate under microscopic observation.

The k_{in} value was significantly increased (1.4-fold) by DTT treatment of the nuclei, and slightly reduced (0.87-fold) by the oxidative stress (Fig. 2D). DTT treatment restored the effect of oxidative stress and resulted in a higher k_{in} value than seen in the non-stressed cells (Fig. 2D). The k_{out} value was also influenced by DTT and oxidative stress, but in a slightly different way. Oxidative stress significantly reduced the efflux rate by 0.68-fold,

while DTT treatment had little effect (Fig. 2D), implying that the influx and efflux of importin β through the NPC are differently regulated by the redox environment. The pre-treatment of the cells with a ROS scavenger (NAC) before adding the stress significantly reduced the effect of oxidative stress on the influx and efflux (Fig. 2C,D), demonstrating that the flux rate of importin β through the NPC is directly affected by the intracellular ROS.

The passage of non-karyopherin protein was also examined. Proteins smaller than 40 kDa are known to go through the NPC without help of transport mediators (Görlich and Kutay, 1999). When purified hexahistidine (His₆)-tagged GFP (28 kDa) was incubated with the nuclei (stressed or non-stressed), the GFP signal swiftly entered the nucleoplasm and reached to a steady state within 10 minutes. The final concentration in the nucleus was almost the same as that in the external medium (Fig. 2E), suggesting that the passage of GFP is predominantly driven by diffusion. Kinetic analyses of this flux data revealed that the rate constants (k_{in} and k_{out}) were not affected by either oxidative stress or DTT (Fig. 2F).

Oxidative stress induces S–S bond formation in a distinct set of Nups

To examine whether Nups indeed form S–S bonds within the NPC, nuclei were isolated in the absence of DTT from stressed

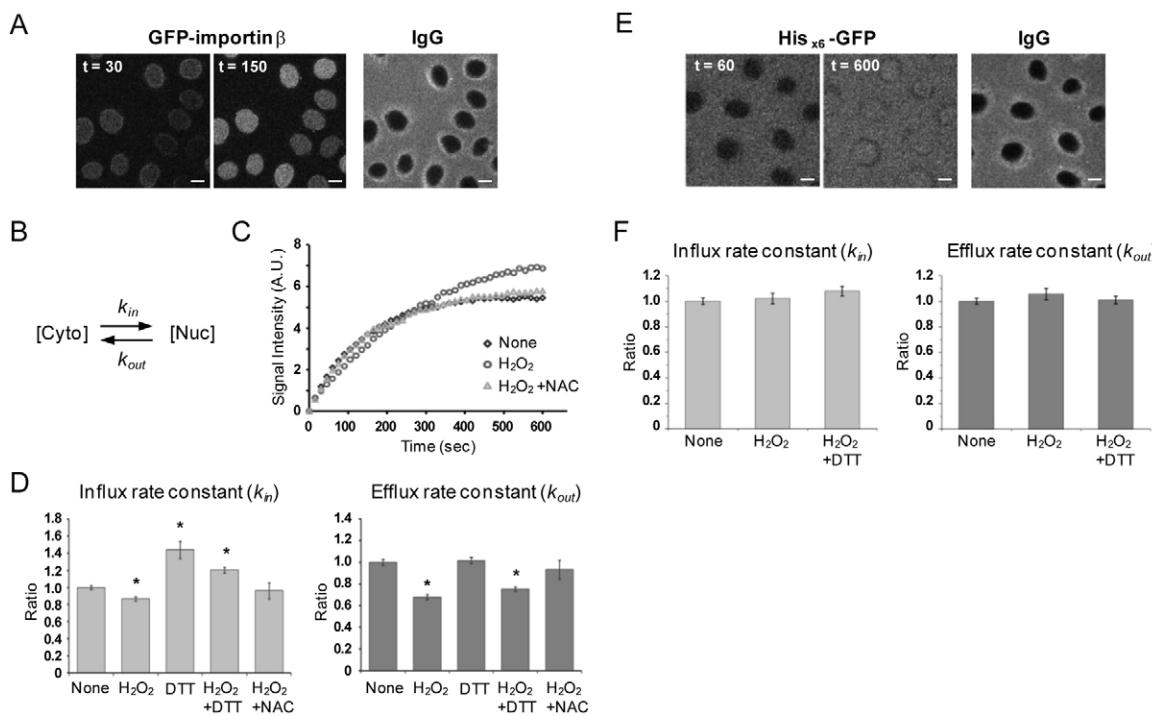


Fig. 2. Oxidative stress reduces the transport rate of importin β but does not affect passive diffusion. HeLa cells were exposed to 0 and 2 mM H_2O_2 and permeabilized with digitonin. Purified GFP-importin β (A–D) or hexahistidine-tagged (His₆)-GFP (E,F) was added together with AlexaFluor568-conjugated IgG, and observed by time-lapse microscopy. (A,E) Fluorescence images of non-stressed cells at indicated times (seconds). The AlexaFluor568-IgG (~150 kDa) signal demonstrates the intact nature of the nuclear envelope. (B) Reaction formula of the transport between the cytoplasm ([Cyto]) and the nucleoplasm ([Nuc]). (C) The fluorescence intensities of GFP-importin β in non-stressed and stressed nuclei in the presence and absence of NAC were plotted against time. Note that at the equilibrium state, the influx rate equals the efflux rate. Therefore, the reduction of the efflux rate constant results in the accumulation of the signal in the nucleus. (D,F) Comparison of k_{in} and k_{out} in the presence and absence of H_2O_2 , NAC and DTT treatments. The data from time-lapse observation (represented as in C) was fitted by an exponential curve and the rate constants of influx (k_{in}) and efflux (k_{out}) were determined as described in Materials and Methods. The obtained rate constants were represented by their ratio to those of non-stressed cells. Error bars represent the s.e.m. of measurements from ~40 cells; * $P < 0.05$; Student's *t*-tests. Scale bars: 10 μ m.

and non-stressed HeLa cells, and analyzed by SDS-PAGE and immunoblotting using Nup-specific antibodies (against Nups 358, 160, 155, 153, 88 and 62) (Fig. 3; the position of each Nup is shown in Fig. 3G). To avoid the oxidation of proteins during the sample preparation, all of the treatments were performed in the presence of the thiol-blocking reagent *N*-ethylmaleimide (NEM, 2 mM). When non-stressed cells (0 mM H₂O₂) were loaded on the gel in the absence of the reducing reagent, the Nup antibodies recognized bands at the expected positions (Fig. 3A–F, asterisks). Several bands (Nups 153, 88 and 160) appeared smear because of the absence of reducing reagent. Careful examination of the immunoreactive bands revealed that Nups 358, 153 and 62 showed additional faint bands with slow migration (Fig. 3A–C; 0 mM H₂O₂, arrows). Since they disappeared upon DTT treatment, it is speculated that they form S–S bonds in non-stressed cells.

Oxidative stress not only increased the amounts of the slow-migrating bands of Nups 358, 153 and 62, but also induced additional slow-migrating bands of Nups 155, 153 and 62 (Fig. 3A–D; 0.2, 2.0 mM H₂O₂, arrows). Since these bands completely disappeared upon DTT treatment, they are also derived from S–S bond formation. No DTT-sensitive slow-migrating bands could be detected in Nups 88 and 160 (Fig. 3E,F). The positions of slow-migrating bands vary Nups to Nups, but most of them appear as sharp bands, implying that

distinct numbers and sets of Nups are involved in S–S bond formation. Especially, Nup62 showed more than three additional slow-migrating bands. One of them seems to correspond to dimer (~120 kDa), but others are much larger than that. Quantitative analysis of the immunoreactive bands revealed that ~41, 35, 19 and 29% of Nups 358, 155, 153 and 62, respectively formed S–S bonds in 2 mM H₂O₂. A similar result was obtained from mAb414, which recognizes four different Nups (Nups 358, 214, 153 and 62) (Fig. 4A). mAb414 detected not only the bands of these Nups at the expected positions but also the DTT-sensitive slow-migrating bands in the absence of oxidative stress (Fig. 4A, arrow). In addition, oxidative stress increased the amount of this slow-migrating band and induced an additional slow-migrating band in a concentration-dependent manner (Fig. 4A, arrows). These results are in good agreement with ones from Nups 358, 153 and 62 (Fig. 3A–C).

We performed similar immunoblot analyses with other ROS, including menadione, an oxidative agent like H₂O₂, and diethylmaleate, a sulphydryl-reactive agent that has been shown to affect nucleocytoplasmic transport (Crampton et al., 2009; Kodiha et al., 2009; Kodiha et al., 2008; Matsuura and Stewart, 2004; Sato et al., 1993). These reagents also increased the intracellular ROS level as measured by the fluorescent probe (Fig. 1G). As shown in Fig. 4, menadione (Fig. 4B) and diethylmaleate (Fig. 4C) showed an immunoreactive band-pattern

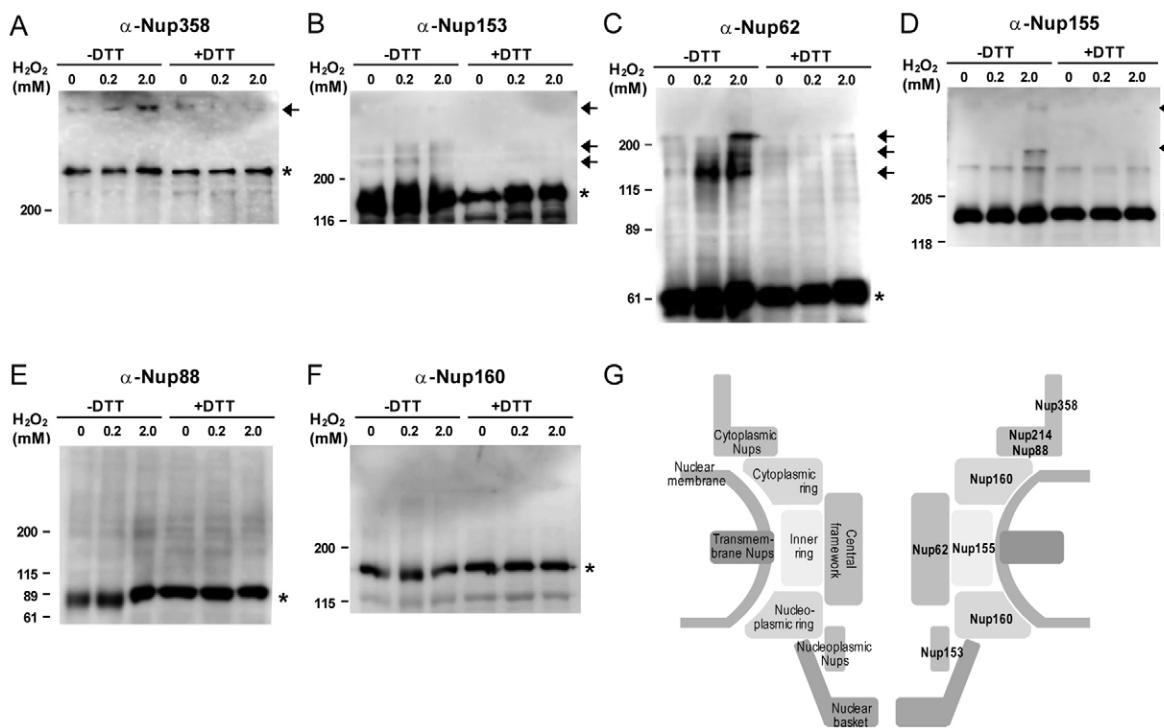


Fig. 3. Oxidative stress promotes S–S bond formation in Nups. (A–F) HeLa cells were exposed to 0, 0.2 and 2.0 mM H₂O₂ and the nuclei collected and prepared for electrophoresis in the absence (−DTT) or presence (+DTT) of 100 mM DTT. The samples were prepared in the presence of NEM to inhibit the formation of S–S bonds during sample preparation. Immunoblot analysis was performed using antibodies against Nup358 (A), Nup153 (B), Nup62 (C), Nup155 (D), Nup88 (E) and Nup160 (F). Slow-migrating bands and bands at the expected positions are indicated by arrows and asterisks, respectively. Nup62 shows a slightly broader (doublet) band in the presence of 2.0 mM H₂O₂, which is reportedly due to phosphorylation and/or O-glycosylation at certain Ser and/or Thr residues (Crampton et al., 2009). A fast-migrating band could also be detected in Nup62 in the presence of 0.2 mM H₂O₂. This might be due to an intramolecular S–S bond, which is known to migrate slightly faster than the expected position (Savitsky and Finkel, 2002). Equal loading of protein was confirmed by stripping the blots and re-probing with anti-β-actin antibody (not shown). (G) The localization of Nup subcomplexes within the NPC is illustrated on the basis of a previous report (Brohawn et al., 2009). The Nups analyzed in this study are indicated.

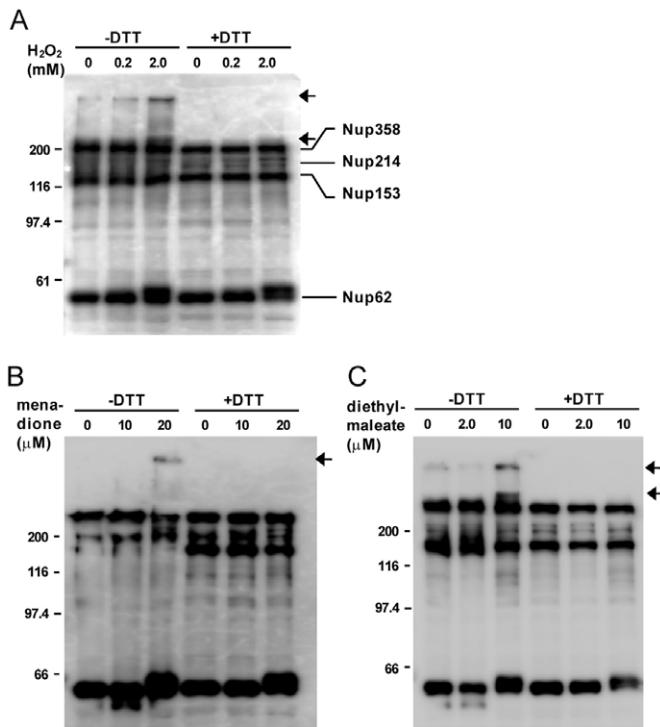


Fig. 4. Other types of ROS also induce S–S bond formation in Nups. HeLa cells were exposed to H_2O_2 (0, 0.2 and 2.0 mM) (A), menadione (0, 10 and 20 μM) (B) or DEM (0, 2.0 and 10 μM) (C) for 1 hour and their nuclei analyzed by immunoblotting with mAb414. The slow-migrating bands are indicated by arrows.

detected by mAb414 similar to that produced by H_2O_2 . These results suggest that the formation of S–S bonds in Nups could be a general response to oxidative stress.

Cysteine residues in Nup62 are directly involved in S–S bond formation and NPC permeability

Nup62 is localized in the central channel of the NPC and plays a crucial role in importin β -dependent nuclear transport (Finlay et al., 1991). The alignment of amino acid sequences of Nup62 revealed two conserved cysteine residues in the C-terminal region (Fig. 5A). We therefore examined whether these cysteine residues form S–S bonds. Hemagglutinin (HA)-tagged Nup62, which carries Cys-to-Ser mutations at these two positions (Fig. 5B), as well as the HA-tagged wild type, were expressed in HeLa cells. The amount of exogenous Nup62 was \sim 1.5- to 2.0-fold that of the endogenous protein, judging from immunoblotting (data not shown). The existence of slow-migrating bands was examined by western blotting using anti-HA antibody. As is the case in endogenous Nup62 (Fig. 3C), oxidative stress induced the bands at higher positions in non-mutated Nup62; one corresponds to dimer and another is above 200 kDa (Fig. 5C, arrows). In contrast, none of the slow migrating bands was detected in the mutant (Fig. 5C), demonstrating that these cysteine residues are (or at least one of these is) involved in the formation of the DTT-sensitive slow-migrating bands.

The role of cysteine residues in NPC permeability was also examined by an *in vitro* transport assay. HeLa cells overexpressing mutant Nup62 were permeabilized with digitonin and incubated with GFP-fused importin β as described in Fig. 2 (Fig. 5D). Time-lapse

observation of the GFP signal demonstrated that both the influx and efflux rate constants were reduced by the oxidative stress in wild-type-expressing cells, whereas none of them was affected in mutant-expressing cells (Fig. 5E). The influx rate of the wild-type was increased by pre-treatment with DTT as is the case in non-transfected HeLa cells (Fig. 2D), whereas the mutant did not exhibit a DTT-sensitive influx rate (Fig. 5E). These results clearly demonstrated that S–S bond formation in Nup62 directly affects the transport of importin β . The export rate was not significantly increased upon DTT treatment (Fig. 5E), suggesting that some modifications in the cysteine residues other than S–S bonds regulate the export of importin β . This result, as well as Fig. 2D, supports the idea that the influx and efflux through the NPC can be independently regulated (see Discussion).

The transport rate of NLS cargo by importin α/β pathway was also examined by the cells overexpressing mutant Nup62. As shown in Fig. 5F, the influx rate of NLS cargo was reduced by oxidative stress in the case of wild-type expressing cells, but less affected in mutant-expressing cells. This is consistent with the fact that the influx rate of importin β was reduced by the stress in wild-type Nup62 but not affected by the stress in mutant Nup62 (Fig. 5E). These results all demonstrated that stress-induced S–S bond formation of Nup62 affects the passage of importin β and also importin- α/β -dependent cargo transport.

Different types of Nups form intermolecular S–S bridges

When Nup62 was knocked down by siRNA and then the cells were exposed to oxidative stress followed by western blot analysis, the immunoreactive bands for Nup62 were decreased to 48% of those seen in control cells (Fig. 6A,B). Namely, the amounts of monomer (Fig. 6A, asterisk), as well as the slow-migrating populations, were reduced in the knockdown cells. When the same nuclei were analyzed with anti-Nup358 and 153 antibodies, the immunoreactive bands were not affected (Fig. 6C,D). However, in the case of Nup155, two of the slow-migrating bands significantly decreased in Nup62 knockdown cells (Fig. 6C, arrows and Fig. 6D). The knockdown of Nup153 did not affect the slow-migrating bands of Nups 358 and 62 (Fig. 6E,F). These results suggest that Nups 155 and 62 are covalently crosslinked via S–S bonds in the presence of oxidative stress, whereas Nups 358 and 153 form S–S bonds within the same type of Nup. It should be noted that immunoblotting for Nup62 and Nup155 revealed slow-migrating bands at the same positions (Fig. 3C,D, arrows).

Discussion

In this study, we demonstrated that NPC contains a significant amount of S–S bonds which are sensitive to oxidative stress, and that these S–S bonds are directly involved in the regulation of importin β -dependent nuclear transport. The results obtained here imply that the S–S bond is one of the fundamental determinants of the properties of the NPC channel. The fact that Nups form S–S bonds even in the absence of oxidative stress suggests that endogenous ROS and reducing reagents can be regulators of nuclear transport.

Stress-dependent and independent S–S bond formation within Nups

The central channel of the NPC is filled with flexible polypeptide chains of Nups which carry a number of phenylalanine residues (FG-Nups) (Bayliss et al., 2000; Ben-Efraim and Gerace, 2001; Peters, 2009; Strawn et al., 2004; Terry and Wente, 2007). It has been proposed that the flexible polypeptide chains of FG-Nups

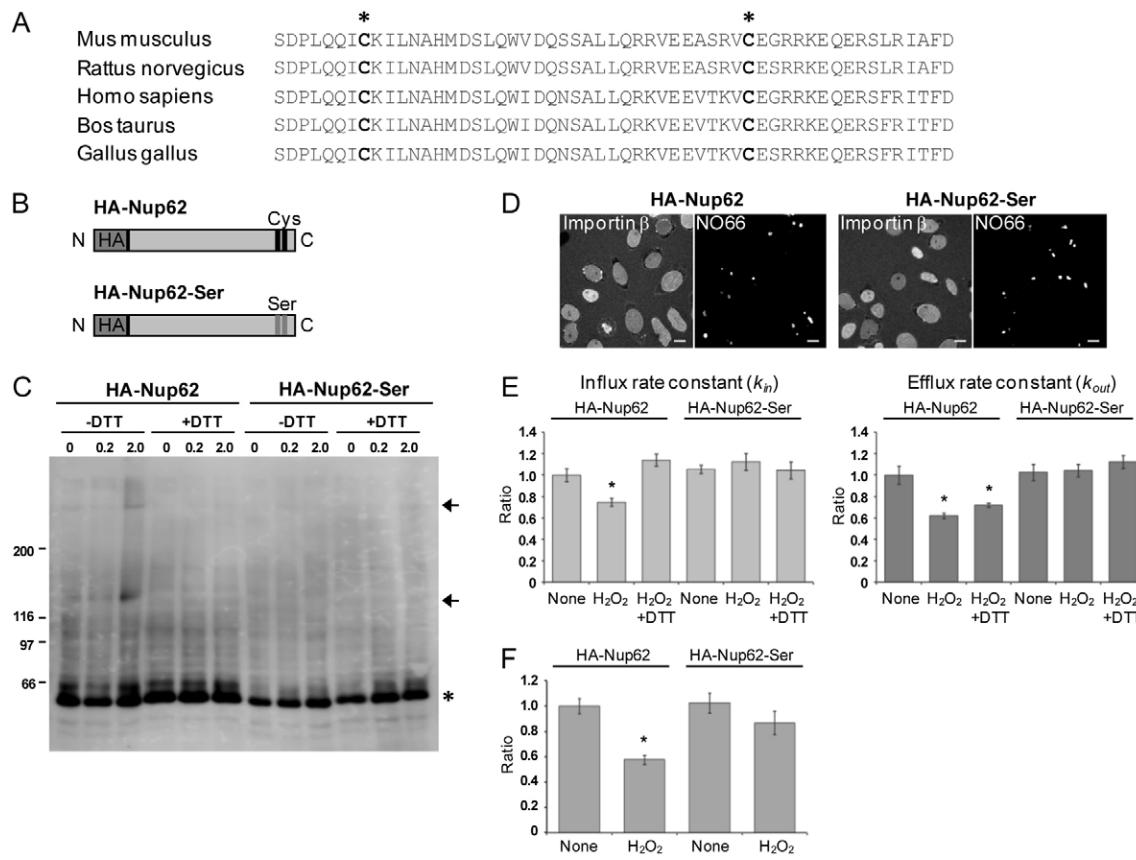


Fig. 5. Two cysteine residues in Nup62 are involved in S–S bond formation and NPC permeability. (A) The amino acid sequences of the C-termini of Nup62 from different species are shown. Cysteine residues are marked with asterisks. (B) Scheme of hemagglutinin-tagged Nup62 (HA-Nup62) and Nup62 containing the point mutations C478S and C509S (HA-Nup62-Ser). (C) HeLa cells expressing HA-Nup62 and HA-Nup62-Ser were treated with H_2O_2 (0, 0.2 and 2.0 mM) and their nuclei analyzed by immunoblotting with anti-HA antibody. The bands are indicated by arrows and asterisks as in Fig. 3. The stress-inducible other modifications that can be observed in Fig. 3C could not be detected, implying that these modifications occur in a limited fraction of Nup62. (D,E) Time-lapse imaging of GFP-importin β was performed using permeabilized HeLa cells that transiently expressed HA-Nup62 or HA-Nup62-Ser and had been exposed to 2.0 mM H_2O_2 . (D) Fluorescence images of cells 150 seconds after the addition of GFP-importin β . mRFP-NO66 is an expression marker of HA-Nup62 (left) and HA-Nup62-Ser (right). (E) Comparison of k_{in} and k_{out} in cells expressing HA-Nup62 and HA-Nup62-Ser in the presence and absence of H_2O_2 and DTT treatment. Rate constants are represented in terms of their ratio to those of HA-Nup62-expressing cells without H_2O_2 and DTT treatment. Error bars represent the s.e.m. of measurements from ~ 10 cells. (F) The import assay of NLS cargo was performed using the nuclei expressing HA-Nup62 and HA-Nup62-Ser as described in Fig. 1C; * $P < 0.01$; Student's *t*-tests. Scale bars: 10 μ m.

form a meshwork via hydrophobic interactions between hydrophobic residues (mainly phenylalanine) (Frey et al., 2006; Mohr et al., 2009; Moussavi-Baygi et al., 2011; Ribbeck and Görlich, 2002). This meshwork prevents the passage of large proteins, but allows diffusion of proteins smaller than the mesh size (Mohr et al., 2009). Karyopherins are able to migrate in this hydrophobic meshwork because of their hydrophobic characteristics. The S–S bonds among these Nups could change the characteristics of the meshwork; intermolecular covalent crosslinking of polypeptides could reduce the flexibility of the meshwork and hence the permeability of karyopherins.

