

Global and local alignments

Needleman-Wunsch algorithm, mathematical form

$$\mathbf{M}(0, j) = j \times p \quad \text{first row, } p = \text{gap penalty}$$

$$\mathbf{M}(i, 0) = i \times p \quad \text{first column}$$

$$\mathbf{M}(i, j) = \max \left(\begin{array}{c} \mathbf{M}(i-1, j) + p \\ \mathbf{M}(i, j-1) + p \\ \mathbf{M}(i-1, j-1) + s(a_i, b_j) \end{array} \right) \begin{array}{l} \text{top} \\ \text{left} \\ \text{diagonal} \end{array}$$

$s(a_i, b_j)$ = match/mismatch score for sites i and j
in sequences a and b

Needleman-Wunsch in Python

```
# Fill in the first row
for j in range(0, n + 1):
    score[0][j] = gap_penalty * j

# Fill in the first column
for i in range(0, m + 1):
    score[i][0] = gap_penalty * i

# Fill in all other values in the score matrix
for i in range(1, m + 1):          # loop over all rows
    for j in range(1, n + 1):      # loop over all columns
        # Calculate the score by checking the top, left, and diagonal cells
        insert = score[i][j - 1] + gap_penalty      # top
        delete = score[i - 1][j] + gap_penalty      # left
        match = score[i - 1][j - 1] + \            # diagonal
            match_score(seq1[j-1], seq2[i-1])

        # Record the maximum score from the three possible ones
        score[i][j] = max(match, delete, insert)
```

Global vs. local alignments

- Global: align all nucleotides
- Local: align subsequences with best score

Align these sequences: GCAT, GCT
(match = 1, mismatch = -1, gap = -1)

global alignment:

GCAT

GC-T

local alignment:

?

We can make local alignments using the Smith-Waterman algorithm

Like Needleman-Wunsch, with 2 changes:

- Don't allow negative scores, set them to 0
- Backtrack from cell with highest score, stop at 0

We can make local alignments using the Smith-Waterman algorithm

Like Needleman-Wunsch, with 2 changes:

- Don't allow negative scores, set them to 0
- Backtrack from cell with highest score, stop at 0

Needleman-Wunsch

	–	G	C	A	T
–	0	-1	-2	-3	-4
G	-1	1	0	-1	-2
C	-2	0	2	1	0
T	-3	-1	1	1	2

GCAT

GC–T

We can make local alignments using the Smith-Waterman algorithm

Like Needleman-Wunsch, with 2 changes:

- Don't allow negative scores, set them to 0
- Backtrack from cell with highest score, stop at 0

Needleman-Wunsch

	–	G	C	A	T
–	0	-1	-2	-3	-4
G	-1	1	0	-1	-2
C	-2	0	2	1	0
T	-3	-1	1	1	2

G C A T

G C – T

Smith-Waterman

	–	G	C	A	T
–	0	0	0	0	0
G	0	1	0	0	0
C	0	0	2	1	0
T	0	0	1	1	2

G C

G C

Smith-Waterman algorithm, mathematical form

$$\mathbf{M}(0, j) = 0$$

first row

$$\mathbf{M}(i, 0) = 0$$

first column

$$\mathbf{M}(i, j) = \max \left(\begin{array}{c} 0 \\ \mathbf{M}(i-1, j) + p \\ \mathbf{M}(i, j-1) + p \\ \mathbf{M}(i-1, j-1) + s(a_i, b_j) \end{array} \right)$$

top
left
diagonal

$s(a_i, b_j)$ = match/mismatch score for sites i and j
in sequences a and b

BLAST

(Basic Local Alignment Search Tool)