Immunoblot analysis indicated that the amount of S–S bonds significantly increased upon the addition of the stress (Nups 358, 155, 153 and 62), although a small amount could be detected in the absence of the stress (Nups 358, 153 and 62) (Fig. 3). Therefore, H_2O_2 -dependent reduction of transport is due to S–S bond formation in these Nups. It should be noted that Nup62, a component of the central channel of the NPC, has been demonstrated to be a stress sensor, and phosphorylated and

glycosylated upon exposure to cellular stresses (Crampton et al., 2009; Miller et al., 1999). Therefore, S–S bond formation and the concomitant reduction of nuclear transport is one of the mechanisms of Nup62-dependent stress responses. The presence of the S–S bonds of Nups 358, 153 and 62 even in the absence of the stress imply that they might be one of the fundamental components of the hydrophobic meshwork in the NPC. In good agreement with this is the effect of DTT to the non-stressed cells (Figs 1E and 2D); the treatment of non-stressed nuclei with DTT slightly increased the nuclear import of the NLS cargo and influx rate of importin β . The fact that DTT treatment enhanced the flux rate of importin β but not that of GFP (Fig. 2) suggests that the minimum size of the mesh is not affected by S–S bridging.

Nup positioning within the NPC and S–S bond formation
Our knockdown experiments using siRNA imply that Nup62 and Nup155 are crosslinked via S–S bond(s) (Fig. 6). This is a reasonable result since Nups 62 and 155 exist in the central part

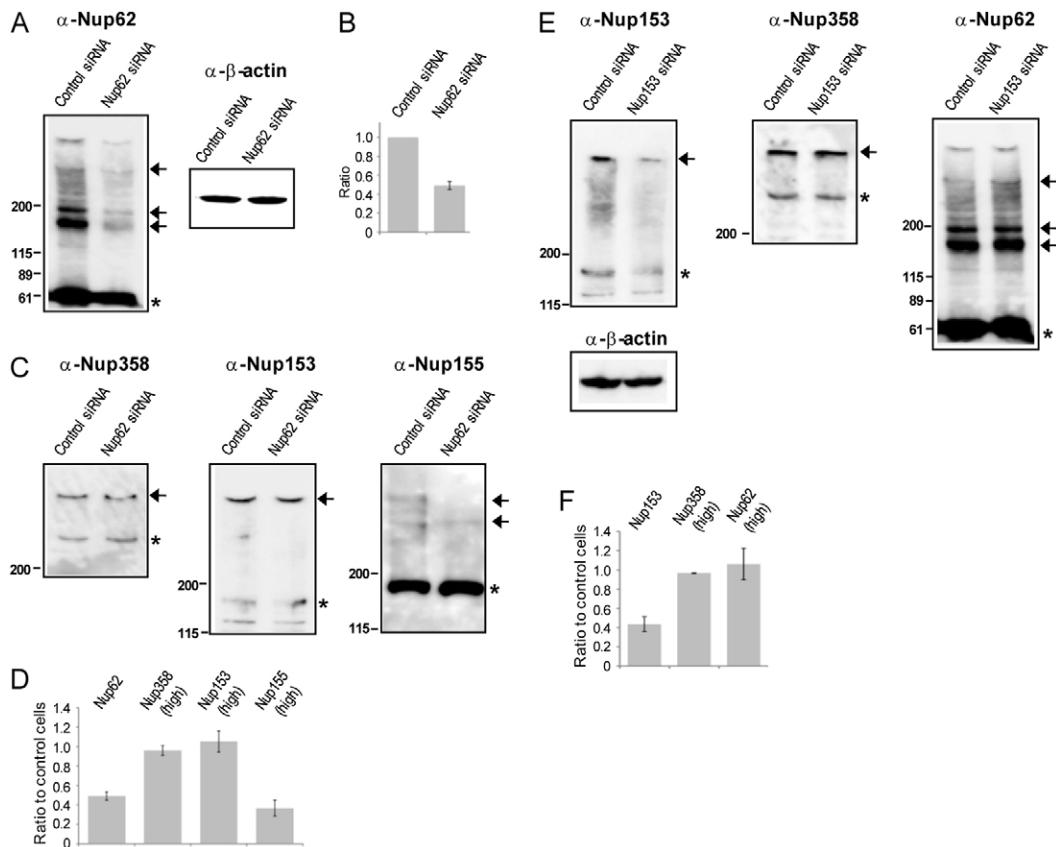


Fig. 6. Nup depletion by RNAi affects some of the stress-inducible bands. HeLa cells were transfected with siRNA against Nup62 (A–D) and Nup153 (E–F) and exposed to 2.0 mM H₂O₂. Nuclei were subjected to immunoblot analysis. siRNA against luciferase was used as a negative control. (A,C,E) Immunoblot analysis of isolated nuclei using anti-Nup62, 358, 153 and 155 antibodies; anti-β-actin antibody was a loading control. The bands are indicated by arrows and asterisks as in Fig. 3. (B,D,F) The intensities of the Nup62 band (B) and of the high molecular weight bands of Nups 62, 358, 153 and 155 (D,F) were quantified and presented in terms of their ratio to the values seen in control cells. Error bars represent s.e.m. from at least three independent experiments.

of the NPC and are supposed to be relatively close to each other (Fig. 3G). On the other hand, knockdown of Nup153 (existing in the nucleoplasmic side of the NPC) did not affect the slow-migrating bands of Nups 358 and 62 (Fig. 6E), suggesting that Nup153 does not form S–S bonds with these Nups. Immunoblot analysis with anti-Nup62 antibody revealed several slow-migrating bands at 120~200 kDa (Fig. 3C). These bands could be either a homomultimer of Nup62 or a heteromultimer with other Nups. The most plausible partners of heteromultimer could be Nups 58, 54 and 45, all of which are known to make a complex with Nup62 (Nup62 complex) (Solmaz et al., 2011; Stoffler et al., 1999). Nups in the Nup93 subcomplex (Nups 205, 188, 155, 93 and 35) are also candidates, since the Nup62 complex is anchored to the Nup93 subcomplex (Grandi et al., 1997; Krull et al., 2004; Sachdev et al., 2012). Further study will be required to elucidate the S–S network among Nups.

We could not find any clear relationship between the formation of S–S bonds and the number of conserved cysteine residues (39 residues in Nup358, 17 in Nup153, 2 in Nup62, 20 in Nup155, 27 in Nup160, and 19 in Nup88; supplementary material Fig. S1). This means that S–S bonds do not form in random positions, but rather form between distinct sets of Nups. Neighboring amino acid sequences, higher-order architectures, and/or spatial locations in the NPC may decide which cysteine residues are to be involved in S–S bond formation. A previous study has

demonstrated that a basic amino acid adjacent to a cysteine residue increases the reactivity of the thiol group (Winterbourne and Hampton, 2008). Indeed, there are several basic amino acids around the two cysteine residues of Nup62 (Fig. 5A). Nups 358, 153 and 155 also contain several cysteine residues just adjacent to either lysine or arginine (18 out of 77 cysteines in Nup358, 9 out of 28 in Nup153, 3 out of 28 in Nup155). These cysteine residues could be the targets of S–S bridging.

Are influx and efflux through the NPC differently regulated?

Our kinetic analysis showed that while oxidative stress influenced both the influx and efflux of importin β, DTT treatment affected only the influx but not the efflux (Fig. 2D; Fig. 5E). This implies that oxidative stress regulates the efflux via mechanisms other than S–S bond formation. Previous studies have demonstrated that Nups 214, 153, 98, 88 and 62 are phosphorylated and/or glycosylated by oxidative stress (Crampton et al., 2009; Kodiha et al., 2009). Other studies have reported that the Nup214/Nup88 complex and Nup98 are involved in export but not in import (Hutten and Kehlenbach, 2006; Oka et al., 2010). Therefore, it might be the case that phosphorylation and glycosylation in these Nups inhibit export but not import. Other possibility is that NPCs may not be homogeneous. Recent studies utilizing super-resolution fluorescence microscopy reported that the Nup composition of the NPC (Nup214 and Nup62) varies between individual NPCs within

a single mammalian cell (Kinoshita et al., 2012). Oxidative stress might introduce different kinds of modifications into distinct NPCs, resulting in differential regulation of import and export. Alternatively, oxidative stress might increase the affinities of some factors in the nucleus to importin β , which would result in the reduction of efflux in stressed cells.

The NPC channel has a redox environment distinct from that of the cytoplasm

In this report, we show a line of evidence for the direct regulation of a cellular function by S–S bonds. Recently it has been reported that S–S bond formation within Lamin A, a scaffold protein of the nuclear envelope, plays an important role in tolerance to ROS and preventing cells from senescence (Pekovic et al., 2011). Since nuclear transport is tightly linked to the entire intracellular signaling pathway, S–S bond formation within the NPC would also contribute to cellular homeostasis.

Cysteine modifications have so far been known to regulate protein function via one or several of the following mechanisms: (i) modification of a thiol group in the catalytic center directly changes the enzymatic activity of the protein, (ii) thiol modification produces an allosteric effect on the enzyme, and (iii) thiol modification alters interactions with other proteins (Jones, 2008). The S–S bonds within the NPC do not seem to belong to any of these mechanisms, and therefore may represent a novel mechanism for the regulation of protein function. The cytoplasm is normally maintained in a reducing state due to ubiquitous reducing reagents such as glutathione. Our results shown here imply that the inner channel of the NPC is in a different redox environment from the cytoplasm (more oxidative), and may be more sensitive to oxidative stress and intracellular reducing reagents than the cytoplasm.

Materials and Methods

Cell culture and oxidative stress

HeLa S3 cells (ATCC, CCL-2.2) were cultured in Dulbecco's Modified Eagle's Medium (DMEM) (Sigma, St. Louis, MO) with 10% fetal bovine serum (FBS). Cells were treated with H_2O_2 (0.1–2.0 mM), menadione (10 μ M and 20 μ M), and diethylmaleate (2.0 μ M and 10 μ M) for 1 hour. The generation of ROS was blocked by the pre-treatment of cells with 10 mM N-acetyl cysteine (NAC) (Nacalai Tesque, Kyoto, Japan) for 1 hour before the addition of H_2O_2 .

Antibodies

Antibodies against Nups were purchased from the following companies; mAb414 (Covance, in Princeton, NJ), anti-Nup358 (Affinity BioReagents, Golden, CO), anti-Nup153 (Immunoquest, Baltimore, MD), anti-Nup62 (BD Biosciences, Franklin Lakes, NJ), and anti-Nup160, 88 (Santa Cruz Biotechnology, Santa Cruz, CA). A rabbit polyclonal anti-Nup155 antibody is a kind gift from Dr Mattaj (European Molecular Biology Laboratory) (Franz et al., 2005). Anti- β -actin antibody and anti-Ran antibody (clone 20) were purchased from Sigma and BD Biosciences, respectively. For the detection of Nup160 and Nup153, biotinylated anti-sheep/goat antibody (GE Healthcare, Little Chalfont, UK) and streptavidin-conjugated horseradish peroxidase (HRP)-coupled antibody (GE Healthcare) were used. In other cases, HRP-coupled secondary antibodies against mouse (GE Healthcare), rabbit (GE Healthcare), or goat (Cappel Laboratories, Malvern, PA) were used.

Plasmids, cDNAs and protein expression

The cDNA of rat Nup62 (Otsuka et al., 2008) was subcloned into the expression vector pcDNA3.1 (Invitrogen, Carlsbad, CA) with an HA tag at the N-terminus. Site-directed mutagenesis of Nup62 was performed using the GeneTailor Site-Directed Mutagenesis system (Invitrogen). cDNA encoding human NO66 was amplified from the cDNA pool of HeLa cells by PCR and inserted into a vector in which the EGFP coding region in the pEGFP-C1 vector (Invitrogen) is replaced by the cDNA of mRFP (a kind gift from Dr Yoneda, Osaka University). The plasmids were introduced into HeLa cells with the transfection reagent, Effectene (Qiagen, Valencia, CA), according to the manufacturer's protocol. Recombinant proteins (importin α 1, importin β 1, Ran, and GFP) were expressed in *E. coli* cells

(BL21-CodonPlus(DE3)-RIL, Agilent Technologies, Wilmington, DE) as affinity-tagged fusion proteins (GST or His_x) and affinity purified as described previously (Kumeta et al., 2010; Yoshimura et al., 2006). As for GST-fused proteins, proteins were cleaved from GST by protease digestion, if necessary (Otsuka et al., 2008). We generated siRNAs against Nup62 (Hubert et al., 2009) and Nup153 (Harborth et al., 2001) by using an *in vitro* transcription kit (Takara, Shiga, Japan). The siRNAs against luciferase were purchased from Invitrogen. HeLa cells were transfected with siRNA using Lipofectamine 2000 (Invitrogen) 45–50 hours before the immunoblot analysis.

Quantification of intracellular ROS

The intracellular ROS was quantitated by using ROS-reactive fluorescence probe as described in the previous study (Pekovic et al., 2011). HeLa cells were cultured in DMEM without phenol red and supplemented with 10% FBS. Carboxyl-H₂DCFDA (5-(and-6)-carboxy-2',7'-dichlorodihydrofluorescein diacetate, Invitrogen, Carlsbad, CA) was added to the culture medium at a final concentration of 10 μ M, and incubated for 1 hour at 37°C. The cells were observed under the fluorescence microscope equipped with a stage heater. H_2O_2 was added to the culture medium and microscopic observation was continued up to 1 hour. To block the generation of ROS, 10 mM NAC was also added to the culture medium during the pre-incubation time. The cells were then exposed to the oxidative stress and harvested after one hour. The cells were washed three times with phosphate-buffered saline (PBS) and the fluorescence signal was measured with an excitation wavelength at 488 nm.

Immunostaining for digitonin-treated HeLa cells

HeLa cells were washed twice with transport buffer (TB; 20 mM HEPES, pH 7.3, 110 mM potassium acetate, 5 mM sodium acetate, 2 mM magnesium acetate, and 1 mM EGTA), permeabilized by TB containing 40 μ g/ml digitonin for 5 minutes on ice, washed twice with TB, incubated with TB at 37°C for 10 minutes, and washed twice with TB. Cells were then fixed with 4% paraformaldehyde and immunostained with anti-Ran antibody and fluorescein isothiocyanate-conjugated anti-mouse IgG (Cappel Laboratories) as described in the previous report (Kumeta et al., 2010).

Immunoblotting for purified nuclei

For immunoblotting in Fig. 1, HeLa cells were washed twice with TB, permeabilized by TB containing 40 μ g/ml digitonin for 5 minutes on ice, washed twice with TB, incubated with TB at 37°C for 10 minutes, and washed twice with TB. Digitonin-treated or non-treated cells were harvested and collected by centrifugation (700×g for 2 minutes), suspended in sample buffer, boiled with 100 mM DTT, and subjected to SDS-PAGE and western blotting. Ran and histone H3 were detected using anti-Ran antibody (C-20, Santa Cruz Biotechnology) and anti-histone H3 antibody (Upstate Biotechnology, Lake Placid, NY), respectively. For immunoblotting experiments in Figs 3–5, HeLa cells (with or without oxidative stress) were washed twice with PBS, harvested by a scraper, and collected by centrifugation (700×g for 2 minutes). The cells were permeabilized by a treatment with 40 μ g/ml digitonin in PBS containing 2 mM *N*-ethylmaleimide (NEM) (Nacalai Tesque, Kyoto, Japan) for 5 minutes and the nuclei were separated from cytosolic components by centrifugation (700×g for 2 minutes). The isolated nuclei were further incubated with PBS containing 0.5% Triton X-100 and 2 mM NEM for 5 minutes and soluble nucleoplasmic proteins were removed by centrifugation (700×g for 2 minutes). All steps were carried out at 4°C. Finally, the enriched nuclei were suspended in the sample buffer, boiled for 5 minutes with or without 100 mM DTT, and subjected to SDS-PAGE followed by immunoblot detection. For immunoblotting in Fig. 6, the digitonin and Triton X-100 treatment was performed without NEM. The amount of slow-migrating band at 2 mM H_2O_2 was quantitated in each Nup. In immunoblotting, the transfer efficiency of a protein band to the blotting membrane varies depending on the molecular weight of the protein; larger proteins are less transferrable to the membrane. Therefore, the fraction(s) of slow-migrating band(s) in the total amount of each subunit was estimated by subtracting the band intensity at the expected position (asterisk) in the absence of DTT from that in the presence, by using non-saturating immunoblot signals.

In vitro transport assay

The transport assay was performed as described in previous reports (Kumeta et al., 2012; Kumeta et al., 2010), except that digitonin-treated cells were pre-incubated with or without DTT for 10 minutes at 37°C before the addition of fluorescent proteins. For the transport assay of NLS cargo, the cells were incubated with 4 μ M importin α , 4 μ M importin β , 25 μ M His_x-RanGDP, 2.5 μ M GST-NLS-GFP, and ATP regeneration system (1 mM ATP, 5 mM creatine phosphate and 200 U/ml creatine phosphokinase) at room temperature for 5 minutes. The cells were then fixed with 4% paraformaldehyde and observed by confocal microscopy (LSM 5 PASCAL; Zeiss, Oberkochen, Germany). For time-lapse observation of NPC permeability in Fig. 2, 0.5 μ M His_x-GFP or GFP-fused importin β was applied to digitonin-treated cells together with Alexa-Fluor-568-conjugated IgG (Invitrogen), and observed by confocal microscopy (LSM510; Zeiss). Images were collected

every 10 seconds for 10 minutes for His_{x6}-GFP and every 5 seconds for 5 minutes for GFP-importin β . The image of Alexa-Fluor-IgG was taken after the time-lapse observation. The mean nuclear fluorescence intensity was quantified by the Zeiss LSM software. For the time-lapse experiment in Fig. 5, 1.0 μM GFP-importin β was added to permeabilized cells and observed using confocal microscopy (LSM 5 PASCAL). Images were collected every 12 seconds. The image of mRFP-NO66 (transfection marker) was taken after time-lapse observation. The fluorescence intensity was measured only in cells expressing mRFP-NO66.

Kinetic analysis of nuclear transport

The rate of protein influx from the cytoplasm to the nucleoplasm can be expressed using the following equation:

$$\frac{d[\text{Nuc}]}{dt} = k_{in}[\text{Cyt}] - k_{out}[\text{Nuc}], \quad (1)$$

where [Nuc] and [Cyt] are the concentrations of GFP-fused proteins in the nucleoplasm and in the cytoplasm, respectively, and k_{in} and k_{out} are the rate constants of influx and efflux, respectively. In the *in vitro* transport assay using permeabilized cells, [Cyt] corresponds to the substrate concentration in the chamber, which is constant throughout the measurement. Therefore, Eq. 1 can be converted to:

$$[\text{Nuc}] = k_{in}[\text{Cyt}] / k_{out} \{1 - \exp(-k_{out}t)\}. \quad (2)$$

The average fluorescence intensity of each nucleus was measured and plotted against time, and fitted with Eq. 2 to obtain k_{in} and k_{out} .

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Author contributions

S.O., M.T. and S.H.Y. performed all experiments and analyses. S.O. and S.H.Y. designed the study. S.O., S.H.Y., K.M. and K.T. discussed the results and wrote the paper.

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References

- Bayliss, R., Littlewood, T. and Stewart, M. (2000). Structural basis for the interaction between FxFG nucleoporin repeats and importin-beta in nuclear trafficking. *Cell* **102**, 99-108.
- Ben-Efraim, I. and Gerace, L. (2001). Gradient of increasing affinity of importin beta for nucleoporins along the pathway of nuclear import. *J. Cell Biol.* **152**, 411-417.
- Brohawn, S. G., Partridge, J. R., Whittle, J. R. and Schwartz, T. U. (2009). The nuclear pore complex has entered the atomic age. *Structure* **17**, 1156-1168.
- Crampton, N., Kodiha, M., Shrivastava, S., Umar, R. and Stochaj, U. (2009). Oxidative stress inhibits nuclear protein export by multiple mechanisms that target FG nucleoporins and Crm1. *Mol. Biol. Cell* **20**, 5106-5116.
- Finlay, D. R., Meier, E., Bradley, P., Horecka, J. and Forbes, D. J. (1991). A complex of nuclear pore proteins required for pore function. *J. Cell Biol.* **114**, 169-183.
- Franz, C., Askjaer, P., Antonin, W., Iglesias, C. L., Haselmann, U., Schelder, M., de Marco, A., Wilm, M., Antony, C. and Mattaj, I. W. (2005). Nup155 regulates nuclear envelope and nuclear pore complex formation in nematodes and vertebrates. *EMBO J.* **24**, 3519-3531.
- Frey, S., Richter, R. P. and Görlich, D. (2006). FG-rich repeats of nuclear pore proteins form a three-dimensional meshwork with hydrogel-like properties. *Science* **314**, 815-817.
- Görlich, D. and Kutay, U. (1999). Transport between the cell nucleus and the cytoplasm. *Annu. Rev. Cell Dev. Biol.* **15**, 607-660.
- Grandi, P., Dang, T., Pané, N., Shevchenko, A., Mann, M., Forbes, D. and Hurt, E. (1997). Nup93, a vertebrate homologue of yeast Nic96p, forms a complex with a novel 205-kDa protein and is required for correct nuclear pore assembly. *Mol. Biol. Cell* **8**, 2017-2038.
- Harborth, J., Elbashir, S. M., Bechert, K., Tuschl, T. and Weber, K. (2001). Identification of essential genes in cultured mammalian cells using small interfering RNAs. *J. Cell Sci.* **114**, 4557-4565.
- Hubert, T., Vandekerckhove, J. and Gettemans, J. (2009). Exo70-mediated recruitment of nucleoporin Nup62 at the leading edge of migrating cells is required for cell migration. *Traffic* **10**, 1257-1271.
- Hutten, S. and Kehlenbach, R. H. (2006). Nup214 is required for CRM1-dependent nuclear protein export *in vivo*. *Mol. Cell. Biol.* **26**, 6772-6785.
- Jones, D. P. (2008). Radical-free biology of oxidative stress. *Am. J. Physiol. Cell Physiol.* **295**, C849-C868.
- Kinoshita, Y., Kalir, T., Dottino, P. and Kohtz, D. S. (2012). Nuclear distributions of NUP62 and NUP214 suggest architectural diversity and spatial patterning among nuclear pore complexes. *PLoS ONE* **7**, e36137.
- Kobayashi, A., Kang, M. I., Watai, Y., Tong, K. I., Shibata, T., Uchida, K. and Yamamoto, M. (2006). Oxidative and electrophilic stresses activate Nrf2 through inhibition of ubiquitination activity of Keap1. *Mol. Cell. Biol.* **26**, 221-229.
- Kodiha, M., Chu, A., Matusiewicz, N. and Stochaj, U. (2004). Multiple mechanisms promote the inhibition of classical nuclear import upon exposure to severe oxidative stress. *Cell Death Differ.* **11**, 862-874.
- Kodiha, M., Tran, D., Qian, C., Morogan, A., Presley, J. F., Brown, C. M. and Stochaj, U. (2008). Oxidative stress mislocalizes and retains transport factor importin-alpha and nucleoporins Nup153 and Nup88 in nuclei where they generate high molecular mass complexes. *Biochim. Biophys. Acta* **1783**, 405-418.
- Kodiha, M., Tran, D., Morogan, A., Qian, C. and Stochaj, U. (2009). Dissecting the signaling events that impact classical nuclear import and target nuclear transport factors. *PLoS ONE* **4**, e8420.
- Krull, S., Thyberg, J., Björkroth, B., Rackwitz, H. R. and Cordes, V. C. (2004). Nucleoporins as components of the nuclear pore complex core structure and Trp as the architectural element of the nuclear basket. *Mol. Biol. Cell* **15**, 4261-4277.
- Kumeta, M., Yoshimura, S. H., Harata, M. and Takeyasu, K. (2010). Molecular mechanisms underlying nucleocytoplasmic shuttling of actinin-4. *J. Cell Sci.* **123**, 1020-1030.
- Kumeta, M., Yamaguchi, H., Yoshimura, S. H. and Takeyasu, K. (2012). Karyopherin-independent spontaneous transport of amphiphilic proteins through the nuclear pore. *J. Cell Sci.* **125**, 4979-4984.
- Matsuura, Y. and Stewart, M. (2004). Structural basis for the assembly of a nuclear export complex. *Nature* **432**, 872-877.
- Mattaj, I. W. and Englmeier, L. (1998). Nucleocytoplasmic transport: the soluble phase. *Annu. Rev. Biochem.* **67**, 265-306.
- Miller, M. W., Caracciolo, M. R., Berlin, W. K. and Hanover, J. A. (1999). Phosphorylation and glycosylation of nucleoporins. *Arch. Biochem. Biophys.* **367**, 51-60.
- Miyamoto, Y., Saiwaki, T., Yamashita, J., Yasuda, Y., Kotera, I., Shibata, S., Shigeta, M., Hiraoka, Y., Haraguchi, T. and Yoneda, Y. (2004). Cellular stresses induce the nuclear accumulation of importin alpha and cause a conventional nuclear import block. *J. Cell Biol.* **165**, 617-623.
- Mohr, D., Frey, S., Fischer, T., Güttler, T. and Görlich, D. (2009). Characterisation of the passive permeability barrier of nuclear pore complexes. *EMBO J.* **28**, 2541-2553.
- Mosammaparast, N. and Pemberton, L. F. (2004). Karyopherins: from nuclear-transport mediators to nuclear-function regulators. *Trends Cell Biol.* **14**, 547-556.
- Motohashi, H. and Yamamoto, M. (2004). Nrf2-Keap1 defines a physiologically important stress response mechanism. *Trends Mol. Med.* **10**, 549-557.
- Moussavi-Baygi, R., Jamali, Y., Karimi, R. and Mofrad, M. R. (2011). Brownian dynamics simulation of nucleocytoplasmic transport: a coarse-grained model for the functional state of the nuclear pore complex. *PLOS Comput. Biol.* **7**, e1002049.
- Oka, M., Asally, M., Yasuda, Y., Ogawa, Y., Tachibana, T. and Yoneda, Y. (2010). The mobile FG nucleoporin Nup98 is a cofactor for Crm1-dependent protein export. *Mol. Biol. Cell* **21**, 1885-1896.
- Osuka, S., Iwasaka, S., Yoneda, Y., Takeyasu, K. and Yoshimura, S. H. (2008). Individual binding pockets of importin-beta for FG-nucleoporins have different binding properties and different sensitivities to RanGTP. *Proc. Natl. Acad. Sci. USA* **105**, 16101-16106.
- Paradise, A., Levin, M. K., Korza, G. and Carson, J. H. (2007). Significant proportions of nuclear transport proteins with reduced intracellular mobilities resolved by fluorescence correlation spectroscopy. *J. Mol. Biol.* **365**, 50-65.
- Patel, V. P., Defranco, D. B. and Chu, C. T. (2012). Altered transcription factor trafficking in oxidatively-stressed neuronal cells. *Biochim. Biophys. Acta* **1822**, 1773-1782.
- Pekovic, V., Gibbs-Seymour, I., Markiewicz, E., Alzoghaibi, F., Benham, A. M., Edwards, R., Wenhert, M., von Zglinicki, T. and Hutchison, C. J. (2011). Conserved cysteine residues in the mammalian lamin A tail are essential for cellular responses to ROS generation. *Aging Cell* **10**, 1067-1079.

- Peters, R.** (2009). Translocation through the nuclear pore: Kaps pave the way. *Bioessays* **31**, 466-477.
- Rhee, S. G., Kang, S. W., Jeong, W., Chang, T. S., Yang, K. S. and Woo, H. A.** (2005). Intracellular messenger function of hydrogen peroxide and its regulation by peroxiredoxins. *Curr. Opin. Cell Biol.* **17**, 183-189.
- Ribbeck, K. and Görlich, D.** (2002). The permeability barrier of nuclear pore complexes appears to operate via hydrophobic exclusion. *EMBO J.* **21**, 2664-2671.
- Sachdev, R., Sieverding, C., Flötenmeyer, M. and Antonin, W.** (2012). The C-terminal domain of Nup93 is essential for assembly of the structural backbone of nuclear pore complexes. *Mol. Biol. Cell* **23**, 740-749.
- Sato, H., Ishii, T., Sugita, Y., Tateishi, N. and Bannai, S.** (1993). Induction of a 23 kDa stress protein by oxidative and sulfhydryl-reactive agents in mouse peritoneal macrophages. *Biochim. Biophys. Acta* **1148**, 127-132.
- Savitsky, P. A. and Finkel, T.** (2002). Redox regulation of Cdc25C. *J. Biol. Chem.* **277**, 20535-20540.
- Solmaz, S. R., Chauhan, R., Blobel, G. and Melčák, I.** (2011). Molecular architecture of the transport channel of the nuclear pore complex. *Cell* **147**, 590-602.
- Spickett, C. M., Pitt, A. R., Morrice, N. and Kolch, W.** (2006). Proteomic analysis of phosphorylation, oxidation and nitrosylation in signal transduction. *Biochim. Biophys. Acta* **1764**, 1823-1841.
- Stochaj, U., Rassadi, R. and Chiu, J.** (2000). Stress-mediated inhibition of the classical nuclear protein import pathway and nuclear accumulation of the small GTPase Gsp1p. *FASEB J.* **14**, 2130-2132.
- Stoffler, D., Fahrenkrog, B. and Aeby, U.** (1999). The nuclear pore complex: from molecular architecture to functional dynamics. *Curr. Opin. Cell Biol.* **11**, 391-401.
- Strawn, L. A., Shen, T., Shulga, N., Goldfarb, D. S. and Wente, S. R.** (2004). Minimal nuclear pore complexes define FG repeat domains essential for transport. *Nat. Cell Biol.* **6**, 197-206.
- Terry, L. J. and Wente, S. R.** (2007). Nuclear mRNA export requires specific FG nucleoporins for translocation through the nuclear pore complex. *J. Cell Biol.* **178**, 1121-1132.
- Weis, K.** (2003). Regulating access to the genome: nucleocytoplasmic transport throughout the cell cycle. *Cell* **112**, 441-451.
- Winterbourn, C. C.** (2008). Reconciling the chemistry and biology of reactive oxygen species. *Nat. Chem. Biol.* **4**, 278-286.
- Winterbourn, C. C. and Hampton, M. B.** (2008). Thiol chemistry and specificity in redox signalling. *Free Radic. Biol. Med.* **45**, 549-561.
- Yasuda, Y., Miyamoto, Y., Saiwaki, T. and Yoneda, Y.** (2006). Mechanism of the stress-induced collapse of the Ran distribution. *Exp. Cell Res.* **312**, 512-520.
- Yoshimura, S. H., Takahashi, H., Otsuka, S. and Takeyasu, K.** (2006). Development of glutathione-coupled cantilever for the single-molecule force measurement by scanning force microscopy. *FEBS Lett.* **580**, 3961-3965.

Fig. S1. Sequence alignments of nucleoporins. The amino acid sequences of Nups358, 153, 62, 155, 160, and 88 from different species are shown. Cysteine residues are highlighted with yellow.

Nup358

Mus musculus	-MRRSKADVERYIASVQGSAPSREKSMGFYFAKLYYEAEKEYDLAKKYISTYINVQERD	59
Rattus norvegicus	-MRRSKAEVERYIASVQGSAPSREKSMGFYFAKLYYEAEKEYDLAKKYISTYINVQERD	59
Homo sapiens	-MRRSKADVERYIASVQGSTPSPRQKSMGFYFAKLYYEAEKEYDLAKKYISTYINVQERD	59
Bos taurus	-MRRSKADVRHIASVQGSAPSREKSMGFYFAKLYYEAEKEYDLAKKYISTYINVQERD	59
Gallus gallus	MIRRTKPEVERYVASVQAAASSPRERSLKGFLFAKLYFEIKEYELAKRYSIYLSVQERD	60
Mus musculus	PKAHRFLGLLYEVEENIDKAVECYKRSELNPQTKDVLVKIAELLCKNDVTDGRAKYWVE	119
Rattus norvegicus	PKAHRFLGLLYEIEENTDKAVECYKRSELNPQTKDVLVKIAELLCKNDVTDGRAKYWVE	119
Homo sapiens	PKAHRFLGLLYELEENTDKAVECYRSELNPQTKDVLVKIAELLCKNDVTDGRAKYWLE	119
Bos taurus	PKAHRFLGLLYEVEENIEKAVECYKRSELNPQTKDVLVKIAELLCKNDVTDGRAKYWVE	119
Gallus gallus	PKAHRFLGQIYEAQDNIEKAFCYCZRSELNPQMQLFDVLVKIAELLCKNDVTDGRAKYWVE	120
Mus musculus	RAAKLFPGPSAIYKLKEQQLDCKGEDGWNLKFDFLIQSELYARPDDIHVNIRLVELYRSNK	179
Rattus norvegicus	RAAKLFPGPSAIYKLKEQQLDCKGEDGWNLKFDFLIQSELYARPDDDVHNIRLVELYRSNK	179
Homo sapiens	RAAKLFPGPSAIYKLKEQQLDCEGEDGWNLKFDFLIQSELYVRPDDDVHNIRLVEVYRSTK	179
Bos taurus	RAAKLFPGPSAIYKLKEQQLDCKGEDGWNLKFDFLIQSELYARPDDDVHNIRLVELYRSNS	179
Gallus gallus	KAARLFPGNPAAYRLKEQLLERKGEDGWNLQFDMIQTELYARPDDIYLIRVALYRSNN	180
Mus musculus	RLKDAVAHCHEADRNALRSSLEWNLCVVQTLKEYLESQCLDSDKSTWRATNKKDLLAY	239
Rattus norvegicus	RLKDAVAHCHEADRNALRSSLEWNCSVQTLKEYLESQCLDSDKSTWRATNKKDLLAY	239
Homo sapiens	RLKDAVAHCHEARNIALRSSLEWNCSVQTLKEYLESQCLESDKSDWRATNTKDLLAY	239
Bos taurus	RLRDAVAHCQAERNALRSSLEWNCSVQTLKEYLESSQCLESDSKNWRATSQDLLAY	239
Gallus gallus	RLRDAVLHCEQAEKKIPIDSSLEWNCVIKTLEEYLESVRDLEPDKNWRAIKKDHLAY	240
Mus musculus	ANIMLLTLSTRDVQEGRE-----LLESFDALSQSVKSSVGGNDELSATFLETKGHFM	292
Rattus norvegicus	SNIMLLTLSTRDVQESRE-----LLESFDALSQSVKSSVGGNDELSATFLETKGHFM	292
Homo sapiens	ANIMLLTLSTRDVQESRE-----LQSFDALSQSVKS-LGGNDELSATFLETKGHFM	291
Bos taurus	ANIMLLTLMSMRDAQESRE-----LLESFDALSQSVKFQAGNEELSATFLEVRGHFM	292
Gallus gallus	SSLVKTLLASRDVCESRGAXKASFRLHSSFDRLHSVKPYVNGPDELTSRFLEMKGHFM	300
Mus musculus	HVGSLLLKMGQQS-DIQWRALSELAAALCYLVAFQVPRPKVKLIK-G-EAGQNLLETMAHDR	350
Rattus norvegicus	HVGSLLLKMGQQS-DIQWRALSELAAALCYLIAFQVPRPKVKLIK-ETGQNLLEMMAHDR	350
Homo sapiens	HAGSLLLKMGQHSSNVQWRALSELAAALCYLIAFQVPRPKVKLIK-G-EAGQNLLEMMACDR	350
Bos taurus	HAGSLLLKMGQHS-DVQWRALSELAAALCYLIAFQIPRPTKLIK-G-EAGQSLLEMMAYDR	350
Gallus gallus	HAGTFLLKMAQNN-EARWRDACELAALCYLKSFQIPKPKSKLICKGDPTQGQDMLMLEMLACDR	359
Mus musculus	LSQSGHMLLNLSRGKQDFLKEVVESFANKSGQSAQDALFSSQSSKERSFLGNDDIGNLD	410
Rattus norvegicus	LSQSGHMLLNLSRGKQDFLKEVVESFANKSGQSAQDALFSSQSSKDRSFLGNDDIGNLD	410
Homo sapiens	LSQSGHMLLNLSRGKQDFLKEIVETFANKSGQSALEYDALFSSQSPKDTSLFGSDDIGNID	410
Bos taurus	LSQSGHMLLNLSRDKQDFLKEVVESFANRGQSALEYDALFSRQLPKDSQFLGNDDIGSID	410
Gallus gallus	KSQSGHMLLNLSHKGEDFLREIVESFANKSGLFTLFEGLFGSGASRSERSFLGTTDDMGDVS	419
Mus musculus	GQVPDPDDLARYDTGAVRAHNGSLQHLTWLGLQWNSLSTLPAIRKWLQLFHHLQPETSR	470
Rattus norvegicus	GQVPDPDDLARYDTGAVRAHNGSLQHLTWLGLQWNSLTPAIRKWLQLFHHLQPETSR	470
Homo sapiens	VREPELEDLTRYDVGAIARAHNGSLQHLTWLGLQWNSLPALPGIRKWLQLFHHLPHETSR	470
Bos taurus	VQEPDFDELARYDVGAIARAHNGSLQHLTWLGLQWDSLPTLPAIRKWLQLFHHLQPETSR	470
Gallus gallus	TQAPAQGELSKEYDIGAVRMHCGSLQHLWGLQWNSMSVLFPLRKLLKQLFH-LPQETSR	478
Mus musculus	LETNAPEVICILDLEVFLLGVIYTSHLQLKECNSHHTSYQPLCLPLPVCRQLCTERQKT	530
Rattus norvegicus	LETNAPEVICILDLEVFLLGVIYTSHLQLREKSNSHHTSYQPLCLPLPVCRQLCTERQKS	530
Homo sapiens	LETNAPEVICILDLEVFLGVVYTSHLQLKECNSHHSYYQPLCLPLPVCKQLCTERQKS	530
Bos taurus	LETNAPEVICILDLEVFLGVVYTSHLQLKEKSNSHCSFYQPLCLPLPVCKQLCTERQKA	530
Gallus gallus	LETDAPESICILDLEVFLGMVFTSNLQLQEKFNTHYGTHQPPFLPLLCKQYSTEKQRS	538
Mus musculus	WWDAVCTLITLHRKALPGTSAKLRLLLVQREINSLRGQEKHGLQPALLVHWAQSLQKTGSSLN	590
Rattus norvegicus	WWDAVCTLITLHRKALPGTSAKLRLLLVQREINSLRGQEKHGLQPALLVHWAQSLQKTGSSLN	590
Homo sapiens	WWDAVCTLITLHRKAVPGNVAKLRLLLVQHEINTLRAQEKGHQPLALLVHWAECLOKTGSGLN	590

<i>Bos taurus</i>	WWDAV C NLIHRKAVPGTSAKLRLLVQRDINTLRGQEKTGLQPALLVHWAK C LQKTGSLN 590
<i>Gallus gallus</i>	WWDAVRTLMQKKTTPDSATKLKLLVQHGLSTLRALEKHGLQPALMIHWARSLQKTGVSLN 598
<i>Mus musculus</i>	SFYDQREYIGRSVHYWRKVLP <i>L</i> KMIRKKNSIPEPIDPLFKHFHSVDIQASEIGEYEEDA 650
<i>Rattus norvegicus</i>	SFYDQREYIGRSVHYWRKVLP <i>L</i> KKMIRKKNSIPEPIDPLFKHFHSVDIQVEIGEYEEDA 650
<i>Homo sapiens</i>	SFYDQREYIGRSVHYWKKVLP <i>L</i> KKMIRKKNSIPEPIDPLFKHFHSVDIQASEIVEYEEDA 650
<i>Bos taurus</i>	SFYDQREYIGRSVHYWKKVLP <i>L</i> KKMIRKKNSIPEPADPLFRFHFSADIQACEVGEYEDEA 650
<i>Gallus gallus</i>	SFYDQKEYIGRSVYYWKKTLLSKTICKHHKSIEPTDPLFKHFHSVDIQVFQVAAYEEE 658
<i>Mus musculus</i>	HITFAILDAVNGNIEDAMTAFESIKNVVSYWNLNALIFHRKAEDIENDALSPEEQEECKNY 710
<i>Rattus norvegicus</i>	HITFAILDAVNGNIEDAMTAFESIKNVVSYWNLNALIFHRKAEDIENDALSPEEQEECKNY 710
<i>Homo sapiens</i>	HITFAILDAVNGNIEDAVTAFESIKSVVSYWNLNALIFHRKAEDIENDALSPEEQEECKNY 710
<i>Bos taurus</i>	RITFAILDVVNGNIDDAMAFESINNNVISYWNLNALLFHRKAEDIDNDVLSSEEQEECKNY 710
<i>Gallus gallus</i>	YIAFAMLDAVEGKTDALLAFESIKNVVAYWNLAVL C QRKAAEELENDDDMLPEEQEEHKTY 718
<i>Mus musculus</i>	LRKTRDYLIRILDDSDSNTSVVQKLPVPLESVKEMLNSVMQELEDYSEGGTLYKNG C WRS 770
<i>Rattus norvegicus</i>	LRKTRDYLIKILDDSDSNTSVVQKLPVPLESVKEMLNSVMQELEDYSEGGTLYKNG C FRS 770
<i>Homo sapiens</i>	LRKTRDYLIKILDD C DSNLSVVVKLPVPLESVKEMLNSVMQELEDYSEGGPLYKNGSLRN 770
<i>Bos taurus</i>	LRKTRDYLIKILDD C DSNLSVVVKLPVPLESVKEMLNSVMQELEDYSEGGPLYKNGSVRN 770
<i>Gallus gallus</i>	LLKRKHYLMKIIDESSSDPSVADKLPVSIETVTMLNTVIQELGGNEEGESLASRNIAQA 778
<i>Mus musculus</i>	ADSELKHSTPSPTKYSLSPSKS C YSPKTPPRWAEDQNSLLKMI C QQVEAIKKEMQELKL 830
<i>Rattus norvegicus</i>	ADSELKHSTPSPTKYSLSPSKS C YSPKTPPRWAEDQNSLLKMI C QQVEAIKKEMQELKL 830
<i>Homo sapiens</i>	ADSEIKRSTPSPTRYSLSPSKSY C YSPKTPPRWAEDQNSLLKMI C QQVEAIKKEMQELKL 830
<i>Bos taurus</i>	ADSEIKHSTSSPTKYS C YSPSPNRS C YSPKTPPPQWAEDQNC C LLKMI C QQVEAIKKEMQELKL 830
<i>Gallus gallus</i>	AHLEVKHPIPKPKL C FSPTNTYKFSPKTL C PQWAEDHKSLLQML C QQVEALKNEMQEMKL 838
<i>Mus musculus</i>	NSN-NSASPHRWPAEPYGQDPAPDGYQGSQTFHGAPLTVATTGPSVYYQS C PAYNSQYLL 889
<i>Rattus norvegicus</i>	NSN-NSASPHRWPAEHYRQDPVDPGYQGSQTFHGAPLTVATTGPSVYYQS C PAYNSQYLL 889
<i>Homo sapiens</i>	NSS-NSASPHRWPTENYGPDSVPDGYQGSQTFHGAPLTVATTGPSVYYQS C PAYNSQYLL 889
<i>Bos taurus</i>	NSS-SSGSPHRWPENYGPDPVPDSYQGSQNHFHGAPLTVATTGH C SV C YSQS C PAYNTQYLL 889
<i>Gallus gallus</i>	NSSSVSSHRWPAESYGTDTVSDGYQRAQNLHEAPLTVATTGPSVYYQS C PAYNSQYLL 898
<i>Mus musculus</i>	RPAAN-VTPTKGPVYGMNRLLPPQ C HQHIYAYSQQMHTPPVQSSSA C MFQS C EMYGPP-LRFES 947
<i>Rattus norvegicus</i>	RPAAN-VTPTKGPVYGMNRLLPPQ C HQHIYAYSQQMHTPPVQSSSS C MFQS C EMYGPP-LRFES 947
<i>Homo sapiens</i>	RPAAN-VTPTKGPVYGMNRLLPPQ C HQHIYAYPQ C QMHTPPVQSSSA C MFQS C EMYGPP-LRFES 948
<i>Bos taurus</i>	RPAAN-VTPTKGPVYGMNRLLPPQ C HQHVYGYPQ C QMHTPPVQSSSA C MFQS C DQMYGPP-LRFES 947
<i>Gallus gallus</i>	RTAATNVTPTKAPVYGMNR C LAQ C QHQHIYAYQQPI C HTPP C LQNTSACVFPQDIYGTP-LRFDA 957
<i>Mus musculus</i>	PATGILSPRG-DDYFNYNVQQTSTNPPLPEPGYFTKPPLVAHASRSAESKVIEFGKSNFV 1006
<i>Rattus norvegicus</i>	PATGILSPRG-DDYFNYNVQQTSTNPPLPEPGYFTKPPLVAHASRSAESKVIEFGKSNFV 1006
<i>Homo sapiens</i>	PATGILSPRG-DDYFNYNVQQTSTNPPLPEPGYFTKPPIAAHASRSAESKVIEFGKTNFV 1007
<i>Bos taurus</i>	PATGILSPRG-DDYFNYNVQQTSTNPPLPEPGYFTKPPLAAHASRSAEPKVLEFGKTSFV 1006
<i>Gallus gallus</i>	PAAGIISPRGADDYNYGVPQASSNPPLPEPGYFTKPSVAPATLKPAESKVVEFSKAKFG 1017
<i>Mus musculus</i>	QPMQGEVIRPPLTTPAHTTQPTPFKNFSNFKSNDGFTFSSPQVVAQPPSTAYSNSESLL 1066
<i>Rattus norvegicus</i>	QPMQGEVIRPPLATPAHTTQPTPFKNFSNFKSNDGFTFSSPQVVTQSPSTAYSNSESLL 1066
<i>Homo sapiens</i>	QPMPEGRLRPSLPTQAHATTQPTPFKNFSNFKSNDGFTFSSPQVVTQPPPAAYSNSESLL 1067
<i>Bos taurus</i>	QPVPGEGMRPSLAAAPAHATTQPTPFKNFSNFKSNDGFTFSSPQVVAQPPATSYNNNESLL 1066
<i>Gallus gallus</i>	QPGTAEGSKP-----PQPTTFKFNTNFKNFKSNDGFTFSSPLAATQPANGAFNSSL 1069
<i>Mus musculus</i>	GLLTSDKPLQGDGYSGLKPIS-GQASGRNTFSFGSKNT----L TEN MGPNQQK N FGFHR 1121
<i>Rattus norvegicus</i>	GLLTSDKPLQGDGYSGLKPIS-AQTGGSRNTFSFGSKST----L TEN MGPNQQK N FGFRR 1121
<i>Homo sapiens</i>	GLLTSDKPLQGDGYSGAKPIPGGQTIGPRNTFNFGSKNVSGISFTENMGSSQQK N SGFRR 1127
<i>Bos taurus</i>	GLLTSDKPLQGDGYSGPKAAQ---NMGPRNTFNFGSKNVPGISFTENMGTNQPKNSG F RR 1123
<i>Gallus gallus</i>	KLLTSDKPLPDER C I C QKGSN-SHANGQRNVFS C UNKHSSGV C TESAGQNAHK N LA F E K 1128
<i>Mus musculus</i>	SDDMFAFHGP G PKSVFTAASELANKSHETDGGSAHG-DEEDDGPHFE P VPLPD K IEV K T 1180
<i>Rattus norvegicus</i>	SDDMFTFHGP G KSIFTPTSELANKSHETDGGSAHG-DEEDDGPHFE P VPLPD K IEV K T 1180