BLAST is the primary method to find sequences in modern sequence data bases



Stephen Altschul

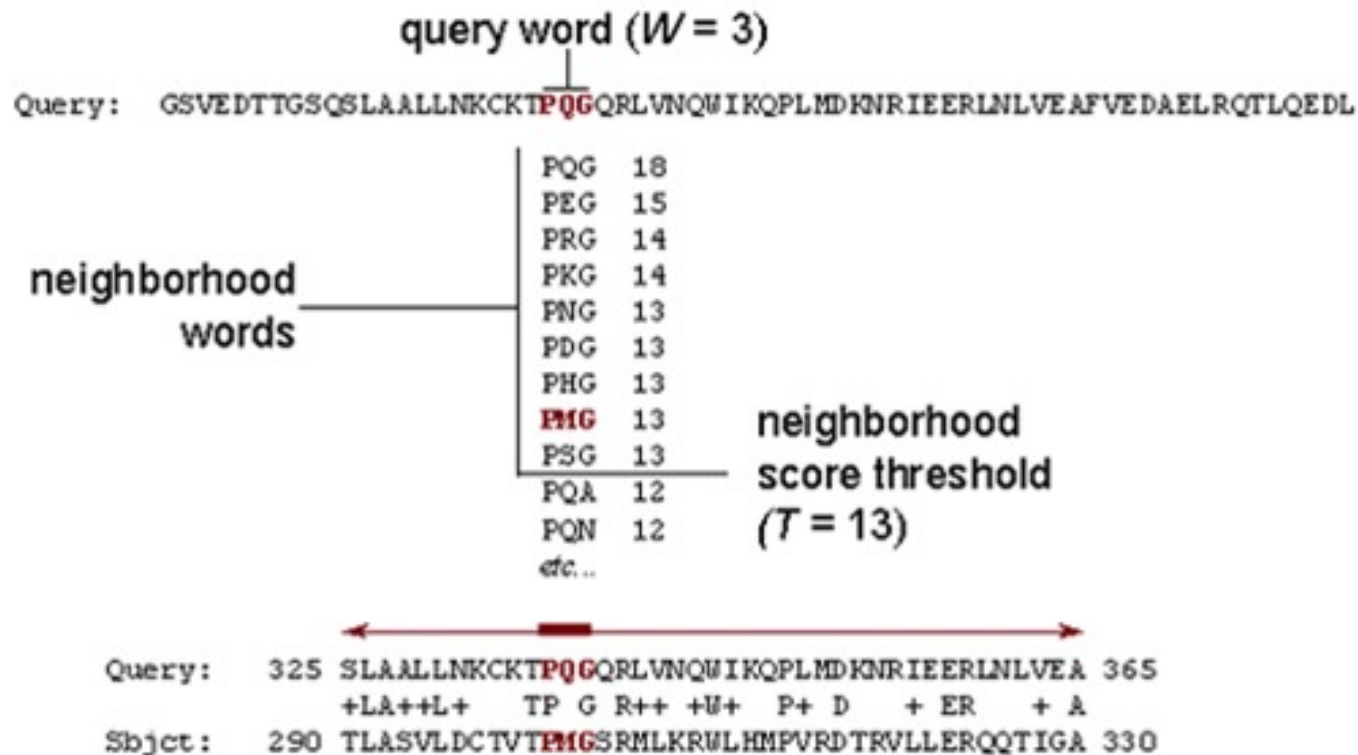
NCBI, NLM, NIH

[Bioinformatics](#)

Verified email at nih.gov

Title	1–20	Cited by	Year
Basic local alignment search tool	SF Altschul, W Gish, W Miller, EW Myers, DJ Lipman Journal of molecular biology 215 (3), 403-410	54882	1990
Gapped BLAST and PSI-BLAST: a new generation of protein database search programs	SF Altschul, TL Madden, AA Schäffer, J Zhang, Z Zhang, W Miller, ... Nucleic acids research 25 (17), 3389-3402	54781	1997
Identification of FAP locus genes from chromosome 5q21.	KW Kinzler, MC Nilbert, LK Su, B Vogelstein, TM Bryan, DB Levy, ... Science (New York, NY) 253 (5020), 661	2060	1991
Detecting subtle sequence signals: a Gibbs sampling strategy for multiple alignment	CE Lawrence, SF Altschul, MS Boguski, JS Liu, AF Neuwald, JC Wootton	1963	1993

The BLAST Search Algorithm



High-scoring Segment Pair (HSP)

Primary BLAST quality metric: E value

The **Expectation value** or **E value** represents the number of different alignments with scores equivalent to or better than the one observed that are expected to occur in a database search by chance.

The lower the E value, the more significant the score and the alignment.

Anatomy of a BLAST result

glycoprotein precursor [Junin virus]

Sequence ID: [gb|ABI51595.1|](#) Length: 485 Number of Matches: 1

Range 1: 1 to 241 [GenPept](#) [Graphics](#)