<i>Homo sapiens</i>	SDDMFTFHGPCKSVFGPTLETANKNHETDGGSAGH-DDDDDGPHFEPVPLPDKIEVKT	1186
<i>Bos taurus</i>	SDDMFTYSPGKSVFGVPATEPASKGHADGGSAQG-DEEDDGPHFEPVPLPDKIEVRT	1182
<i>Gallus gallus</i>	SD-MFNQEPSKQLFMPNDSLANSHETEGGSTHGGDEDDGPHFDPVPLPDKIEVKT	1187
<i>Mus musculus</i>	GEEDEEEFFCNRAKLFRFDGESKEWKERGIGNVKILRHKTSGKIRLLMRREQVLKICANH	1240
<i>Rattus norvegicus</i>	GEEDEEEFFCNRAKLFRFDGESKEWKERGIGNVKILRHKTSGKIRLLMRREQVLKICANH	1240
<i>Homo sapiens</i>	GEEDEEEFFCNRAKLFRFDVESKEWKERGIGNVKILRHKTSGKIRLLMRREQVLKICANH	1246
<i>Bos taurus</i>	GEEDEEEFFCNRAKLYRFDAAESREWKERGIGNVKILRHKTSGKIRLLMRREQVLKICANH	1242
<i>Gallus gallus</i>	GEEDEEEFFCNRAKLFRFDAESKEWKERGIGNVKILKHKGKFRLLMRDQVLKICANH	1247
<i>Mus musculus</i>	YISPDMKLTPNAGSDRSFVWHALDYADELPKPEQLAIRFKTPEEAALFKCKFEEAQNILK	1300
<i>Rattus norvegicus</i>	YISPDMKLTPNAGSDRSFVWHALDYADELPKPEQLAIRFKTPEEAALFKCKFEEAQNILK	1300
<i>Homo sapiens</i>	YISPDMKLTPNAGSDRSFVWHALDYADELPKPEQLAIRFKTPEEAALFKCKFEEAQSLIK	1306
<i>Bos taurus</i>	YISPDMALAPNAGSDRSFVWYALDYADESPKPEQLAIRFKTPEEAALFKCKFEEAQSLIK	1302
<i>Gallus gallus</i>	YINTDMKLTPNAGSDRSFVWHALDYADELPKPEQLAIRFKTPEEAILFKSKFEECQHTLK	1307
<i>Mus musculus</i>	ALGTNTSTAPNHTLRIVKESATQDNKDI CKADGGNLNFQIVKKEGPYWNCSFKNA	1360
<i>Rattus norvegicus</i>	ALGTNSTAAANTLRLIVKEPATQDNKDICKSDGGNLNFQIVKKEGPFWNCNSCSFKNA	1360
<i>Homo sapiens</i>	APGTNVAMASNQAVRIVKEPTSHDNKDICKSDAGNLNFQIVKKEGPFWNCNSCSFKNA	1366
<i>Bos taurus</i>	ASGANVATTTHQATKTVKEPTGHDSDKIDKSDGVTMFQVAKKEGSWWYCNSCSLKNM	1362
<i>Gallus gallus</i>	TLGSSADASMAQSTGTAKETTNQDVKESSGSTLGLNNSVQFSRDSVTSESDSKGSFTST	1367
<i>Mus musculus</i>	ATAKKCVSCQNTNPNTSNKELLGPPLVENGFAPKTGLENAQDRFATMTANKEGHWDCSVCL	1420
<i>Rattus norvegicus</i>	ATATKCVCQNTKPTNGKELLGSPLVENGFASKTGPNVQDRFALMTPNKEGHWDCSVCL	1420
<i>Homo sapiens</i>	STAKKCVSCQNLNPSN-KELVGPPPLAETVFTPPTSPEVNQDRFALVTPKKEGHWDCSVCL	1425
<i>Bos taurus</i>	ATAKKCVSCQNLNPGS-KELLGPPLVETISTPKPSSEHTPGRSALVTLKNEGHWNCGVCL	1421
<i>Gallus gallus</i>	STAPATFSFG-----KEA1QTYSSGGFGQSPLKKNQWECKVCL	1405
<i>Mus musculus</i>	VRNEPTVSRClACQNTKSAS---SFVQTS-FKFGQGDLPLKSVSDFRSVFSKKEGQWEC	1475
<i>Rattus norvegicus</i>	VRNEPTVSRClACQNTKSANKNGSSFAQTS-FKFGQGDLPLKSVSDFRSVFSKKEGQWDC	1479
<i>Homo sapiens</i>	VRNEPTVSRClACQNTKSANKSGSSVHQASFKFGQGDLPLKPINSDFRSVFSTKEGQWDC	1485
<i>Bos taurus</i>	VRNEPTVSRClACQNKPKASKSESPLIKQPSFKFGQGDLPLKAASSDFKSVFSVKEGQWDC	1481
<i>Gallus gallus</i>	VRNEATAKNCASCQSPNPDTWETRGIPTVTEASALKASG-SATQEKFGBFAKKEGQWDC	1464
<i>Mus musculus</i>	SVCLVRNERSAKKCVACENPGKQF-----K	1500
<i>Rattus norvegicus</i>	SICLVRNEASSTKCVACQNPQKQF----VSSPASFKAGTSVSKTSKSGFDDMFAKKEG	1535
<i>Homo sapiens</i>	SACLVQNEGSSSTKCAACQNPQKQSPATSIPTPASFKFGTSETSCTLKSGFEDMFAKKEG	1545
<i>Bos taurus</i>	SVCLIGNEGSSSVKCEACQTPRQKS-----	1505
<i>Gallus gallus</i>	NICSVRNEPTATKCIACQNPSTKN-----	1488
<i>Mus musculus</i>	EWHCSLCVNVNEAHAIKCVACNNPVPSLSTAP---PSFKFGTSEMSKPFTRIGFEGMFAK	1557
<i>Rattus norvegicus</i>	QWDCSLCSVRNEANAVKCVACQNPVKPSSSTTVLPSFKFGTSEMTKPPRSGFEGMFAK	1595
<i>Homo sapiens</i>	QWDCSSCLVRNEANATRCVACQNPDKPSPTSVPAPASFKFGTSETSCKPSKSGFEGMFTK	1605
<i>Bos taurus</i>	-----SPAFAAPASLKFGETSETSKTPKSGFEGVFTK	1538
<i>Gallus gallus</i>	-----SEVSPQOFSFKLEHVDAKPTTQSDLGTAFLS	1519
<i>Mus musculus</i>	KEGQWDCSLCFVRNEASATHClACQYPNQNPQPTS-----CVSAP---ASSETSRSRSPKS	1608
<i>Rattus norvegicus</i>	KEGQWDCSLCFVRNEASASQClACQNPQNPQPTS-----AVSAP---ASSETSKSPK	1646
<i>Homo sapiens</i>	KEGQWDCSCLVRNEASATKClACQNPQPGKQNQTT-----AVSTP---ASSETSKAPKS	1656
<i>Bos taurus</i>	KEGQWDCS---VQNEASMAEVACQNPQPG-QNPAS-----AAPAP---ASSETVKAPKS	1585
<i>Gallus gallus</i>	K-GQWNCSVCLVQNEANDENCHSOSPNQSQANPVPSAVQALPAPSFGSAADASKPQKN	1578
<i>Mus musculus</i>	GFEGLFPKKEG-----	1619
<i>Rattus norvegicus</i>	GFEGLFTRKEG-----	1657
<i>Homo sapiens</i>	GFEGMFTKKEGQWDCSVCLVRNEASATKClACQNPQPGKQNQTTSAVTPASSETSKAPKG	1716
<i>Bos taurus</i>	GLEGLFAKKEG-----	1596
<i>Gallus gallus</i>	AFAELFGKKEG-----	1589
<i>Mus musculus</i>	-----	

<i>Rattus norvegicus</i>	-----	
<i>Homo sapiens</i>	FEGMFTKKKGQWD C SV C LVRNEASATK C IA C Q C PSKQNQTTAISTPASSEISKAPKSGF	1776
<i>Bos taurus</i>	-----	
<i>Gallus gallus</i>	-----	
<i>Mus musculus</i>	-----EWECAVCSVQNESSSLK C VACEASKPTHKP-HEAPSAFTVGSKSQSNESAGSQ	1671
<i>Rattus norvegicus</i>	-----EWECTVCSVQNESSSLK C VSCDASKPTHKPIAEAPSAFTVGSKSQLNESAGSQ	1710
<i>Homo sapiens</i>	GMFIRKGQWDCSVCVQNESSSLK C VACDASKPTHKPIAEAPSAFTLGSEMLHDSSGSQ	1836
<i>Bos taurus</i>	-----QWDCDV C LIRNEGSSPK C VACGASNPTQNPAAEVPLSFPVGSTAEGNS C ASQ	1649
<i>Gallus gallus</i>	-----QWDCNT C LVRNESSSSPA C VACQTNPNPKP-TSNASLFTSDLKNSSEPVG C Q	1641
<i>Mus musculus</i>	VGTEFKSNFPEKKNFKVGISEQKF C FHVQDQEKT C TPSFQGGSNTEFKSIKDGF C IPVS	1731
<i>Rattus norvegicus</i>	VGTEFKSNFPEKKNFKVGISEQKF C FHVQDQEKT C TPSFQGGSNTEFKSIKDGF C IPVS	1770
<i>Homo sapiens</i>	VGTGFKSNFSEKASKFGNTEQGFK C FHVQDQEKT C PSFMFQGSSNTEFKSTKEGFS--IPVS	1894
<i>Bos taurus</i>	TGTGFKSNFSEKAFKFGNAEQGFK C FHVQDQEKT C PSFMFQGSSNTEFKSTKEGFSFSSPAS	1709
<i>Gallus gallus</i>	LGTGF C FLG-----KSFKFGHADQGKTPAFTFQNLADEAKPSKEGFNFMSMLMP	1692
<i>Mus musculus</i>	ADGFKFG C IQEKG-----NQEKKSEKHLENDFSFQAHDTS C GQKNGS	1771
<i>Rattus norvegicus</i>	ADGFKFG C IQEKG-----NQEKKSEKHLENDFPGFQAHDTS C GQKNGS	1810
<i>Homo sapiens</i>	ADGFKFG C ISEPG-----NQEKKSEKPLLENGTGFQAQDISGQKNGR	1934
<i>Bos taurus</i>	AGGF C KFG C IQETE-----NQEKT C EKSFGEDTGGQAQDTGGQKDG C S	1749
<i>Gallus gallus</i>	PGGF C KFG C IQESSK C TAKKDDPP C E C TTLK C SIDE C DKN C ELPSSGVRLQS C ETAD-KDKD	1751
<i>Mus musculus</i>	GVVFGQTS-STFTFADLAKSTSREGFQFGKKDPNF C KFG C SGAGE C EKF C L C FSSQ C GKVAEKANTS	1830
<i>Rattus norvegicus</i>	GVVFGQTS-STFTFADLAKSTSREGFQFGKKDPNF C KFG C SGAGE C EKF C L C FSSQ C GKVAEKANTS	1869
<i>Homo sapiens</i>	GVVFGQTS-STFTFADLAKSTSREGFQFGKKDPNF C KFG C SGAGE C EKF C L C FSSQ C Y C GKMAN C ANTS	1993
<i>Bos taurus</i>	TVVFGQ C TG-STFTFADLAKSN C SEG C QFG C KKDPNF C KFG C SGAGE C EKF C L C FSSQ C SKLV C D C A C 1808	
<i>Gallus gallus</i>	EFTFGQ C NSSTFTFADLAK C STP C SEGFQFG C KKDPNF C EG C FG C SGAGE C QL C FSS C KASKTGH C ASTS	1811
<i>Mus musculus</i>	SDLEKDDD-AYKTEDSDDIHFEPVVQ C MPEKVELTGEDE C EV C KVL C YS C RV C KL C FR C DAE C ISQ C W	1889
<i>Rattus norvegicus</i>	-DLEKDDD-AYKTEDSDDIHFEPVVQ C MPEKVELTGEDE C EV C KVL C YS C RV C KL C FR C DAE C ISQ C W	1927
<i>Homo sapiens</i>	GDFEKDDD-AYKTEDSDDIHFEPVVQ C MPEKVELTGEDE C EV C KVL C YS C RV C KL C FR C DAE C VSQ C W	2052
<i>Bos taurus</i>	ADLEKDDD-AYKTEDSDDIHFEPVVQ C MPEKVELTGEDE C EV C KVL C YS C RV C KL C FR C DAE C ISQ C W	1867
<i>Gallus gallus</i>	ADL C EKDDD C VY C KTEDSDDIHFEP C IV C QM C PEK C VE C PFT C GEDE C EV C KVL C YS C RV C KL C FR C DP C ETSQ C W	1871
<i>Mus musculus</i>	KERGLGNL C KIL C NEVNG C KLR C ML C MR C RE C QVL C K C ANH C W C IT C TM C N C L C P C LS C GS C D C RAW C M C WL C AS C DF	1949
<i>Rattus norvegicus</i>	KERGLGNL C KIL C NEVNG C KLR C ML C MR C RE C QVL C K C ANH C W C IT C TM C N C L C P C LS C GS C D C RAW C M C WL C AS C DF	1987
<i>Homo sapiens</i>	KERGLGNL C KIL C NEVNG C KLR C ML C MR C RE C QVL C K C ANH C W C IT C TM C N C L C P C LS C GS C D C RAW C M C WL C AS C DF	2112
<i>Bos taurus</i>	KERGLGNL C KIL C NEVNG C KLR C ML C MR C RE C QVL C K C ANH C W C IT C TM C N C L C P C LS C GS C D C RAW C M C WL C AS C DF	1927
<i>Gallus gallus</i>	KERGVGNL C KIL C NEVNG C KVR C IL C MR C RE C QVL C K C ANH C W C IT C TM C N C L C P C LS C GS C D C KA C WM C W C AS C DF	1931
<i>Mus musculus</i>	SDGDAK C LEQ C LA C AK C F C KTP C EL C A C E C EF C Q C K C FE C C C Q C R C L C LL C DI C PL C Q C T C PH C K C L C VD C T C GRA C AK C LI C Q C RA C E C E C 2009	
<i>Rattus norvegicus</i>	SDGDAK C LEQ C LA C AK C F C KTP C EL C A C E C EF C Q C K C FE C C C Q C R C L C LL C DI C PL C Q C T C PH C K C L C VD C T C GRA C AK C LI C Q C RA C E C E C 2047	
<i>Homo sapiens</i>	SDGDAK C LEQ C LA C AK C F C KTP C EL C A C E C EF C Q C K C FE C C C Q C R C L C LL C DI C PL C Q C T C PH C K C L C VD C T C GRA C AK C LI C Q C RA C E C E C 2172	
<i>Bos taurus</i>	SDGDAK C LEQ C LA C AK C F C KTP C EL C A C E C EF C Q C K C FE C C C Q C R C L C LL C DI C PL C Q C T C PH C K C L C VD C T C GRA C AK C LI C Q C RA C E C E C 1987	
<i>Gallus gallus</i>	SDGDAK C LEQ C LA C AK C F C KTP C EL C A C E C EF C Q C K C FE C C C Q C K C LL C DI C PL C Q C T C PH C K C L C VD C T C GRA C AK C LI C Q C RA C E C E C 1991	
<i>Mus musculus</i>	MKSGLKDF C KTFL C TND C QVK C VT C DE C EN C ASS C GAD C APS C DT C TA C Q C N C P C D C NT C G C PA C LE C WD C NY C DL C RED	2069
<i>Rattus norvegicus</i>	MKSGLKDF C KTFL C TND C QAK C V C TE C EN C ASS C GAD C ASS C DT C TV C Q C N C P C D C NT C G C PA C LE C WD C NY C DL C RED	2107
<i>Homo sapiens</i>	MKSGLKDF C KTFL C TND C QTK C V C TE C EN C NG C SG C GT C AA C GA C SD C TT C I C K C P C N C P C ENT C G C T C LE C WD C NY C DL C RED	2232
<i>Bos taurus</i>	MKSGLKDF C KTFL C TND C QTK C V C DE C ES C K C D C R C AG C AT C TA C ADV C G C AP C NT C T C ET C G C T C LE C WD C NY C DL C RED	2047
<i>Gallus gallus</i>	MKSGLKDL C KTFL C TDD C KT C IA C EE C NV C NS- C AG C ST C SD C CV C AK C PH C AE C GT C GP C AV C EW C NS C EL C REE	2050
<i>Mus musculus</i>	ALDDSVSSSSV C HAS C PL C ASS C PVR C KNL C RF C G C EST C T C GF C N C FS C KS C AL C SP C SK C PA C KL C N C Q C SG C AS C VG	2129
<i>Rattus norvegicus</i>	ALDDSVSSSSV C HAS C PL C ASS C PVR C KNL C RF C G C EST C T C GF C N C FS C KS C AL C SP C SK C PA C KL C N C Q C SG C TS C VG	2167
<i>Homo sapiens</i>	ALDDSVSSSSV C HAS C PL C ASS C PVR C KNL C RF C G C EST C T C GF C N C FS C KS C AL C SP C SK C PA C KL C N C Q C SG C TS C VG	2292
<i>Bos taurus</i>	ALDDSVSSSSV C HAS C PL C ASS C PVR C KNL C RF C G C EST C T C GF C N C FS C KS C AL C SP C SK C PG C KL C N C Q C SG C AS C VG	2107
<i>Gallus gallus</i>	VLD C DS C LS C SSS-VY C AS C PL C ASS C PVR C KNL C RF C G C EST C T C GF C N C FS C KS C AL C SP C SK C PA C Q C N C Q C SG C TS C VG	2109

<i>Mus musculus</i>	TDEESDVTQEEERDGQYFEPVVPLPDLVEVSSGEENEQVVFSHRAKLYRYDKDVGQWKER	2189	
<i>Rattus norvegicus</i>	TDEESDVTQEEERDGQYFEPVVPLPDLIEVSSGEENEQVVFSHRAKLYRYDKDVGQWKER	2227	
<i>Homo sapiens</i>	TDEESDVTQEEERDGQYFEPVVPLPDLVEVSSGEENEQVVFSHRAKLYRYDKDVGQWKER	2352	
<i>Bos taurus</i>	TDEDSDVTQEEERDGQHFEPPVPLPDLVEVSSGEENEQVVFSHRAKLYRYDKDAGQWKER	2167	
<i>Gallus gallus</i>	TDEDSDLTQEEERDGQYFEPVVPLPDLVEVTSGEENEQVVFSHRAKLYRYDKDTNQWKER	2169	
<i>Mus musculus</i>	GIGDIKILQNYDNKQVRIVMRRDQLVKLCANHRITPDMLTQTMKGTERVWWTA	CDFADG 2249	
<i>Rattus norvegicus</i>	GIGDIKILQNYDNKQVRIVMRRDQLVKLCANHRITPDMLTQTMKGTERVWWTA	CDFADG 2287	
<i>Homo sapiens</i>	GIGDIKILQNYDNKQVRIVMRRDQLVKLCANHRITPDMLTQNMKGTERVWLWTAC	CDFADG 2412	
<i>Bos taurus</i>	GIGDIKILQNYENKQVRIVMRRDQLVKLCANHRITPDMLTQNMKGTERVWWTA	CDFADG 2227	
<i>Gallus gallus</i>	GIGDIKILQNYDSKQARIVMRRDQLVKLCANHRITPDMMNMQMKGSRAWVWTAC	CDFADG 2229	
<i>Mus musculus</i>	ERKIEHLAVRFKLQDVADSFKKIFDEAKTAQEKDLSITPHVSHLSTPRESPC	CGKIAIAVL 2309	
<i>Rattus norvegicus</i>	ERKIEHLAVRFKLQDVADSFKKIFDEAKTAQEKDLSITPHVSHLSTPRESPC	CGKIAIAVL 2347	
<i>Homo sapiens</i>	ERKVEHLAVRFKLQDVADSFKKIFDEAKTAQEKDLSITPHVSRSSTPRESPC	CGKIAAVVL 2472	
<i>Bos taurus</i>	ERKIEHLAVRFKLQDVADSFKKIFDEAKVAQETDFLITPHVARSATPRESPC	CGKMAAVVL 2287	
<i>Gallus gallus</i>	ERKVELLAVRFKLQDVADSFQKTFDEAKQAQEKGTLITPHVSRTNTANTSP	CGKNAAVVL 2289	
<i>Mus musculus</i>	EETTRERTDLTQGDEVIDTTSEAGETSSTSETTPKAVVSPPKFVFGSESVKSIFSSEKSK	2369	
<i>Rattus norvegicus</i>	EETTRERTDLTQGDEVVDTTSEAGETSSTSETTPKAVVSPPKFVFGSESVKSIFSSEKSK	2407	
<i>Homo sapiens</i>	EETTRERTDVIQGDDVADATSEV-EVSSSTSETTPKAVVSPPKFVFGSESVKSIFSSEKSK	2531	
<i>Bos taurus</i>	EETTRERTDLSQGDDAADTTSEVGVSGTPEPTTKAVVSPPKFVFGSESVKSIFSSEKSK	2347	
<i>Gallus gallus</i>	EETTRERTDLSHGNDASDATVEALEVSSTSETPTKTVVSPPKFVFGSESVKSIFSNEKSK	2349	
<i>Mus musculus</i>	PFAFGNSSATGSLFGFSFNAPLNNSNSEMTSRVQSGSEGKVKPDKC	ELPQNNSDIKQSSDG 2429	
<i>Rattus norvegicus</i>	PFAFGNSSATGSLFGFSFNAPLNNSNSEISSIVQSGSEGKVDPDKGELPPNSDIKQSSDG	2467	
<i>Homo sapiens</i>	PFAFGNSSATGSLFGFSFNAPLNNSNSESSVVAQSGSEGKVEPKK	CQELSKNNSDIEQSSDS 2591	
<i>Bos taurus</i>	PFAFGNSSTTGSLFGFSNTPLKNNNSSEASSAAQSGSERKVEPGGRQESQNSDLKSASDG	2407	
<i>Gallus gallus</i>	TFTFGNTSATGSLFGFSNPPRKSADSISSSQKAEQKKTGVTE-----PPKSC	SAPQDS 2403	
<i>Mus musculus</i>	KVKNLSA-FSKENSSTSYTFKTPEKAQEKSXPEDLPSDNDILIVELYELTPTEPEQKALAEL	2488	
<i>Rattus norvegicus</i>	KVKNLIA-FSKETSST---FKTPEKAREKNKPEDPPSDTDILIVELYELTPTEPEQKALAEL	2523	
<i>Homo sapiens</i>	KVKNLFASFPTEESSINYTFKTPPEAKEKEKKPEDPSDDDVLIVELYELTPTAEQKALATKL	2651	
<i>Bos taurus</i>	KVKNTSPAFLKEQFSTSHTFKTPEKVEERKKPEDLPSDDDVLIVELYELTPTEPEQRALASRL	2467	
<i>Gallus gallus</i>	KASSLAP--AAQDGPSNFSFKILEQAEKTAEPSENPPSDDVMIVELYELTPTEPEQRALAGFL	2461	
<i>Mus musculus</i>	LLPSTTFCYKNRPGYVSEEEDDEDYEMAVKKLNGKLYLDDSE--KPLEEN--LADNDK	2543	
<i>Rattus norvegicus</i>	LLPSTTFCYKNRPGYVSEEEDDEDDEFEMAVKKLNGKLYVDDSE--KPLEEN--LADNDK	2578	
<i>Homo sapiens</i>	KLPPTFCYKNRPGDYVSEEEDDEDFTAVKKLNGKLYLDGSEKCRPLEEN--TADNEK	2708	
<i>Bos taurus</i>	QLPPTFCYKNRPGDYVSEEEDDEDFTAVKKLNGKLYLDDSETCRLEEN--VTDNEK	2524	
<i>Gallus gallus</i>	KLPSTFCYKNRPGYVSEED-DDEDYETAVKKLNGRLYPNEKERRKWQVGSPVKQELER	2520	
<i>Mus musculus</i>	ECVIVWEKKPTVEERAKADTLKLPPTFFCGVCSDTD--NGNGEDFQSELRKV	CEAQKS 2601	
<i>Rattus norvegicus</i>	ECVIVWEKKPTVEERAKADTLKLPPTFFCGVCSDTD--NGNGEDFQSELRKV	QEAQKS 2636	
<i>Homo sapiens</i>	ECVIVWEKKPTVEEKAKADTLKLPPTFFCGVCSDTD--NGNGEDFQSELQKV	QEAQKS 2766	
<i>Bos taurus</i>	ECVIVWEKKPTVEEKAKADTLKLPPTFFCGI	CSDTD--NGNAEDFQSELQKV	QEAQKS 2582
<i>Gallus gallus</i>	ECVTASETPK-SEEKAEGETPQLSTSAC	CGVSSNAEDAGPEGSQK	EVKSERKKESEVTSS 2579
<i>Mus musculus</i>	QNEKVTDRVGIEHIG--ETEVTPNPVGCKSEEPDSDTKHSSSPVS-GTMDKPVDLSTRK	2657	
<i>Rattus norvegicus</i>	QSEKVTNTVGIEQTG--ETEATNPDGSKSEEPDSDTKHSSSPVP-GTMDKPVDLSTRK	2692	
<i>Homo sapiens</i>	QTEEITSTTDHSVYTG--GTEVMVPSFK	CKSEEPDSITKSISSPVSSETMDKPVDLSTRK 2823	
<i>Bos taurus</i>	QDENIASSADGM	CTD--DTKVTVFPLCKSEEFTTKVSSPSVSSGTVDKPVDLSTRK 2639	
<i>Gallus gallus</i>	TDLVSTSKEDLHASSEESTAVFVQSAASSEEADSTETAHVSQNL	F-GGDDKPVDLSTRK 2638	
<i>Mus musculus</i>	ETDMEFPS-KGENKPVLFGFGSGTGLSFADLASSNSGDFAFGS	KDKNFQWANTGAAVFG- 2715	
<i>Rattus norvegicus</i>	ETDMEFPS-QGESKTVLFGFGSGTGLSFADLASSNSGDFAFGP	KDKNFQWANTGAAVFG- 2750	
<i>Homo sapiens</i>	EIDTDSTS-QGESKIVSFGFGSSTGLSFADLASSNSGDFAFGS	KDKNFQWANTGAAVFGT 2882	
<i>Bos taurus</i>	ENDADSTS-QVESKTVFGFGSGPGLS	FADLASSNSGDFAFGS	KDKNFQWANTGAAVFG- 2697
<i>Gallus gallus</i>	ESDLE	CSESTQEHKPISFGFGNASGLSFADLASKNSGDFAFGS	KDKNFQWANTGAAVFG- 2697

<i>Mus musculus</i>	----TQTTSKGGEDEDGSDEDVHHNEDIHFEPIVSLPEVEVKSGEDEEVLFKERAKLYR	2771
<i>Rattus norvegicus</i>	----TQSTS KDGDEDGSDEDVHHNEDIHFEPIVSLPEVEVKSGEDEEVLFKERAKLYR	2806
<i>Homo sapiens</i>	QSVGTQSAGKVGEDEDGSDEEVHHNEDIHFEPIVSLPEVEVKSGEDEEILFKERAKLYR	2942
<i>Bos taurus</i>	----AQSTS KVGDEDGSDEEVHHNEDIHFEPIVSLPEVEVKSGEDEEILFKERAKLYR	2753
<i>Gallus gallus</i>	----VQTASKADEDEGGSDDEVHSDDIHFEPIVSLPEVEVKSGEDEEILFKERAKLYR	2753
<i>Mus musculus</i>	WDRDVSQWKERGIGDIKILWHTMKYYRILMRRDQVFVCANHVITKAMELKPLNVSNNA	2831
<i>Rattus norvegicus</i>	WDRDVSQWKERGIGDIKILWHSVKNYRILMRRDQVFVCANHVITKAMELKPLNFSNNA	2866
<i>Homo sapiens</i>	WDRDVSQWKERGVGDIKILWHTMKNYRILMRRDQVFVCANHVITKTMELKPLNVSNNA	3002
<i>Bos taurus</i>	WDREASQWKERGVGDIKILWHTVKNYFRILMRRDQVFVCANHVITKTMELKPLNVSNNA	2813
<i>Gallus gallus</i>	WDRDATQWKERGVGELKILFHTQKKYYRILMRRDQVLVCANHVITKEMNLVPSDTSNNV	2813
<i>Mus musculus</i>	LVWTASDYADGEAKVEQLAVRFKTKEMTESFKKKFEECQQNI I KLNQNGHTSLAAELSKDT	2891
<i>Rattus norvegicus</i>	LVWTASDYADGEAKIEQLAVRFKTKITECFKKKIEECQQNIMKLQNQVSLAAELSKET	2926
<i>Homo sapiens</i>	LVWTASDYADGEAKVEQLAVRFKTKEVADCFFKTFEECQQNLMKLIQKGHVS LAAELSKET	3062
<i>Bos taurus</i>	LVWTASDYADGEAKVEQLAVRFKTKEMADCFFKKFEECQQNLLKPQKGQDSLTAEFSKET	2873
<i>Gallus gallus</i>	LIWTATDYADGEVKEQFAVRFKVQELANSFKRRFEECQQSLSLEQKGHL SLAAVLSKDT	2873
<i>Mus musculus</i>	NPVVFFDV CADGEPLGRIIMELFSNIVPQTAENFRALCTGEKGFGFKNSIFHRVVPDFIC	2951
<i>Rattus norvegicus</i>	NPVVFFDV CVDGEPLGRIIMELFSNIVPQTAENFRALCTGEKGFGFKNSIFHRVVPDFIC	2986
<i>Homo sapiens</i>	NPVVFFDV CADGEPLGRITMELFSNIVPRTAENFRALCTGEKGFGFKNSIFHRVIPDFVC	3122
<i>Bos taurus</i>	NPVVFFDICADDEPLGRITMELFSNIVPKTAENFRALCTGEKGFGFKSSI FHRVIPDFVC	2933
<i>Gallus gallus</i>	NPVVYFNVSANDEPLGRITMELFANIVPRTAENFRALCTGEKGFGFKNTTFHRIVSDFIC	2933
<i>Mus musculus</i>	QGGDITKYNGTGGQSIYGDKFDDENFDLKHTGPGLLSMANYGQNTNSSQFFITLKAELH	3011
<i>Rattus norvegicus</i>	QGGDITKYNGTGGQSIYGDKFDDENFDLKHTGPGLLSMANCQNTNSSQFFITLKAELH	3046
<i>Homo sapiens</i>	QGGDITKHDTGGQSIYGDKFEDENFDVKHTGPGLLSMANQGQNTNNSSQFVITLKAELH	3182
<i>Bos taurus</i>	QGGDITKHDTGGRSIYGDKFEDENFDVKHTGPGLLSMANRGQDTNNSSQFITLKAERL	2993
<i>Gallus gallus</i>	QGGDITNHDTGGRSIYGEAFEDENFEVKHTGPGLLSMANRGRTDNNSQFITLKAELH	2993
<i>Mus musculus</i>	DFKHVVFGFVKDGMDTWRKIESFGSPKGSVSRICITECGQL	3053
<i>Rattus norvegicus</i>	DFKHVVFGFVKDGMDTWRKIESFGSPKGSVSRICITECGQL	3088
<i>Homo sapiens</i>	DFKHVVFGFVKDGMDTWRKIESFGSPKGSVCRITITECGQI	3224
<i>Bos taurus</i>	DFKHVVFGFVKDGMDTWRKIESFGSPKGSVSRIIITECGQI	3035
<i>Gallus gallus</i>	DFKHVVFGFVKDGMDVVKKIESFGSPKGVLNVGRVVITDCGQI	3035

Nup153

<i>Mus musculus</i>	MASEAGGIGGGGGGGKIRTRRCHQGPVKPYQQGRPQHQGILSRVTEVKNIVPGWLQRYF	60
<i>Rattus norvegicus</i>	MASGAGGIGGGGGGGKIRTRRCHQGPVKPYQQGRPQHQGILSRVTEVKNIVPGWLQRYF	60
<i>Homo sapiens</i>	MASGAGGVGGGGGG-KIRTRRCHQGPVKPYQQGRPQHQGILSRVTEVKNIVPGWLQRYF	59
<i>Bos taurus</i>	MASGAGGRGGGGGGKIRTRRCHQGPMPKPYQQGRPQHQGILSRVTEVKNIVPGWLQRYF	60
<i>Gallus gallus</i>	-----MREG----LGIISRMTEVKNIVPGWLQKYF	27
<i>Mus musculus</i>	NKSENACSCSPDADEVPPWPENREDEHAIYADENTNTDDGRITPDPAGSNTEEPSTTSTA	120
<i>Rattus norvegicus</i>	NKSENACSCSVNADEVPRWPENREDEREIYVDENTNTDDGRITPPEAVSNTEEPSTTSTA	120
<i>Homo sapiens</i>	NKNEDVCSCSTDTESEVPRWPENKEDHLVYADEESSNITDGRITPPEAVSNTEEPSTTSTA	119
<i>Bos taurus</i>	SKNEDVCSCSTDTRVPQWPENREDDHIYSDE-SANIHDGRITPPEFTGSNTEEPSTTSTA	119
<i>Gallus gallus</i>	NKSEDEC---VDTNESTNQEENPVNYHDYGEDDTIMTDGRVTPEPAGINLEEPSTSRS	84
<i>Mus musculus</i>	SNYPDVLTRPSLHRSHLNFSVLES PALHCQPSTSSAFPIGSSGFLVKEIKDSTFQHDD	180
<i>Rattus norvegicus</i>	SNYPDVLTRPSLHRSHLNFSVLES PALHCQPSTSSAFPIGSSGFLVKEIKDSTS QHDD	180
<i>Homo sapiens</i>	SNYPDVLTRPSLHRSHLNFSMLES PALHCQPSTSSAFPIGSSGFLVKEIKDSTS QHDD	179
<i>Bos taurus</i>	SNYPDVLTRPSLHRSHLNFSMLD PALHCQPSTSSAFPIGSSGFLVKEIKDSTS QHDD	179
<i>Gallus gallus</i>	LNFSVVLTRPSLHRSHLNCTVLDSTVPPCQPSSTSSTL GIGNPGLSLVKEIKDSTS QHDD	144

<i>Mus musculus</i>	NISTTSGFSSRASEKDIAVSKNTSLPPLWSPEAERSHLSQHTAISSKKPAFNLSAFGTL	240
<i>Rattus norvegicus</i>	NISTTSGFSSRASEKDIAVSKNTSLPPLWSPEAERSHLSQHTAISSKKPAFNLSAFGTL	240
<i>Homo sapiens</i>	NISTTSGFSSRASDKITVSKNTSLPPLWSPEAERSHLSQHTATSSKKPAFNLSAFGTL	239
<i>Bos taurus</i>	NISTTSGFSSRASDKDIAVSKNTSVPLWSPEAERSHSFSQHTATSSKKPAFNLSAFGAL	239
<i>Gallus gallus</i>	NISTTSGFSSRASDKDIAVSKNNSAPLITWSTEERSHSLSQHSASSSKKPAFNLSAFGAL	204
<i>Mus musculus</i>	STSLGNSSILKTSQLDSPFYPGKTTYGAAAAVRQNKRSTPYQAPVRRQMAKQQLNAQ	300
<i>Rattus norvegicus</i>	STSLGNSSILKTSQLDSPFYPGKTTYGAAAAVRQNKRSTPYQAPVRRQMAKQQLNAQ	300
<i>Homo sapiens</i>	SPSLGNSSILKTSQLDSPFYPGKTTYGAAAAVRQSCLRNPYQAPVRRQMAKQQLSAQ	299
<i>Bos taurus</i>	SPSLGNSSIFKTSQLDSPFYPGKTTYGAAAAVRQSCLRNPYQAPVRRQMAKQPSAQ	299
<i>Gallus gallus</i>	SPSLGNNTSVFKTSQLDSPFYPGKTTYGAAAAARQTKVRIAPYQTPTVRRQMAKQANVQ	264
<i>Mus musculus</i>	SYGVTSSTARRILQSLEKMSSPLADAKRIPSAVSSPLNSPLDRSGIDNT-VFQAKKEKVD	359
<i>Rattus norvegicus</i>	SYGVTSSTARRILQSLEKMSSPLADAKRIPSAVSSPLNSPLDRSGIDST-VFQAKKEKVD	359
<i>Homo sapiens</i>	SYGVTSSTARRILQSLEKMSSPLADAKRIPSIIVSPLNSPLDRSGIDIT-DFQAKREKVD	358
<i>Bos taurus</i>	AYGVTSSTARRILQSLEKMSSPLADAKRIPSVFSSPLNSPLDRSGMDTTDFQAKREKVD	359
<i>Gallus gallus</i>	SYGVTSSTARRILQSLEKMSSPLADAKRIPSSVTSPLSSPVDRSVLGIT-GFHSTRKQME	323
<i>Mus musculus</i>	SQYPPVQRLMTPKPVSIATNRVTYFKPSLTPSGDLRKTNQRIDKKNSTVDEKSIS-RQNR	418
<i>Rattus norvegicus</i>	SQYPPVQRLMTPKPVSIATNRVTYFKPSLTPSGDLRKTNQRIDKKNSTVDEKNIS-RQNR	418
<i>Homo sapiens</i>	SQYPPVQRLMTPKPVSIATNRSVYFKPSLTPSGEFRKTNQRIDNK <color>STGYEKNMTPGQNR</color>	418
<i>Bos taurus</i>	SQYPPVQRLMPIPKV рSIAANRTVYFKPSLTPSGELRKTNQRIDKKYSTDYEKNTTPGQNR	419
<i>Gallus gallus</i>	SQHPPVQKLVTPKAISLSGSRTQYFKPSLTPSADSSKIHQRVDTKHKEKSLPEEQRV	383
<i>Mus musculus</i>	EQ-ESGFSPNFSIPAANGLSSGVGGGGKMRER-THFVAPKPPENEVEAPLLPQISL	476
<i>Rattus norvegicus</i>	EQ-ESGFSPNFSIPAANGLSSGVGGGGKMRERTHFVASKPSEEEEVEVPPLLPOISL	477
<i>Homo sapiens</i>	EQRESGFSPNFSLPAANGLSSGVGGGGKMRER-TRFVASKPLEEEEMEVPVLPKISL	477
<i>Bos taurus</i>	EQQESGFSPNFSMSAANGLSPGVGGGGKMRER-TRVASKPQEKEEVEVPVLPKISL	478
<i>Gallus gallus</i>	EPSESNLTYPKFSTPASNGLSSGVGGG-KMRRERGVHYVS-KSGQEQEVEEPVLPKISL	441
<i>Mus musculus</i>	PISSSSLPTFSFSSP-VTSASPSPVSSQPLPNKVQMTSLGSTGSPVFTFSSPIVKSTQA	535
<i>Rattus norvegicus</i>	PISSSSLPTFNFSSPAISAASSSSVSPSQPLSNKVQMTSLGSTGNPVTFFSSPIVKSTQA	537
<i>Homo sapiens</i>	PITSSSLPTFNFSSEPIITSSSPSPINSSQALTNKVQMTSPSTSГPMFKFSSPIVKSTEA	537
<i>Bos taurus</i>	PITSSSLPTFNFSSSVITTSSSPSPISPSQSLTNKVQVTSPNSTGSPLFRFSSPIVKSTES	538
<i>Gallus gallus</i>	PISTASLAPFNFSFLTSSTVSSPSTVSTSVMNKVQPTS--NVGSPVFRFSSPIVKSTEA	499
<i>Mus musculus</i>	AVLPPASIGFTFSVPLAKT-EFGSGNSSSETVLSS--SAQDITAVNSSSYKKR-SAP <color>CED</color>	591
<i>Rattus norvegicus</i>	DVLPPASIGFTFSVPLAKT-ELSGPNSSSETVLSSSVTAQDNTVVNSSSSKKR-SAP <color>CED</color>	595
<i>Homo sapiens</i>	NVLPPSSIGFTFSVPAKTAELSGSSSTLEPISS--SAHHVTTVNSTN <color>CKTPPEDCEG</color>	595
<i>Bos taurus</i>	DVLPPSSIGFTFSVPAKTAELSGPSSVSEPISS--SAQDTTAVNSTS <color>CKKQDEDCE</color>	596
<i>Gallus gallus</i>	EVLPLSIGFTFSVPPVKAERSGSSDTPVTSLLT---RDTTTVNSISNKKEEKEYDG	555
<i>Mus musculus</i>	PFTPAAKILREGSVDILKTPGFASPKVDSPALQPTTSSIVYTRPAISTFSSSGIEYGES	651
<i>Rattus norvegicus</i>	PFTPAAKILREGSVDILKTPGFMSPKVDSPALQPTTSSIVYTRPAISTFSSSGVEFGES	655
<i>Homo sapiens</i>	PFRPAEILKEGSVLDILKSPGFASSKADSLAAQPGTTSPVHTRPAISSFSSSGIGFGES	655
<i>Bos taurus</i>	PFRVAKTLKEGSVLDILKSPGFASSKADSLAAQPGTTSPVHTRPAISSFSSSGTGFGE	656
<i>Gallus gallus</i>	PFKPAKVLKEGSVLDILRSPGFTSVKTHSSASAQPITSTAVYTRPAISSFSAG---KETP	612
<i>Mus musculus</i>	LKAGSSWQ <color>CDTC</color> --LLQNKVTDNK <color>CIACQAAKPLKETAKQTGTGTPSKSDKP-ASTSGT</color>	708
<i>Rattus norvegicus</i>	LKAGSSWQ <color>CDTC</color> --LLQNKVTDNK <color>CIACQAAKPLKETAKQTGTGIGTPSKSDKP-ASTSGT</color>	712
<i>Homo sapiens</i>	LKAGSSWQ <color>CDTC</color> --LLQNKVTDNK <color>CIACQAAKLSPRDTAKQTGIEPTNKGKTTLSASGT</color>	713
<i>Bos taurus</i>	LKAGSSWQ <color>CDTC</color> --LLQNKVTDNK <color>CIACQAAKLSPRDTAKQTGIEPTNKGKTTLSASGT</color>	714
<i>Gallus gallus</i>	KQASSYWQSDPC <color>CDPC</color> QSNKAADSKQVT <color>CIACQAAKVSTAESTKQTTSSPSGSTKAAAPPVGM</color>	672
<i>Mus musculus</i>	G-FGDKFKPAIGTWD <color>CDTC</color> CLVQNKPEAVKCVACETPKPGTGVKRALT <color>LT</color> VASESPVT---	764
<i>Rattus norvegicus</i>	G-FGDKFKPAIGTWD <color>CDTC</color> CLVQNKPEAVKCVACETPKPGTGVKRALT <color>LT</color> VASESPVT---	768
<i>Homo sapiens</i>	G-FGDKFKPAIGTWD <color>CDTC</color> CLVQNKPEAVKCVACETPKPGTGVKRALT <color>LT</color> VASESPVT-	772
<i>Bos taurus</i>	AGFGDKFKPAIGTWD <color>CDTC</color> CLVQNKPEAVKCVACETPKPGTGVKRALT <color>LT</color> VASESPVT-	774
<i>Gallus gallus</i>	LGFGDKFKPAIGTWD <color>CDTC</color> CLVQNKPEAVKCVACETPKPGTGVKRALT <color>LT</color> VASESPVT-	731

<i>Mus musculus</i>	ASSSTTVTTGTLGFDKFKRPVGSWECPVCCVNKAEDNRCVSCTSEKPG-LVSASSSP	823
<i>Rattus norvegicus</i>	ASSSTTVTTGTLGFDKFKRPVGSWECPVCCVSNAEDSRCSCTSEKPG-LVSASSNP	827
<i>Homo sapiens</i>	SSSSCTVTTGTLGFDKFKRPVGSWECSVCCVSNNAEDENKCVSCMSEKPGSSVPASSST	832
<i>Bos taurus</i>	SSSSCTVTTGALGFADKFKRPVGSWECPVCCVSNNAEDENKCVSCMSEKPGSSVPSSSM	834
<i>Gallus gallus</i>	SSSSSTDVTVTLGFDKFKKPKGSWDCATCFVSNKAEDSKCVAQSEKPGSSVPVTSSA	791
<i>Mus musculus</i>	AP-VSLSSGGCLGLDKFKKPEGSWDCEVCLVQNKAEDSKCIACESAKPGTKSEFKGFGTS	882
<i>Rattus norvegicus</i>	VP-VSLPSGGCLGLDKFKKPEGSWDCEVCLVQNKAEDSKCIACESAKPGTKSEFKGFGTS	886
<i>Homo sapiens</i>	VP-VSLPSGGSGLLEKFKKPEGSWDCELCVCLVQNKAEDSKCLACESAKPGTKSGFKGFDTS	891
<i>Bos taurus</i>	APSISSGGCLGLDKFKKPEGSWNCEVCLVQNKAEDSKCIACETVKSHTKPEFTGFGTS	894
<i>Gallus gallus</i>	SA-FAAPSGDLDLDFKPKGSWDCEVCLVQNKAEDSKCVAQSEKPGSSVPVTSSA	850
<i>Mus musculus</i>	SSLNP--APSAFKFGIPSSSSGLSQTLTSTGNFKFDQGGFKLGTSSDSGSTNTMNTNFK	940
<i>Rattus norvegicus</i>	SSLNP--APSAFKFGIPSSSSGLSQTFTSTGNFKFDQGGFKLGTSSDSGSTNTMNTNFK	944
<i>Homo sapiens</i>	SSSSNSAASSSFKFGVSSSSSGPSQTLTSTGNFKFDQGGFKIGVSSDGSINPMSEGFK	951
<i>Bos taurus</i>	SSSSN-TATSSFKFGIPSPSSGPSPQLANTGNFKFDQGGFKIGVSSDLGSANPLSEGFK	953
<i>Gallus gallus</i>	AVSTN-AALPSFTFGVQSSSD-SQTSSVTGSFKGEQGGFKFGIASESASSNTAPGGFK	908
<i>Mus musculus</i>	FSKPTGDFKFGVLS-DSKPVEVKNDKNK-NFQFGSSGLTNPASSAPFQFGVSTLGQQE	998
<i>Rattus norvegicus</i>	FPKPTGDFKFGVLP-DSKPVEIKNDSKN-NFQFGPSSGLSNPASSAPFQFGVSTLGQQE	1002
<i>Homo sapiens</i>	FSKPIGDFKFGVSS-ESKPVEVKDKSKN-NFKFGLSSGLSNPVLTFQFGVSNLQOE	1009
<i>Bos taurus</i>	FSKPIGDFKFGVSS-DSKPVEVKDKSKNDSNFKFGLSSGLSNPAPLAPFQFGVSSLGQQE	1012
<i>Gallus gallus</i>	FPSSSGNFKFGVSSSDSKPEESKKEDKSN-NFTGLPS-TSSPAPLT-FQFGTASLGQQE	965
<i>Mus musculus</i>	KKEELPKSSPAGFSFGAGVNNPPN-AAIDTTATSENKS---GFNFGLDTKSVSVPFTY	1054
<i>Rattus norvegicus</i>	KKEELPQSSSAGFSFGAGVANPSS-AAIDTTVSENKS---GFNFGLDTKSVSVPFTY	1058
<i>Homo sapiens</i>	KKEELPKSSSAGFSFGTGVINSTP-APANTIVTSENKS---SFNLGTIETKSASVAPFTC	1065
<i>Bos taurus</i>	KKEELPKSSSTGFSGFSGVINPPTAAADTAVTSENKS---GFSFGTDTKSVSVPFTC	1069
<i>Gallus gallus</i>	KKEQQPVVLG--GFSFGS-----SSTS VTTSENKTGVAGFTFGTVAENEVASASFAF	1014
<i>Mus musculus</i>	KTTEAKKEDAPATKGFFTGFVGSSSLPSSSMFVLGRTEEKQQEPVTSLSVFGKKADSE	1114
<i>Rattus norvegicus</i>	KTTEAKKEDASATKGFFTGFVDSAALSSPSMFVLGRTEEKQQEPVTSLSVFGKKADNE	1118
<i>Homo sapiens</i>	KTSEAKKEEMPATKGFFSFGNVEPASLPSASVFLVLRTEEKQQEPVTSLSVFGKKADNE	1125
<i>Bos taurus</i>	QTSEAKKEETPATKGFFAFGSVDPTPLPSASLFLVLRTEEKQQEPVTSLSVFGKKADNE	1129
<i>Gallus gallus</i>	KKSDEKDETPTKGFFSFGNVES---APASQFVLGRTEEKQDSVSSAAPLLFGKKADNE	1071
<i>Mus musculus</i>	EPKQPVFSFGNSEQTKEDESS-KPTFSFSVAKPGSKGESEQQLAKATFAFGNQTNTTDQGA	1173
<i>Rattus norvegicus</i>	EPKQPVFSFGNSEQTKEDESSKPTFSFSVAKPSVKESDLQAKATFAFGNQTNTTDQGA	1178
<i>Homo sapiens</i>	EPKQPVFSFGNSEQTKEDENSSKTSFSMSKTPSEKESEQPAKATFAFGAQQTSTADQGA	1185
<i>Bos taurus</i>	EPKQPVFSFGNSEQTKEDEGSSKTSFSVVKPSEKESEQPAKPAFFGAQTSTAADQGV	1189
<i>Gallus gallus</i>	ESKAQPVFSVQGSEHTKEESTAKPMFNFSVFKPSEKENEQ-AKPTFSFGAQASTSADQGA	1130
<i>Mus musculus</i>	AKPVFSFLNSSSSSSPATSS-SGGIFGSSTSSNPP---VAAFVFGQASNPVSSSAFGN	1230
<i>Rattus norvegicus</i>	AKPAFSLNLSNNSSSPATSS-SASIFGSSTSSSSP---VAAFVFGQASNPVSSSAFGN	1235
<i>Homo sapiens</i>	AKPVFSFLNNSSSSSPATSA-GGGIFGSSTSSNPP---VATFVFGQSSNPVSSSAFGN	1242
<i>Bos taurus</i>	AKPVFNFLNNSSSNSPATSV-GGGIFGSCTSSSSP---VAAFVFGQASNPVSSSAFGN	1246
<i>Gallus gallus</i>	AKPSFSFLNNSSSSSAIPATSANSSVFGSITSSNPAPVPTFVFGQASNTVSSTAFGN	1190
<i>Mus musculus</i>	AAESSTSQSLLFPQESEPATSS-TAPAASPFVFGTGASSNS-VSSGFTFGATTSSSSG	1288
<i>Rattus norvegicus</i>	SAESSTSQPLLFQDGKPATTSS-TASAAPPFVFGTGASSNSTVSSGFTFGATTSSSSG	1294
<i>Homo sapiens</i>	TAESSTSQSLLFSQDSLKATTSS-TGTAVTPFVFGPAGSNNTTSFGFGATTSSSAG	1301
<i>Bos taurus</i>	AAESSTSQSLLFSQESKPATTSS-TGTAVTPFVFGTGASSNNTATSGFNGATTSSSAG	1305
<i>Gallus gallus</i>	SAESTASQSFGFSQESKPATTSSTTGAAVAPFVFGSGASSSSAASSGFTFGATATSSSTG	1250
<i>Mus musculus</i>	SS--FVFGTGHAPSASPAFGANQTPTFGQSQGASQPNNPSSFGSISSSTALFSAGSQPVP	1346
<i>Rattus norvegicus</i>	SF--FVFGTGHAPSASPAFGANQTPTFGQSQGASQPNNPSSFGSISSSTALFSAGSQPVP	1352
<i>Homo sapiens</i>	SS--FVFGTGPSAPSASPAFGANQTPTFGQSQGASQPNNPSSFGSISSSTALFPTGSQPA	1359
<i>Bos taurus</i>	SS--FVFGTGAAPSASPAFGANQTPTFGQSQGASQPNNPSSFGSISSSGALFSAGSQPA	1363

Gallus gallus	SSSSFVFGSGSSAPAAGPAFGAGQLPAFGQSQGSSQPNAPSFGSLS--TTLFSAGSQPAP 1308
Mus musculus	PPIFGTVSSSSQPPVFGQQPSQ-SAFGSGTA-NASSVFQFGSST-TNFNFTNNNPGVFT 1403
Rattus norvegicus	PPTFGTVSSSSQPPVFGQQPSQ-SAFGSGTA-NASSVFQFGSST-TNFNFTNNNPGVFT 1409
Homo sapiens	P-TFGTVSSSSQPPVFGQQPSQ-SAFGSGTPNSSSAFQFGSST-TNFNFTNNSPSGVFT 1416
Bos taurus	P-TFGTVSSSGQPPVFGQQPGQ-SAFGSGTAPNPSSVFQFGSSTATNFNFTNSSPSGVFT 1421
Gallus gallus	P-AFGSVTSSTQPPVFGQQSSQQPGFGSGTS---SPVFQFGSST-SNFNFTSN--PEVFT 1361
Mus musculus	FGASPSTPAASAQPSGSQGVFSFSQSPASFTVGNSGNMFSSSGTSVGRKIKTAVRRKK 1462
Rattus norvegicus	FGASPSTPAAAAQPSGSQGGFSFSQSPASFTVGNSGNMFSSSGTSVGRKIKTAVRRKK 1468
Homo sapiens	FGANSSTPAASAQPSGSQGGFPFNQSPAATFTVGNSGNVFSSSGTSVGRKIKTAVRRKK 1475
Bos taurus	FGASPSTPAASSQPSGSQGGFQSQSSAAFTVGNSGNMFSSSGPSVGRKIKTAVRRKK 1480
Gallus gallus	FGANPPAPAASVQPSGSQGSFSQ=PPAFTVGTNGKNIFSASGSSSVRKIKTAVRRKK 1419

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Mus musculus	MSGFNFGGTGAPAGGFTFGTAKTAT-TTPATGFSFSASGTGTGGFNFGTPSQPAATTNST 59
Rattus norvegicus	MSGFNFGGTGAPAGGFTFGTAKTAT-TTPATGFSFSASGTGTGGFNFGTPSQPAATTNST 59
Homo sapiens	MSGFNFGGTGAPTGFTFGTAKTAT-TTPATGFSFSSTS--GTGGFNFGAPFQPATSTPST 57
Bos taurus	MSGFNFGGTGASTGGFTFGNTKTAT-TTPATGFSFSAS--STGGFSFGTPSQSAASTPAT 57
Gallus gallus	MSQFNFS-SAPAGGGFSFSTPKTAASTTAATGFSFTPAP--SSGFTFGGAAPTPASSQPV 57
Mus musculus	SLFSLTTQTPTTQTPGFNFG-----TTPASGGTGFSLGISTPKLSSLNAATPATANTGS 114
Rattus norvegicus	SLFSLATQTSTTQTPGFNFG-----TTPASGGTGFSLGISTPKLSSLSTAATPATANTGS 114
Homo sapiens	GLFSLATQTPATQTTGFTFGT-----ATLASGGTGFSLGIGASKLNLNSNTAATPAMANPSG 113
Bos taurus	SLFSLSTQTPATQTPAFSFGT-----TTPASGATGFSLGSNTPKLSLGSTAPAPAQP--AG 111
Gallus gallus	TPFSFSTPASSALPTAFSGTPATATTAAAPAASVPLGGNAPKLNFGGTSTTQATGITGG 117
Mus musculus	FGLGSSLTNAIISGSTSNQGTAPTFGVFGSSTTS-APSTGST-----GFSFTSGSASQP 168
Rattus norvegicus	FGLGSSLTNAIISGSTSSQGTAPTFGVFGSSTTS-APSTGTT-----GFSFTSGSASQP 168
Homo sapiens	FGLGSSNLTNNAISSTVTSSQGTAPTFGVFGPSTTSVAPATTSG-----GFSFTGGSTAQP 168
Bos taurus	FGLGGSTLSSAVSASTSAQGAAPGGFVFGSATASAAPPSTS---GGFSFTGGSTSQT 168
Gallus gallus	FGFGTSAPTSVPSS----QAAAPSGFMFGTAATTTTTAAQPGTTGGFTFSSGTTQA 172
Mus musculus	GASGFSLGSVGSQAQPTALSGSPF--TPATLVTTAG--ATQPAAA----- 210
Rattus norvegicus	GASGFNIGSVGSQLAQPTALSGSPF--TPATLATTAG--ATQPAAA----- 210
Homo sapiens	--SGFNIGSAGNSAQPTAPATLPF--TPATPAATTAG--ATQPAAP----- 208
Bos taurus	GTSGFNIGSLGGPAQPPALGGLPF--TAAAPAATGAG--AAQPAAP----- 210
Gallus gallus	GTTGFNIGATSTAAPQAVPTGLTGAAPAAAATTASLGSTTQPAATPFSLGGQSSAATG 232
Mus musculus	APTAATTS-----AGSTLFASIAA--APASS 234
Rattus norvegicus	PTPAATTS-----AGSTLFASIAA--APASS 234
Homo sapiens	TPTATATTS-----TGPSLFASIAT--APTSS 232
Bos taurus	TPAATTTS-----AGPSLFTSLAT--APTSS 234
Gallus gallus	APTATLATSTSQGPTLSFGSKLGVTTASTTAASTAPLLGSTGPVLFASTIASSSAPASS 292
Mus musculus	SATGLSLPAPVTTAATPSAGTGLFSLKAPGAAPGASTTSTTTTTTTAAAAAATTT 294
Rattus norvegicus	STTVLSSLAPATTAATPTAGTGLFSLKAPGAAPGASTTSTTTTTTTAATSSS-TTT 293
Homo sapiens	ATTGLSLC ^T PTVTTAGAPTAGTQGFSLKAPGAASGTSTTSTAATATATTTS----SSST 287
Bos taurus	AATGLSLGTPATTGTAGAGTVGFNLKAPGVAS-TTSTATTTTTAATTS-----T 285
Gallus gallus	TSTGLSLGAPST---GTTGLGTSGFGLKPPGTTAAATSTATSTSASS----- 336
Mus musculus	TGFALSLKPLVSAGPSS---VAATALPASSTAAGTATGPAMTYAQLESLINKWSLELEDQ 351
Rattus norvegicus	TGFALSLKPLVPAGPSS---VAATALPASSTAAGTATGPAMTYAQLESLINKWSLELEDQ 350
Homo sapiens	TGFALNLKPLAPAGIPSNTAAVTAPPGPAGAAAGASSAMTYAQLESLINKWSLELEDQ 347
Bos taurus	TGFSLNIKPLTPAGIPSNTAASGSAPSGASAAAGSGSAALTYAQLESLINKWSLELEDQ 345
Gallus gallus	--FALNLKPLTTGTIG----AVTSTAAITTPSAPPVMTYAQLESLINKWSLELEDQ 389

<i>Mus musculus</i>	ERHFLQQATQVNAWDRTLIENGEKITSLHREVEVKLDQKRQLDQEELDFILSQQKELEDLL	411
<i>Rattus norvegicus</i>	ERHFLQQATQVNAWDRTLIENGEKITSLHREVEVKLDQKRQLDQEELDFILSQQKELEDLL	410
<i>Homo sapiens</i>	ERHFLQQATQVNAWDRTLIENGEKITSLHREVEVKLDQKRQLDQEELDFILSQQKELEDLL	407
<i>Bos taurus</i>	ERHFLQQATQVNAWDRTLIENGERITSLHREVEVKLDQKRQLDQEELDFILSQQKELEDLL	405
<i>Gallus gallus</i>	EKHFLHQATQVNAWDRTLIENGEKITSLHREVEVKLDQKRQLDQEELDFILSQQKELEDLL	449
<i>Mus musculus</i>	SPLEESVKEQSGTIYLQHADEREKTYKLAENIDAQLKRMAQDLKDIIIEHLMAGGPADT	471
<i>Rattus norvegicus</i>	SPLEESVKEQSGTIYLQHADEREKTYKLAENIDAQLKRMAQDLKDIIIEHLMAGGPADT	470
<i>Homo sapiens</i>	SPLEELVKEQSGTIYLQHADEREKTYKLAENIDAQLKRMAQDLKDIIIEHLNTSGAPADT	467
<i>Bos taurus</i>	SPLEESVKEQSGTVHLQHADEREKTYKLAENIDAQLKRMAQDLKDIIIEHLNTSGGPADT	465
<i>Gallus gallus</i>	TPLEESVKEQSGTIYLQHADEEERERTYKLAENIDAQLKRMAQDLKDIIIEHLNTSGRPADT	509
<i>Mus musculus</i>	SDPLQQICKILNAHMDSLQWVDQSSALLQRRVEEASRVCEGRRKEQERSLRIAFD	526
<i>Rattus norvegicus</i>	SDPLQQICKILNAHMDSLQWVDQSSALLQRRVEEASRVCESRRKEQERSLRIAFD	525
<i>Homo sapiens</i>	SDPLQQICKILNAHMDSLQWIDQNSALLQRKVEEVTKVCEGRRKEQERSFRITFD	522
<i>Bos taurus</i>	SDPLQQICKILNAHMDSLQWIDQNSALLQRKVEEVTKVCEGRRKEQERSFRITFD	520
<i>Gallus gallus</i>	SDPLQQICKILNAHMDSLQWIDQNSALLQRKVEEVTKVCESRRKEQERSFRITFD	564

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<i>Mus musculus</i>	MP-SVLGSMMVASTSAAASLQEALENAGRIDLDRQLQEDRMPDLSLELLMSAPNSPTVSG	59
<i>Rattus norvegicus</i>	MP-SMLGSMMVASTSAPS-LQEALENAGRIDLDRQLQEDRMPDLSLELLMSAPNSPTVSG	58
<i>Homo sapiens</i>	MPSSLLGAAMPASTSAAA-LQEALENAGRIDLDRQLQEDRMPDLSLELLMSAPNNPTVSG	59
<i>Bos taurus</i>	MPSSLLGSAMPASTSAAA-LQEALENAGRIDLDRQLQEDRMPDLSLELLMSAPNNPTVSG	59
<i>Gallus gallus</i>	MP----AAMSPTVPHAG---EALEIAGRIIDRQICQDDRCYPDLSELLAVPAPGSPTVSG	52
<i>Mus musculus</i>	MSDMDYPLQGPGLLSVPSLPEISTIRRVPPLPELVEQFGHMQCNCMMGVFPPISRAWLTI	119
<i>Rattus norvegicus</i>	MSDMDYPLQGPGLLSVPSLPEISTIRRVPRLSWLNSLDTCVTAMMGVFPPISRAWLTI	118
<i>Homo sapiens</i>	MSDMDYPLQGPGLLSVPNLPEISSIRRVPPLPELVEQFGHMQCNCMMGVFPPISRAWLTI	119
<i>Bos taurus</i>	MSDMDYPLQGPGLLSVPNLPEISSIRRVPPLPELVEQFGHMQCNCMMGVFPPISRAWLTI	119
<i>Gallus gallus</i>	MTDMDYPLQGPGLLSIPNLPEISSVRVPPLPELVEQFGHMQCNCMMGVFPEISRAWLTI	112
<i>Mus musculus</i>	DSDIFMWNYEDGGDLAYFDGLSETILAVGLVKPKAGIFQPHVRHLLVLATPVDIVILGLS	179
<i>Rattus norvegicus</i>	DSDIFMWNYEDGGDLAYFDGLSETILAVGLVKPKAGIFQPHVRHLLVLATPVDIVILGLS	178
<i>Homo sapiens</i>	DSDIFMWNYEDGGDLAYFDGLSETILAVGLVKPKAGIFQPHVRHLLVLATPVDIVILGLS	179
<i>Bos taurus</i>	DSDIFMWNYEDGGDLAYFDGLSETILAVGLVKPKPGIFQPHVRHLLVLATPVDIVILGLS	179
<i>Gallus gallus</i>	DSDIFMWNYEDGGDLAYFDGLSETILAVGLVKPKGGIFQPHVRHLLVLATPVDIVILGLS	172
<i>Mus musculus</i>	YANVQTGSGILNDSMCGGMQLLPDPLYSLPTDNTYLLTITSTDNGRIFLAGKDGCLYEVA	239
<i>Rattus norvegicus</i>	YANVQTGSGILNDSCGGLQLLPDPLYSLPTDNTYLLTITSTDNGRIFLAGKDGCLYEVA	238
<i>Homo sapiens</i>	YANLQTGSGVLNDSLSGGMQLLPDPLYSLPTDNTYLLTITSTDNGRIFLAGKDGCLYEVA	239
<i>Bos taurus</i>	YTNLQTGSGVLNDSMCGGMQLLPDPLYSLPTDNTYLLTITSTDNGRIFLAGKDGCLYEVA	239
<i>Gallus gallus</i>	CANTQAGTGPLNDLSLGGMQLLPDPLYSLPTDNTYISAITSTDNGRIFLAGKDGCLYEVA	232
<i>Mus musculus</i>	YQAEAGWFSQLCRKINHSKSSLFLVPSLLQFTFSEDDPIVQIEIDNSRNILYTRSEKGV	299
<i>Rattus norvegicus</i>	YQAEAGWFSQLCRKINHSKSSLFLVPSLLQFTFSEDDPIVQIEIDNSRNILYTRSEKGV	298
<i>Homo sapiens</i>	YQAEAGWFSQLCRKINHSKSSLFLVPSLLQFTFSEDDPILQIAIDNSRNILYTRSEKGV	299
<i>Bos taurus</i>	YQAEAGWFSQLCRKINHSKSPLSFLVPSLLQFTFSEDDPIVQIAVDNSRNILYTRSEKGV	299
<i>Gallus gallus</i>	YQAEAGWFSQLCRKINHSKSALSLIPSLLQFTFSEDDPVVQIAIDNSRNILYTRSEKGV	292
<i>Mus musculus</i>	IQVYDLGHGQGMSRVASVSQNAIVSAAGNIARTIDRSVFKPPIVQIAVISSSESIDCQLL	359
<i>Rattus norvegicus</i>	IQVYDLGHGQGMSRVASVSQNAIVCAAGNIARTIDRSVFKPPIVQIAVIENSESIDCQLL	358
<i>Homo sapiens</i>	IQVYDLQGDQGMSRVASVSQNAIVSAAGNIARTIDRSVFKPPIVQIAVIENSESIDCQLL	359
<i>Bos taurus</i>	IQVYDLGHGQGMSRVASVSQNSIVSAAGNIARTIDRSVFKPPIVQIAVIENSESIDCQLL	359
<i>Gallus gallus</i>	LQVYDLQGDQGMSRVTLSQNAIVSAAGSIARTIDRSVFKPPIVQIAVIENSESIDCQLL	352

<i>Mus musculus</i>	AVTHAGVRLYFSTCPFRQPLARPNTLTVHVRLLPPGSASSTVEKPSKVHKALYSKGILL	419
<i>Rattus norvegicus</i>	AVTHAGVRLYFSTCPFRQPLARPNTLTVHVRLLPPGSASSTVEKPSKVHKALYSKGILL	418
<i>Homo sapiens</i>	AVTHAGVRLYFSTCPFRQPLARPNTLTVHVRLLPPGSASSTVEKPSKVHKALYSKGILL	419
<i>Bos taurus</i>	AVTHAGVRLYFSTCPFRQPLARPNTLTVHVRLLPPGSASSTVEKPSKVHKALYSKGILL	419
<i>Gallus gallus</i>	AVTHAGVRLYFSTSQFKHPAARPSMLTLVHVRLLPPGSASSNVEKPSKVHRALYCKGVLL	412
<i>Mus musculus</i>	MTASENEDNDILWCVNHDTPFPQKPKMMETQMTRDGHSWALSAIDELKVDKIITPLNKD	479
<i>Rattus norvegicus</i>	MTASENEDNDILWCVNHDTPFPQKPKMMETQMTRDGHSWALSAIDELKVDKIITPLNKD	478
<i>Homo sapiens</i>	MAASENEDNDILWCVNHDTPFPQKPKMMETQMTRDGHSWALSAIDELKVDKIITPLNKD	479
<i>Bos taurus</i>	MAASENEDNDILWCVNHDTPFPQKPKMMETQMTRDGHSWALSAIDELKVDKIITPLNKD	479
<i>Gallus gallus</i>	MAASENEDNDILWCINHDSFPQKPKMMETQMTRDGHSWALSAIDEFKVQKIVTPLNKD	472
<i>Mus musculus</i>	HIPITDSPVVVQQHMLPPKKFVLLSAQGSLMFHKLRPVQLRHLLSVNVGGDGEIERFF	539
<i>Rattus norvegicus</i>	HIPITDSPVVVQQHMLPPKKFVLLSAQGSLMFHKLRPVQLRHLLSVNVGGDGEIERFF	538
<i>Homo sapiens</i>	HIPITDSPVVVQQHMLPPKKFVLLSAQGSLMFHKLRPVQLRHLLSVNVGGDGEIERFF	539
<i>Bos taurus</i>	HIPITDSPVVVQQHMLPPKKFVLLSAQGSLMFHKLRPVQLRHLLSVNVGGDGEIERFF	539
<i>Gallus gallus</i>	VIPITDSPIVVQQHMLPPKKFVLLSAQGSLMFHKLRPVQLRHLLSVNTGGDGEIERFF	532
<i>Mus musculus</i>	KLHQEDQACATLILACSTAACDREVSAWATRAFFRYGGEAQMRFPATLPTPSNVGPILG	599
<i>Rattus norvegicus</i>	KLHQEDQACATLILACSTAACDREVSAWATRAFFRYGGEAQMRFPATLPTPSNVGPILG	598
<i>Homo sapiens</i>	KLHQEDQACATLILACSTAACDREVSAWATRAFFRYGGEAQMRFPATLPTPSNVGPILG	599
<i>Bos taurus</i>	KLHQEDQACATLILACSTAACDREVSAWATRAFFRYGGEAQMRFPATLPTPSNVGPILG	599
<i>Gallus gallus</i>	KLHQEDQACATLILACSTAACDTEVSAWATRAFFRYGGEAQMRFPATLPTPSNVGPILG	592
<i>Mus musculus</i>	SPMYSSSPVPSGPSPYPNPSSLGTPSHGAQPPTMSTPMCAVGSPAMQAAS--MSGLTGPEI	657
<i>Rattus norvegicus</i>	SPMYSSSPVPTGPSPYPNPSSLGTPSHGAQPPTMSTPMASVGNPAMQAAS--LSGLTGPEI	656
<i>Homo sapiens</i>	SPVYSSSPVPSGPSPYPNPSFLGTPSHGIQPMPATQATN--MSCVTGPEI	657
<i>Bos taurus</i>	SPVYSSSPVPSGTLYPNPSFLGTPSQGVHPAVSTPVCALGSPATQATS--MSCMAGPEI	657
<i>Gallus gallus</i>	SPIPPVSPLTVDSPYPSPLSLTGPGPGLQSTTVSTPIFPPGNVSHPGTISSSGIMGPEI	652
<i>Mus musculus</i>	VYSGKHNGICIYFSRIMGNIWADSLVVERVFKNSSREITAIESSVPVQLLESVLQELKGL	717
<i>Rattus norvegicus</i>	VYSGKHNGICIYFSRIMGNIWADSLVVERVFKNSSREITAIESSVPVQLLESVLQELKGL	716
<i>Homo sapiens</i>	VYSGKHNGICIYFSRIMGNIWADSLVVERIFKSGNREITAIESSVPVQLLESVLQELKGL	717
<i>Bos taurus</i>	VYSGKHNGICIYFSRIMGNIWADSLVVERVFKNSSREITAIESSVPSQLLESVLLELKGL	717
<i>Gallus gallus</i>	VFSGRHNGICIYFARIIGNIWDSIVVEKIFKSGNREVVAIESSVPSHVLVCVLQELKGL	712
<i>Mus musculus</i>	QEFLDRNSQFS-GGFLGNPNTTARVQQRLLVGFMRPENGNTOQQMQUELQRKFQ-EAQIASEK	775
<i>Rattus norvegicus</i>	QEFLDRNSQFS-GGFLGNPNTTAKVQQRLLGVMRPENGNTOQQMQUELQRKFH-EAQIASEK	774
<i>Homo sapiens</i>	QEFLDRNSQFA-GGFLGNPNTTAKVQQRLLIGFMRPENGNPQQMQUELQRKFH-EAQIASEK	775
<i>Bos taurus</i>	QEFLDRNSQFT-GGFLGNPNTAAKVQQRLLIGFMRPENGNTOQQMQUELQRKLFH-EAQIASEK	775
<i>Gallus gallus</i>	QEFLDRNSQFATVAGLGNPSTPANLQQRLLGFMRPDGGSSQQVQQLERKYHAEAQLTEK	772
<i>Mus musculus</i>	ISLQAIQQLVORKSYQALALWKLLCEHQFSVIVGELQKEFQEQLKITTFKDLVIRDKEVTG	835
<i>Rattus norvegicus</i>	ISLQAIQQLVORKSYQALALWKLLCEHQFTVIVGELQKEFQEQLKITTFKDLVIREKEVTG	834
<i>Homo sapiens</i>	ISLQAIQQLVORKSYQALALWKLLCEHQFTIIIVAELOQELQEQQLKITTFKDLVIRDKELG	835
<i>Bos taurus</i>	ISLQAIQQLVORKSYQALALWKLLCEHQFTVIVGELQKEFQEQLKITTFKDLVIRDKELG	835
<i>Gallus gallus</i>	NSLQGIQQLVORKTCQALALWKLLCEHQFSVVVGELQKEHLKMTAFKDLVIRDKELG	832
<i>Mus musculus</i>	ALIASLINCYIRDNAAVDGISLHLQDTCPPLLSTDDAVCSKANELLQRSRQVSKTERER	895
<i>Rattus norvegicus</i>	ALIASLINCYIRDNAAVDGISLHLQDTCPPLLSTDDAVCSKANELLQRSRQVSKSERER	894
<i>Homo sapiens</i>	ALIASLINCYIRDNAAVDGISLHLQDICPPLLSTDDAICSKANELLQRSRQVQNKTTERER	895
<i>Bos taurus</i>	ALIASLINCYIRDNAAVDGISLHLQDICPPLLSTDDAICSKANELLQRSRQVQNKEKER	895
<i>Gallus gallus</i>	ALIASLINCYIRDNAAVDGISAHILQDICPPLLSTDDAVCSKANELLQRSRQAQNLEKEK	892
<i>Mus musculus</i>	MLRESLKEYQKISNQVQLPSVCAQYRQVRFYEGVVELSLTAAEKKDQGLGLHFYKHGE	955
<i>Rattus norvegicus</i>	MLRESLKEYQKISNQVQLPSVCAQYRQVRFYEGVVELSLTAAEKKDQGLGLHFYKHGE	954
<i>Homo sapiens</i>	MLRESLKEYQKISNQVQLPSVCAQYRQVRFYEGVVELSLTAAEKKDQGLGLHFYKHGE	955
<i>Bos taurus</i>	MLRESLKEYQKISNQVQLPSVCAQYRQVRFYEGVVELSLTAAEKKDQGLGLHFYKHGE	955
<i>Gallus gallus</i>	MLRESLKEYQKISNQVQLPSVCAQYRQVRFYEGVVELSLTAAEKKDQGLGLHFYKHGE	952

Mus musculus	EEDVVGLQTFQERLNSYK	CITDTLQELVNQSAAAPQSPSVPKPGPPVLSSDPNMLSNEE	1015
Rattus norvegicus	EEDVVGLQTFQERLNSYK	CITDTLQELVNQSAAAPQSPSVPKPGPPVLSSDPNMLSNEE	1014
Homo sapiens	EEDIVGLQAFQERLNSYK	CITDTLQELVNQSAAAPQSPSVPKPGPPVLSSDPNMLSNEE	1015
Bos taurus	EEDIVGLQAFQERLNSYK	CITDTLQELVNQSAAAPQSPSVPKPGPPVLSSDPNMLSNEE	1015
Gallus gallus	EEDAVGLQAFQERLNSYK	CITDTLQELVNQSAAAPQSPSVPKPGPPVLSSDPNMLSNEE	1012
Mus musculus	AGHHFQMLKLAQRSKDELFSSIALYNWLQADLADKLQLIASPFLEPHLVRMARVDQNRV	1075	
Rattus norvegicus	AGHHFQMLKLAQRSKDELFSSIALYNWLQADLADKLQLIASPFLEPHLVRMAKVVDQNRV	1074	
Homo sapiens	AGHHFQMLKLSQRSKDELFSSIALYNWLQVDSLADKLQLQASPFLPHLVRMAKVVDQNRV	1075	
Bos taurus	AGHHFQMLKLSQRSKDELFSSIALYNWLQADLADKLQLIASPFLEPHLVRMAKVVDQNKV	1075	
Gallus gallus	AGHHFQMLKLAQRSTDELFSSIALYNWLQVDSLADKLQLQVTAPFLPEPYLVRMKTIDQNKV	1072	
Mus musculus	RYMDLLWRYYEKNRFSAAARVLSKLADMHSTEISLQQRLEYIARAILSAKSSTAIISSIA	1135	
Rattus norvegicus	RYMDLLWRYYEKNRFSAAARVLSKLADMHSTEISLQQRLEYIARAILSAKSSTAIISSIA	1134	
Homo sapiens	RYMDLLWRYYEKNRFSNAARVLSSLADMHSTEISLQQRLEYIARAILSAKSSTAIISSIA	1135	
Bos taurus	RYMDLLWRYYEKNRFSAAARVLSKLADMHSTEISLQQRLEYIARAILSAKSSTAISSTA	1135	
Gallus gallus	RYMDLLWRYYFEKNRNFNSNAARVLAKLADLHSTEISLQQRLEYIARAILSAKSSTAIISSIA	1132	
Mus musculus	ADGEFLHELEEKMEVARIQLQIQTETLQRQYSHHSSVQDAISQLDSELMIDITKLYGEFADP	1195	
Rattus norvegicus	ADGEFLHELEEKMEVARIQLQIQTETLQRQYSHHSSVQDAISQLDSELMIDITKLYGEFADP	1194	
Homo sapiens	ADGEFLHELEEKMEVARIQLQIQTETLQRQYSHHSSVQDAISQLDSELMIDITKLYGEFADP	1195	
Bos taurus	ADGEFLHELEEKMEVARIQLQIQTETLQRQYSHHSSVQDAISQLDSELMIDITKLYGEFADP	1195	
Gallus gallus	ADGEFLHELEEKMDVARIQLQIQTETLQRQYSHHSSVQDAISQLDSELMIDITKLYGEFADP	1192	
Mus musculus	FKLAECKLAVIH C AGYSDPILVHTLWQDIIEKELNDSVALSSDRMHALS L KLVLLGKIY	1255	
Rattus norvegicus	FKLAECKLAI I H C AGYSDPILVHTLWQDIIEKELSDVTLSSDRMHALS L KLVLLGKIY	1254	
Homo sapiens	FKLAECKLAI I H C AGYSDPILVQTLWQDIIEKELSDVTLSSDRMHALS L KIVLLGKIY	1255	
Bos taurus	FKLAECKLAI I H C AGYSDPILVQTLWQDIIEKELNESVTLSSPDRMHALS L KIVLLGKIY	1255	
Gallus gallus	FKLSECKLAI I H C AGHSDPILVQTLWQE I IEKELSDVS L SPADRMQALSLKMALLGKIY	1252	
Mus musculus	AGTPRFPLDFIVQFLEQQV C TLNWDVG F VIQTMNEIGVPLPR L LEVYDQLFKSRDPFWN	1315	
Rattus norvegicus	AGTPRFPLDFIVQFLEQQV C TLNWDVG F VIQTMNEIGVPLPR L LEVYDQLFKSRDPFWN	1314	
Homo sapiens	AGTPRFPLDFIVQFLEQQV C TLNWDVG F VIQTMNEIGVPLPR L LEVYDQLFKSRDPFWN	1315	
Bos taurus	AGTPRFPLDFIVQFLEQQV C TLNWDVG F VIQTMNEIGVPLPR L LEVYDQLFKSRDPFWN	1315	
Gallus gallus	AGTPRFPLDFIVQFLEQQV C CALNW DVG F V TYTMQEIGVPLPR L LEVYDQLFKARDPYWN	1312	
Mus musculus	RVKSPLHLLDC I HVLLTRYVENPSLVLNC C ERRRTNL C LD A V C GYLVELQSMSSSVAQ A	1375	
Rattus norvegicus	RVKSPLHLLDC I HVLLTRYVENPSLVLNC C ERRRTNL C LD A V C GYLVELQSMSSSVAQ A	1374	
Homo sapiens	RMKKPLHLLDC I HVLLTRYVENPSQVLNC C ERRRTNL C LD A V C GYLVELQSMSSSVAQ A	1375	
Bos taurus	RMKKPLHLLDC I HVLLTRYVENPSQVLNC C ERRRTNL C LD A V C GYLVELQSMSSSVAQ A	1375	
Gallus gallus	RMKKPLHLLC I HVLLSGYVQDPSRVL--MRRRTNV C LD A V C GYLVELQSMSPTLMVQ T	1370	
Mus musculus	ITGNFKSLQAKLERLH	1391	
Rattus norvegicus	ITGNFKSLQAKLERLH	1390	
Homo sapiens	ITGNFKSLQAKLERLH	1391	
Bos taurus	ITGNFKSLQAKLERLH	1391	
Gallus gallus	ITGNFKSLQAKLERLH	1386	

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Mus musculus	-----	-MAAAGSLERSFVELSGAERERPRHFR	26
Rattus norvegicus	-----	-MAAAGSLERSFVELSGAERERPRHFR	26
Homo sapiens	MLHLSAPPAPPPEVTATARPC I S	VGRRGDGGKMAAGALERSFVELSGAERERPRHFR	60
Bos taurus	-----	-MAAAGAVERS F VEVVG A ERERPRHFR	26
Gallus gallus	-----	-MAAGLAERSY M ELGPAPRAPPRLR	25

<i>Mus musculus</i>	EFTVCDIGTASAAFGTVKYSESAGGFYYVESGKLFISITRNRFIHWKTSQDTLELVEESLD	86
<i>Rattus norvegicus</i>	EFTVCDLGTANAAFGAVKYSESAGGFYYVESGKLFISITRNRFIHWKTSQDTLELVEESLD	86
<i>Homo sapiens</i>	EFTVCISGTANAAVAGAVKYSESAGGFYYVESGKLFISVTRNRFIHWKTSQDTLELMEESLD	120
<i>Bos taurus</i>	EFTVCGIGTANAAAGAVKYGESAGGFYYVESGKLFISVTRNRFIHWKASQDTLELLEESLD	86
<i>Gallus gallus</i>	EVSFSPPGTAPVPSG--RYGDSAGGF <ins>CYRE</ins> <ins>CAQLGAATRNR</ins> CVRWTTSGDTLELVEESLD	83
<i>Mus musculus</i>	LNLLNNAVRLKFQNYNILPGGVHVSETQNHHVIIILNTNQTVHRLILPHPSRMYRSELVTE	146
<i>Rattus norvegicus</i>	LNLLNNAVRLKFQNYSLLPGGHVSETQNHHVIIILNTNHTVHRLILPHPSRMYRSELVTE	146
<i>Homo sapiens</i>	INLLNNAIRLKFQNC <ins>SVLPGGVV</ins> SETQNRRVIIILMLTNQTVHRLLLLPHPSRMYRSELVVD	180
<i>Bos taurus</i>	INLLNNAVRLKFQNGVLLPGGVHVSETQNHHVIIILNTNQTVHRLLLLPHPSRMYRSELAI	146
<i>Gallus gallus</i>	TELLNNAVRLHIQGC <ins>PPLPGGVHIC</ins> EVQNHLLVLLTVQSVHRVLLPHPAYAYRGDLITE	143
<i>Mus musculus</i>	SQMOSIFTDIGKVDFRDP <ins>CNSQI</ins> PSVPGLSPGSTTSAAWLSSDGEALFALPSASGGIFV	206
<i>Rattus norvegicus</i>	SQMOSIFTDIGKVDFKDP <ins>CNYQLI</ins> PTVPGLSPSSTTSAAWLSSDGEALFALPSASGGIFV	206
<i>Homo sapiens</i>	SQMOSIFTDIGKVDFTDP <ins>CNYQLI</ins> PAVPGISPNSTASTAWLSSDGEALFALP <ins>CASGGIFV</ins>	240
<i>Bos taurus</i>	SQMOSIFTDIGKVDFRDP <ins>CNYQPI</ins> PSVPGLSPGSATSAAWLSDGEALFALPSASGGIFV	206
<i>Gallus gallus</i>	SQMOSVFTDVGKINFRDPSSYH <ins>LIP</ins> SPVGLAANSVASAAWLSSDGEALFALPSAAGGIFV	203
<i>Mus musculus</i>	LKLPPYDVPGIASVVELKQSSVMQRLLTGWMPTAIRGDHGPSDRALSLAVHCVEHDAFIF	266
<i>Rattus norvegicus</i>	LKLPPYDIPGIASVVELKQSSVMQRLLTGWMPTAIRGDHGPSDRALSLAVHC <ins>VEHDAFIF</ins>	266
<i>Homo sapiens</i>	LKLPPYDIPGMVSVVELKQSSVMQRLLTGWMPTAIRGDQSPSDRPLSLAVHCVEHDAFIF	300
<i>Bos taurus</i>	LKLPPYDIPGVVSVVELKQSSVMQRLLIGWMPTAIRGDQGPSPDRPLSLAVHCVEHNAFIF	266
<i>Gallus gallus</i>	IKLPPHDVPGVVSVVELKQSSVQRFLTGWMP <ins>T</ins> AIRGD-GPSDVPISLAVHCLHDHAFLF	262
<i>Mus musculus</i>	ALCQDHKLRMWSYKDQM <ins>CLMVADM</ins> LEYVPVNKDLRLTAGTGHKLR <ins>LAYS</ins> PSMGLYLG <ins>IY</ins>	326
<i>Rattus norvegicus</i>	ALCQDHKLRMWSYKDQM <ins>CLMVADM</ins> LEYVPVNKDLRLTAGTGHKLR <ins>LAYS</ins> PSMGLYLG <ins>IY</ins>	326
<i>Homo sapiens</i>	ALCQDHKLRMWSYKEQMC <ins>CLMVADM</ins> LEYVPVKDLRLTAGTGHKLR <ins>LAYS</ins> PAMGLYLG <ins>IY</ins>	360
<i>Bos taurus</i>	ALCQDHKLRMWSYKDQM <ins>CLMVADM</ins> LEFVPVNKDLRLTAGTGHKLR <ins>LAYS</ins> PSMGLYLG <ins>VY</ins>	326
<i>Gallus gallus</i>	ALCQDHKLRMWSYKDQM <ins>CLMVADL</ins> LEFMPVSRDLRLA <ins>GTGH</ins> RLRLAFSQSLG <ins>LYLG</ins> VY	322
<i>Mus musculus</i>	HAPKRQGF <ins>C</ins> VFQLVSTENNRYSLDH <ins>ISSLFTS</ins> QETLVDFALTSTD <ins>I</ins> W <ins>H</ins> D <ins>A</ins> E <ins>N</ins> QTIVK	386
<i>Rattus norvegicus</i>	HAPKRQGF <ins>C</ins> IFQLVSTESSRYSLDH <ins>ISSLFTS</ins> QETLVDFALTSTD <ins>I</ins> W <ins>H</ins> D <ins>A</ins> E <ins>N</ins> QTIVK	386
<i>Homo sapiens</i>	HAPKRQGF <ins>C</ins> IFQLVSTESNRYSLDH <ins>ISSLFTS</ins> QETLIDFALTSTD <ins>I</ins> W <ins>H</ins> D <ins>A</ins> E <ins>N</ins> QTIVK	420
<i>Bos taurus</i>	HAPKRQGF <ins>C</ins> VFQLVSAENNRYSLDH <ins>ISSLFTS</ins> QETLIDFALTSTD <ins>I</ins> W <ins>H</ins> D <ins>A</ins> E <ins>N</ins> QTAVK	386
<i>Gallus gallus</i>	HAPKRQGF <ins>C</ins> VFQLVSTESNRYSLDH <ins>ISSLFTS</ins> QETLIDFALTSAE <ins>I</ins> W <ins>H</ins> NEENQTIVK	382
<i>Mus musculus</i>	YINFEHNVAQWNPNVFMQP <ins>LPEEE</ins> IVRDDQDPREMYL <ins>RSLS</ins> FTPGHF <ins>I</ins> NAAL <ins>C</ins> KALQ <ins>I</ins> FC	446
<i>Rattus norvegicus</i>	YINFEHNVAQWNPNVFMQS <ins>LPEEE</ins> IVRDDQDP <ins>R-----</ins> ----- <ins>I</ins> FC	423
<i>Homo sapiens</i>	YINFEHNVAQWNPNVFMQP <ins>LPEEE</ins> IVRDDQDPREMYL <ins>QSL</ins> FTPGQFTNEAL <ins>C</ins> KALQ <ins>I</ins> FC	480
<i>Bos taurus</i>	YINFEHNVAQGWSPVFMQP <ins>LPEEE</ins> IVRDDQDPREMYL <ins>QSL</ins> FTPG <ins>R</ins> F <ins>I</ins> NAAL <ins>C</ins> KALQ <ins>I</ins> FC	446
<i>Gallus gallus</i>	YINFEQNVAQWNQFMQP <ins>LPEEE</ins> IVRDDQDPRETYLEYL <ins>FTPGRFS</ins> NAAI <ins>Q</ins> KALQ <ins>I</ins> FS	442
<i>Mus musculus</i>	RGTERNLDSL <ins>W</ins> NELK <ins>K</ins> EITL <ins>A</ins> VEN <ins>E</ins> LQGSV <ins>T</ins> YE <ins>E</ins> FSQDEF <ins>R</ins> TLQ <ins>QEF</ins> W <ins>C</ins> KFYAC <ins>C</ins> V <ins>L</ins> QY <ins>Q</ins> E	506
<i>Rattus norvegicus</i>	RGTERNLDSL <ins>W</ins> SELK <ins>K</ins> EITL <ins>A</ins> VEN <ins>E</ins> LQGSV <ins>T</ins> YE <ins>E</ins> FSQDEF <ins>R</ins> TLQ <ins>QEF</ins> W <ins>C</ins> KFYAC <ins>C</ins> CLQY <ins>Q</ins> E	483
<i>Homo sapiens</i>	RGTERNLDSL <ins>W</ins> SELK <ins>K</ins> EVT <ins>L</ins> AV <ins>E</ins> NE <ins>L</ins> QGSV <ins>T</ins> YE <ins>E</ins> FSQEE <ins>F</ins> R <ins>N</ins> LQ <ins>QEF</ins> W <ins>C</ins> KFYAC <ins>C</ins> CLQY <ins>Q</ins> E	540
<i>Bos taurus</i>	RGTERNLDSL <ins>W</ins> MELK <ins>K</ins> EVT <ins>L</ins> AV <ins>E</ins> NE <ins>L</ins> QGSV <ins>T</ins> YE <ins>E</ins> FSQEE <ins>F</ins> R <ins>N</ins> LQ <ins>QEF</ins> W <ins>C</ins> KFYAC <ins>C</ins> CLQY <ins>Q</ins> E	506
<i>Gallus gallus</i>	QGTERHMDLTWDELK <ins>K</ins> EVT <ins>L</ins> AV <ins>E</ins> NE <ins>F</ins> QGSV <ins>T</ins> YE <ins>E</ins> CS <ins>PEEF</ins> C <ins>Q</ins> LQ <ins>DF</ins> W <ins>S</ins> K <ins>C</ins> AC <ins>C</ins> CLQY <ins>Q</ins> E	502
<i>Mus musculus</i>	ALSHPLALH <ins>L</ins> NP <ins>V</ins> T <ins>N</ins> M <ins>V</ins> C <ins>L</ins> KK <ins>G</ins> Y <ins>L</ins> SL <ins>V</ins> P <ins>S</ins> L <ins>V</ins> D <ins>H</ins> LY <ins>L</ins> LP <ins>D</ins> E <ins>H</ins> L <ins>T</ins> E <ins>D</ins> ET <ins>T</ins> I <ins>S</ins> DD <ins>A</ins> VA	566
<i>Rattus norvegicus</i>	ALSHPLALH <ins>L</ins> NP <ins>V</ins> T <ins>N</ins> M <ins>V</ins> C <ins>L</ins> KK <ins>G</ins> Y <ins>L</ins> SL <ins>V</ins> P <ins>S</ins> L <ins>V</ins> D <ins>H</ins> LY <ins>L</ins> LP <ins>D</ins> E <ins>H</ins> L <ins>T</ins> E <ins>D</ins> ET <ins>T</ins> I <ins>S</ins> DD <ins>A</ins> VA	543
<i>Homo sapiens</i>	ALSHPLALH <ins>L</ins> NP <ins>H</ins> T <ins>N</ins> M <ins>V</ins> C <ins>L</ins> KK <ins>G</ins> Y <ins>L</ins> SL <ins>V</ins> P <ins>S</ins> L <ins>V</ins> D <ins>H</ins> LY <ins>L</ins> LP <ins>D</ins> E <ins>H</ins> L <ins>T</ins> E <ins>D</ins> ET <ins>T</ins> I <ins>S</ins> DD <ins>V</ins> IA	600
<i>Bos taurus</i>	ALSHPLALH <ins>L</ins> NP <ins>H</ins> T <ins>S</ins> M <ins>V</ins> C <ins>L</ins> KK <ins>G</ins> Y <ins>L</ins> SL <ins>V</ins> P <ins>S</ins> L <ins>V</ins> D <ins>H</ins> LY <ins>L</ins> LP <ins>D</ins> E <ins>H</ins> L <ins>T</ins> E <ins>D</ins> ET <ins>T</ins> I <ins>S</ins> DD <ins>V</ins> VA	566
<i>Gallus gallus</i>	ALSRPLALL <ins>N</ins> P <ins>T</ins> N <ins>M</ins> V <ins>C</ins> LLKK <ins>G</ins> Y <ins>L</ins> SL <ins>V</ins> P <ins>S</ins> L <ins>V</ins> D <ins>H</ins> LY <ins>L</ins> LP <ins>D</ins> E <ins>H</ins> L <ins>T</ins> E <ins>D</ins> AA <ins>I</ins> F <ins>D</ins> DE <ins>L</ins> MS	562
<i>Mus musculus</i>	RDVL <ins>C</ins> LIK <ins>C</ins> LRM <ins>I</ins> GES <ins>V</ins> T <ins>M</ins> DA <ins>V</ins> LM <ins>E</ins> T <ins>C</ins> YN <ins>L</ins> Q <ins>S</ins> PE <ins>K</ins> AA <ins>E</ins> H <ins>I</ins> LED <ins>L</ins> IT <ins>I</ins> D <ins>V</ins> EN <ins>V</ins> M <ins>E</ins> DI <ins>C</ins> S	626
<i>Rattus norvegicus</i>	RDVL <ins>C</ins> LIK <ins>C</ins> LRM <ins>I</ins> GES <ins>V</ins> T <ins>M</ins> DA <ins>V</ins> LM <ins>E</ins> T <ins>C</ins> YN <ins>L</ins> Q <ins>S</ins> PE <ins>K</ins> AA <ins>E</ins> H <ins>I</ins> LED <ins>L</ins> IT <ins>I</ins> D <ins>V</ins> EN <ins>V</ins> M <ins>E</ins> DI <ins>C</ins> S	603
<i>Homo sapiens</i>	RDVIC <ins>C</ins> LIK <ins>C</ins> LR <ins>L</ins> IE <ins>E</ins> S <ins>V</ins> T <ins>V</ins> DM <ins>S</ins> VI <ins>M</ins> E <ins>S</ins> C <ins>Y</ins> N <ins>L</ins> Q <ins>S</ins> PE <ins>K</ins> AA <ins>E</ins> Q <ins>I</ins> LED <ins>M</ins> IT <ins>I</ins> D <ins>V</ins> EN <ins>V</ins> M <ins>E</ins> DI <ins>C</ins> S	660
<i>Bos taurus</i>	RDVM <ins>C</ins> LIK <ins>C</ins> LR <ins>L</ins> IGE <ins>S</ins> V <ins>T</ins> MD <ins>M</ins> SM <ins>M</ins> EM <ins>C</ins> Y <ins>N</ins> L <ins>Q</ins> PE <ins>K</ins> AA <ins>E</ins> Q <ins>I</ins> LED <ins>L</ins> IT <ins>I</ins> D <ins>V</ins> DN <ins>V</ins> M <ins>E</ins> DI <ins>C</ins> S	626
<i>Gallus gallus</i>	RDVV <ins>C</ins> LV <ins>C</ins> CLR <ins>L</ins> IGE <ins>S</ins> IS <ins>M</ins> E <ins>I</ins> AF <ins>M</ins> EM <ins>C</ins> SR <ins>L</ins> Q <ins>P</ins> PE <ins>K</ins> AA <ins>E</ins> Q <ins>I</ins> LG <ins>D</ins> LI <ins>A</ins> ND <ins>T</ins> EN <ins>V</ins> M <ins>E</ins> DI <ins>C</ins> S	622

<i>Mus musculus</i>	KLQEIRNPVHAIGLLIREMDYETEVEMEKGFDPAQPLNVRMNLSQLYGSSTAGYIVCRGV	686
<i>Rattus norvegicus</i>	KLQEIRNPVHAIGLLIREMDYETEVEMEKGFDPAQPLNVRMNLSQLYGSSTAGYIVCRGV	663
<i>Homo sapiens</i>	KLQEIRNPPIHAIGLLIREMDYETEVEMEKGFNPAQPLNIRMNLSQLYGSNTAGYIVCRGV	720
<i>Bos taurus</i>	KLQEIRNPPIHAIGLLIREMDYETEVEMEKGFSQAQPLNVRMNLSQLYGSSTSGBHIVCRSV	686
<i>Gallus gallus</i>	KLQEIRNPPIHAIGVLIREMDYETDTDMERGFSAHPLNMRLNLSQLYGSSTAVSVCWGV	682
<i>Mus musculus</i>	YKIASTRFLICRDLLILQLQLTRLGDAVILGAGQLFQAQQDQLLHRTAPLLSYYLIKWAS	746
<i>Rattus norvegicus</i>	YKIASTRFLICRDLLILQLQLTRLGDAVILGAGQLFQAQQDQLLHRTAPLLSYYLIKWSS	723
<i>Homo sapiens</i>	HKIASTRFLICRDLLILQLQLMRLGDAVILGAGQLFQAQQDQLLHRTAPLLSYYLIKWGS	780
<i>Bos taurus</i>	CKIASTRFLICRDLLILQLQLMRLGDAVILGAGQLFQAQQDQLLHRTAPLLSYYLIKWGS	746
<i>Gallus gallus</i>	CKIATIRFQICRDLLILQLQLLRLGDPVLGGQFLQSQQDLLHRTSPLLSYYLIRWAS	742
<i>Mus musculus</i>	QC LATDVPVDTLESNLQHLSVLELTDSGALMANKLVSSPQTIMELFFQEVARQIISHLF	806
<i>Rattus norvegicus</i>	QC LATDVPVDTLESNLQHLSVLELTDSGALMANKLVSSPQTIMELFFQEVARKHIIISHLF	783
<i>Homo sapiens</i>	ECLATDVPLDTLESNLQHLSVLELTDSGALMANRFVSSPQTIVELFFQEVARKHIIISHLF	840
<i>Bos taurus</i>	QC LATDVPVDTLESNLQHLSVLELTSGALTANKFVSSPQTIVELFFQEVARKHIIISHLF	806
<i>Gallus gallus</i>	QC LASDIPIDTLESNLQHLSVLEADTTVLTPHKLVSSPQTIVELFFRDVARKHIVSRLF	802
<i>Mus musculus</i>	SQP KAPLSQTGLNWPEMITAVTGYLQLLWPSNPGCFLFCCLMGNCQYVQLQDYIQLLHP	866
<i>Rattus norvegicus</i>	SQP KAPLSQTGLNWPEMVTAVGYLQLLWPSNPGCFLFCCLMGNCQYVQLQDYIQLLHP	843
<i>Homo sapiens</i>	SQP KAPLSQTGLNWPEMITAITSYLLQLLWPSNPGCFLFCCLMGNCQYVQLQDYIQLLHP	900
<i>Bos taurus</i>	SQP KAPLSQTGLNWPEMITAVTNYLLQLLWPSNPGCFLFCCLMGNCQYVQLQDYIQLLHP	866
<i>Gallus gallus</i>	LQPNTSLIETSBNWPHLITAIVADFLPLLWPSNPGFLFPECLIGSCQYTQLQEYIRLLQP	862
<i>Mus musculus</i>	WCQVN VGSICRFMLGRCYLVTGEVQKALECFCQAASEVGKEEFLDRLIRSEdgeIVSTPKL	926
<i>Rattus norvegicus</i>	WCQVN VGSICRFMLGRCYLVTGEVQKALECFCQAASEVGKEEFLDRLIRTEDEGEIVSTPKL	903
<i>Homo sapiens</i>	WCQVN VGSICRFMLGRCYLVTGEGQKALECFCQAASEVGKEEFLDRLIRSEdgeIVSTPRL	960
<i>Bos taurus</i>	WCQVN VGSICRFMLGRCYLVTGEGQKALECFCQAASEVGKEEFLDRLIRSEdgeIVSTPRL	926
<i>Gallus gallus</i>	WCQVN MGSCCFMMGRCLVLMGEGHKA LDCFCQAASEVGKEEFLDRLI QPEEGEMVSTPRL	922
<i>Mus musculus</i>	QYYDKVRLRLDVVGLPELVIQLATS AITEAGDDWKSQATLRT CIFKHHLDGHNSQAYEA	986
<i>Rattus norvegicus</i>	QYYDKVRLRLDVVGLPELVIQLATS AITEAGDDWKSQATLRT CIFKHHLDGHNSQAYEA	963
<i>Homo sapiens</i>	QYYDKVRLRLDVVGLPELVIQLATS AITEAGDDWKSQATLRT CIFKHHLDGHNSQAYEA	1020
<i>Bos taurus</i>	QYYDKVRLRLDVVGLPELVIQLATS AITEAGDDWKSQATLRT CIFKHHLDGHNSQAYEA	986
<i>Gallus gallus</i>	QYYSKVRLRLDMVGLPELVIQLASVAIMESADDWRTQATLRT CIFKHHLDGHNSDAYVA	982
<i>Mus musculus</i>	LTQIPDSSRQLDCLRQLVVLCERSQLQDLVEFPVNLHNEVVGIIIESRARAVDLMTHNY	1046
<i>Rattus norvegicus</i>	LTQIPDSSRQLDCLRQLVVLCERSQLQDLVEFPVNLHNEVVGIIIESRARAVDLMTHNY	1023
<i>Homo sapiens</i>	LTQIPDSSRQLDCLRQLVVLCERSQLQDLVEFPVNLHNEVVGIIIESRARAVDLMTHNY	1080
<i>Bos taurus</i>	LTQIPDSSRQLDCLRQLVVLCERSQLQDLVEFPVNLHNEVVGIIIESRARAVDLMTHNY	1046
<i>Gallus gallus</i>	LTQNPDPSRQLDCLRQLVVLCERSQLQDLVEFPVNLHNEVVGIIIESHARAVDLMTHNY	1042
<i>Mus musculus</i>	YELLYAFHIYRHNYRKAGTVMFYGMRLGREVRTLRLGEKQGN CYLAAINCLRLIRPEYA	1106
<i>Rattus norvegicus</i>	YELLYAFHIYRHNYRKAGTVMFYGMRLGREVRTLRLGEKQGN CYLAAINCLRLIRPEYA	1083
<i>Homo sapiens</i>	YELLYAFHIYRHNYRKAGTVMFYGMRLGREVRTLRLGEKQGN CYLAAINCLRLIRPEYA	1140
<i>Bos taurus</i>	YELLYAFHIYRHNYRKAGTVMFYGMRLGREVRTIRGLEKQGN CYLAAINCLRLIRPEYA	1106
<i>Gallus gallus</i>	YELLYAFHIYRHNYRKAGTVMFYGMRLGREVRTLRLQKQGN CYLAAINCLRLIRPEYY	1102
<i>Mus musculus</i>	WIVQPASGA VSDRGASP KRNH DGECTAAPTNRQIEILELEDLEKEYSLARIRLTLARHD	1166
<i>Rattus norvegicus</i>	WIVQPASGA VSDRGASP KRNH DGECTAAPTNRQIEILELEDLEKEYCSLARIRLTLARHD	1143
<i>Homo sapiens</i>	WIVQPVSGAVYDRPGASP KRNH DGECTAAPTNRQIEILELEDLEKEYCSLARIRLTLAQHD	1200
<i>Bos taurus</i>	WIVQPASGA VDYDRPGASP KRNH DGECTAAPTNRQIEILELEDLEKEYCSLARIRLTLAQHD	1166
<i>Gallus gallus</i>	PLHPSVT-----ATRQIEILELEDLERECV LARIRLTLVQHD	1139
<i>Mus musculus</i>	PSVIAIAGSSSAKEMSALLVQAGLFDTAISLCQFTLPLTPVFEGLAFKC IKLQFGGEAA	1226
<i>Rattus norvegicus</i>	PSAIAIAGSSSAKEMSTLLVQAGLFDTAISLCQFTKLPPLTPVFEGLAFKC IKLQFGGEAA	1203
<i>Homo sapiens</i>	PSAVAVAGSSSAEEMVTLLVQAGLFDTAISLCQFTKLPPLTPVFEGLAFKC IKLQFGGEAA	1260
<i>Bos taurus</i>	PSAAA VAGSSSAEEMVTLLVQAGLFDTAISLCQFTKLPPLTPVFEGLAFKC IKLQFGGEAV	1226

Gallus gallus	LSTA AVAGNSTPEETLALLIRAGLFDTAITL C QTFKLPLTAVFEGLTFK C IKLQLGGEEA 1199
Mus musculus	QGEAWSW LATNQLSSVITTKESSATDEAWRLLSTYLERVKVQNNLYHH C VINKLLSHGVP 1286
Rattus norvegicus	QGEAWAWLAANQISSLSSVITTKESSATDEAWRLLSTYLERVKVQNNLYHH C VINKLLSHGVP 1263
Homo sapiens	QAEAWAWLAANQISSLSSVITTKESSATDEAWRLLSTYLERVKVQNNLYHH C VINKLLSHGVP 1320
Bos taurus	QAEAWAWLAANQISSLSSVITTKESSATDEAWRLLSAYLERVKVQNNLYHH C VINKLLSHGVP 1286
Gallus gallus	QAEAEWEWL ASNQISSLSSVITTKESSATDEAWRLLSAYLERVKVQNNLYHH C VINKLLAHGIP 1259
Mus musculus	LPNWLINSYKKVDAEELLRLYLN YDLLEEAVDVLSEYVDAVLGKGHQYFGIEFPLSATAP 1346
Rattus norvegicus	LPNWLINSYKKVDAEELLRLYLN YDLLEEAVDVLSEYVDAVLGKGHQYFGIEFPLSATAP 1323
Homo sapiens	LPNWLINSYKKVDAEELLRLYLN YDLLEEAVDVLSEYVDAVLGKGHQYFGIEFPLSATAP 1380
Bos taurus	LPNWLINSYKKVDAEELLRLYLN YDLLEEAVELVSEYVDAVLGKGHQYFGIEFPLSATAP 1346
Gallus gallus	LPNWLINSYKTVDAAQLLRLYLN YDLLEEAVDVLSEYVDAVLGKGHQYFGIEFPLSATAP 1319
Mus musculus	MVWL PYSSIDQLLQALGENSANSHNI ILSQKILD KLEDYQQKV DKA TRDLYRRDL 1402
Rattus norvegicus	MVWL PYSSIDQLLQALGENSANSHNI ILSQKILD KLEDYQQKV DKA TRDLYRRDL 1379
Homo sapiens	MVWL PYSSIDQLLQALGENSANSHNI AL SQKILD KLEDYQQKV DKA TRDLYRRDL 1436
Bos taurus	MVWL PYSSIDQLLQALGENTANSHNIA LSQKILD KLEDYQQKV DKA TRDLYRRNL 1402
Gallus gallus	MVWL PYTAIDQLLQALRESSANPSNVLLYQKLHDKMDYHQKV SVATRDR LYLRA- 1374

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Mus musculus	MAAAVGPLGD GELWQS WLPN HVVFLRLREGVRN QSPAA EKPA ASTSP C PSLPPH L PTR 60
Rattus norvegicus	MAAAAGPVGD GELWQS WLPN HVVFLRLREGLK NQ SPAEADKP ATSTSP C PPLPPH L PTR 60
Homo sapiens	MAAAEGPVGD GELWQT WLPN HVVFLRLREGLK NQ SPAEADKP ATSTSP C PPLPPH L PTR 58
Bos aurus	MAGAEGGP GD GELWQT WLPN HAVFLRLREGLK NQ STETEK PASS-LPSSPPLPPQLL TR 59
Gallus gallus	MAAEWGP--AEQWRAALPQHAAFGR LRD-----SGPAPS A PRSP-----LIR 41
Mus musculus	NLV FGLGGELFLWDAEGSAFLV VRLRGPSGGGV EPPLSQYQ RLLC INPPLFEIHQVLL SP 120
Rattus norvegicus	NLV FGLGGELFLWDAEGSAFLV VRLRGPSGGSV EPPLSQYQ RLLC INPPLFEIHQVLL SP 120
Homo sapiens	NVVFGLGGELFLWDGEDSSFLV VRLRGPSGGEEPALSQYQ RLLC INPPLFEIYQVLL SP 118
Bos aurus	NLV LGLGGELFLWDPEESSFLV VRLRGPSGAGEEP SLSQYQ RLLC INPPLFEIYQVLL SP 119
Gallus gallus	SLLLGLDG D LLDLWDGERGALLDIDL RRLSG--AEPELGRYQ TLLC INPPLFXVYHTLL SP 99
Mus musculus	TQHHVALIGSKGIMALELPQRWGKDSEFEGGKATVN C STIPIAERFFTSSTS LTLKHA AW 180
Rattus norvegicus	TQHHVALIGTKGIMALELPQRWGKDSEFEGGKATVN C STIPIAERFFTSSTS LTLKHA AW 180
Homo sapiens	TQHHVALIGIKGIMVLELPKRWGKNSEFEGGKSTVNC STTPVAERFFTSSTS LTLKHA AW 178
Bos aurus	TQHHVALIGIKGIMILELPKRWGKNSEFEGGKSTVNC STTPVAERFFTSSTS LTLKHA AW 179
Gallus gallus	ALC HVALIGTKG LSA VELPKRWGKNSEFEGGKATVN C STIPIAERFFTSSTS LTLKHA AW 159
Mus musculus	YPSEMLDPHIVLLTSDNVIRIYSLREPQPTK VIVLSEAE EESLILNKGRAYTASLGETA 240
Rattus norvegicus	YPSEMLDPHIVLLTSDNVIRIYSLREPQPTK VIVLSEAE EESLILNKGRAYTASLGETA 240
Homo sapiens	YPSEILDPHIVLLTSDNVIRIYSLREPQPTK VIVLSEAE EESLILNKGRAYTASLGETA 238
Bos aurus	YPSEMLEPHIVLLTSDNVIRIYSLREPQPTK VIVLSEAE EESLILNKGRAYTASLGETA 239
Gallus gallus	YPC HETLEPHIVLLTSDNTIRIYSLKVPQAPIK VIALS DAEETLII NRGRAYTASLGETA 219
Mus musculus	VAFDFGPLTVSKNIFEQKDR-DVVAYPLYI LYEN GETFLTYV SLLHSPGNIGKLLGPL 299
Rattus norvegicus	VAFDFGPLTVSKNMFEQKDR-EAVAYPLYI LYEN GETFLTYV SLLHSPGNIGKLLGPL 299
Homo sapiens	VAFDFGPLAA VP KTLFGQNGKDEV VAVPLYI LYEN GETFLTYI SLLHSPGNIGKLLGPL 298
Bos aurus	VAFDFGPLSA VP KHF GQKGKEE VAVPLYI LYEN GETFLTYI SLLHSPGSVGKLLGPL 299
Gallus gallus	VAFDFGPLPV PVPSV LGQRGSEEV LAFPLYI LYEN GETFLTYI NLLQ SAGNLGKLLGPL 279
Mus musculus	MHPAAEDNYGYDACA ILCLPCVP NILVIATES EGM LYH C VVLEGE EEDD QT LEK SWD PRAD 359
Rattus norvegicus	MHPAAEDNYGYDACA ILCLPCVP NILVIATES EGM LYH C VVLEGE EEDD QT LEK SWD PRAD 359
Homo sapiens	MHPAAEDNYGYDACA VLCLPCVP NILVIATES EGM LYH C VVLEGE EEDD HT SEK SWD SRID 358
Bos aurus	MHPAAEDNYGYDACA VLCLPCVP NILVIATES EGM LYH C VVLEGE EEDD QT SEK SWD SRAD 359
Gallus gallus	MHPAAEDNYGYDACA VLCLPCIP NILVIATES EGM LYH C VVLEGE EEDD EQS-EK SWD PRSD 338

Mus musculus	FIPSLYVFE C VELELALKLASG-EDDPFASDF C PIKLHRDPK C PSRYHCSHEAGVHSVG	418
Rattus norvegicus	LIPSLYVFE C VELELALKLASA-EDDPFASDF C PIKLHRDPK C PSRYHCSHEAGVHSVG	418
Homo sapiens	LIPSLYVFE C VELELALKLASG-EDDPFDSDFS C PVKLHRDPK C PSRYHCTHEAGVHSVG	417
Bos aurus	LIPSLYVFE C VELELALKLASG-EDEPFDSDF C PIKLHRDPK C PSRYHCTHEAGVHSVG	418
Gallus gallus	LVPSLYVFE C VELELALKLASGDEEPELESDF C PIKLHRDPK C PTRYHCTHEAGVHSVG	398
Mus musculus	LTWIHKLKFLGSDEEDKDLSQELTAEQKC C VEHILCTKPLPCRQPAPIRGFWIVPDILG	478
Rattus norvegicus	LTWIHKLKFLGSDEEDKDLSQELTAEQKC C VEHILCTKPLPCRQPAPIRGFWIVPDILG	478
Homo sapiens	LTWIHKLKFLGSDEEDKDLSQELSTEQKC C VEHILCTKPLPCRQPAPIRGFWIVPDILG	477
Bos aurus	LTWIHKLKFLGSDEEDKDLSQELATEQKC C VEHILCTKPLPCRQPAPIRGFWIVPDILG	478
Gallus gallus	LTWISKLQKFLGSDEEDKDGLQELAEQKC C VEHILCTKPLPCRQPAPVRGFWIVSDVLG	458
Mus musculus	PTMICITSTYE C LIRPLLSTVHPASPPLL C TQEDA E VAESPLRILAETPDSFEKHKRIL	538
Rattus norvegicus	PTMICITSTYE C LIRPLLSTVHPASPPLL C TREDA E GAESPLRILAEPDSFEKHKRIL	538
Homo sapiens	PTMICITSTYE C LIWPLLSTVHPASPPLL C TRDVE E VAESPLRVIAETPDSFEKHIRSIL	537
Bos aurus	PTMICITSTYE C LIRPLLSTVHPASPPLL C TRDVE E VAESPLRILAETPDSFEKHIRSIL	538
Gallus gallus	PTMICITNNYE C ITRPLLTAHVHPASPPLL C TKEDKDDATSPRLVIAESQHSFEKHIQSIL	518
Mus musculus	QRSAANPAFLKSSEKDLAPPPEEC C LQLISRATQVFREQYILQDLAKEEIQRRVKLL C DQ	598
Rattus norvegicus	QRSAANPALLKSSEKDLAPPPEEC C LQLISRATQVFREQYILQDLAKEEIQRRVKLL C DQ	598
Homo sapiens	ORSVANPAFLKASEKDIAPPPEEC C LQLISRATQVFREQYILQDLAKEEIQRRVKLL C DQ	597
Bos aurus	ORSVANPAFLKSSEKDMAPPPEEC C LQLISRATQVFREQYILQDLAKEEIQRRVKLL C DQ	598
Gallus gallus	RTSANPLLLKSADKEAAPPPEEC C LQLLSRATQVFREYILQDLAKEEIQQRVKLLWGQ	578
Mus musculus	KRKQLEDLN C REERKSLREMAERLADKYEEAKEKQEDIMNRMKKVLHSFHAQLPVLSDS	658
Rattus norvegicus	KRKQLEDLN C REERKSLREMAERLADKYEEAKEKQEDIMNRMKKVLHSFHTQLPVLSDS	658
Homo sapiens	KKKQLEDLSY C REERKSLREMAERLADKYEEAKEKQEDIMNRMKKLLHSFHELPVLSDS	657
Bos aurus	KKKQLEDLN C REERKSLREMAERLADKYEEAKEKQEDIMNRMKKVLHSFSQLPVLSDS	658
Gallus gallus	KKKQLEDLN C REEKKSLREMAERLADKYEEAKEKQEDIMNRMKKVLRSFSQLPVISDS	638
Mus musculus	ERDMKKELQLIPDQLRHLGNNAIKQVTMKKDYQQRKMEKVLPSPQKPTITLSAYQRKC C IQS1	718
Rattus norvegicus	ERDMKKELQLIPDQLRHLGNNAIKQVTMKKDYQQRKMEKVLPSPQKPTITLSAYQRKC C IQS1	718
Homo sapiens	ERDMKKELQLIPDQLRHLGNNAIKQVTMKKDYQQQKMEKVLPSPQKPTIILSAYQRKC C IQS1	717
Bos aurus	ERDMKKELQLIPDQLRHLGNNAIKQVTMKKDYQQRKMEKVLPSPQKPTITLSAYQRKC C IQS1	718
Gallus gallus	ERDMKKELQTIHDQIQLQHLSNAIRQVKMKKEYQQKKMEKGISPRKPSITLSAYQS C IQT1	698
Mus musculus	LKEEGEHIREMVKQINDIRNHVTF	742
Rattus norvegicus	LKEEGEHIREMVKQINDIRNHVNF	742
Homo sapiens	LKEEGEHIREMVKQINDIRNHVNF	741
Bos aurus	LKEEGEHIREMVKQINDIRNHVNF	742
Gallus gallus	LKEEGERIREMVKQINDIRGHVNF	722