▼ Next Match ▲ Previous Match

Score		Expect Method		Identities	Positives	Gaps	
278 bits(710)		1e-86	Compositional matrix adjust.	137/252(54%)	168/252(66%)	11/252(4%)	
Query	1	MGQLISFFQEIPVFLQEALNIALVAVSLIAVIKGIINLYKSGLFQFIFFLFLAGRSCSDG					60
		MGQ ISF QEIP FLQEALNIALVAVSLIA+IKGI+NLYKSGLFQF FL LAGRSC++					
Sbjct	1	MGQFISFMQEIPTFLQEALNIALVAVSLIAIIKGIIVNLYKSGLFQFFVFLALAGRSCTEE					60
Query	61	TFKIGLHTEFQSVTFTMQRLLANHSNELPSLCMLNNSFYMKGGANIFLIRVSDVSVLMK					120
		FKIGLHTEFQ+V+F+M L +N+ ++LP LC LN S Y+KGG F+I D++VL+					
Sbjct	61	AFKIGLHTEFQTVSFSMVGLFSNNPHDLPLLCTLNKSHLYIKGGNASFMISFDDIAVLLP					120
Query	121	EYDVSVYEPEDLGNCNLNKSDSSWAIHWFSIALGHDWLMDPPMLCRNKTKEGSNIQFNIS					180
		+YDV + P D+ C D W WF A+GHDW +DPP LCRN+TK EG Q N S					
Sbjct	121	QYDVVIQHPADMSWCSKSDDQIWLSQWFMNAVGHDWHLDPFPLCRNRTKTEGFIFQVNTS					180
Query	181	KADESRVYGKKIRNGMRHLFRGFYDPCEEGKVCYVTINQCGDPSSFEYCGTNYLSKCQFD					240
		K + Y KK + GM HL+R + D C GK+C + P+S+ +C D					
Sbjct	181	KTGVNENYAKKFKTGMHHLYREYPDSC LNGKLCLMK----AQPTSWPL-----QCPLD					229
Query	241	HVNTLHFLVRSK 252					
		HVNTLHFL R K					
Sbjct	230	HVNTLHFLTRGK 241					

Anatomy of a BLAST result

glycoprotein precursor [Junin virus]

Sequence ID: [gb|ABI51595.1|](#) Length: 485 Number of Matches: 1

sequence we found
(subject sequence)

Range 1: 1 to 241 [GenPept](#) [Graphics](#)

Score		Expect Method		Identities	Positives	Gaps	
278 bits(710)		1e-86	Compositional matrix adjust.	137/252(54%)	168/252(66%)	11/252(4%)	
Query	1	MGQLISFFQEIPVFLQEALNIALVAVSLIAVIKGIINLYKSGLFQFIFFFLFLAGRSCSDG					60
		MGQ ISF QEIP FLQEALNIALVAVSLIA+IKGI+NLYKSGLFQF FL LAGRSC++					
Sbjct	1	MGQFISFMQEIPTFLQEALNIALVAVSLIAIIKGIIVNLYKSGLFQFFVFLALAGRSCTEE					60
Query	61	TFKIGLHTEFQSVTFTMQRLLANHSNELPSLCMLNNSFYMKGGANIFLIRVSDVSVLMK					120
		FKIGLHTEFQ+V+F+M L +N+ ++LP LC LN S Y+KGG F+I D++VL+					
Sbjct	61	AFKIGLHTEFQTVSFSMVGLFSNNPHDLPLLCTLNKSHLYIKGGNASFMISFDDIAVLLP					120
Query	121	EYDVSVYEPEDLGNCNLNKSDSSWAIHWFSIALGHDWLMDPPMLCRNKTKEGSNIQFNIS					180
		+YDV + P D+ C D W WF A+GHDW +DPP LCRN+TK EG Q N S					
Sbjct	121	QYDVVIQHPADMSWCSKSDDQIWLSQWFMNAVGHDWHLDPFPLCRNRTKTEGFIFQVNTS					180
Query	181	KADES RVYGKKIRNGMRHLFRGFYDPCEEKVCYVTINQCGDPSSF EYCGTNYLSKCQFD					240
		K + Y KK + GM HL+R + D C GK+C + P+S+ +C D					
Sbjct	181	KTGVNENYAKKFKTGMHHLYREYPDSC L NGKLCLMK-----AQPTSWPL-----QCPLD					229
Query	241	HVNTLHFLVRSK 252					
		HVNTLHFL R K					
Sbjct	230	HVNTLHFLTRGK 241					

Anatomy of a BLAST result

glycoprotein precursor [Junin virus]

Sequence ID: [gb|ABI51595.1|](#) Length: 485 Number of Matches: 1

Range 1: 1 to 241 [GenPept](#) [Graphics](#)

▼ Next Match ▲ Previous Match

Score		Expect	Method		Identities	Positives	Gaps
278 bits(710)		1e-86	E value		matrix adjust.	137/252(54%)	168/252(66%) 11/252(4%)
Query	1	MGQLISFFQEIPVFLQEALNIALVAVSLIAVIKGIINLYKSGLFQFIFFLFLAGRSCSDG					60
		MGQ ISF QEIP FLQEALNIALVAVSLIA+IKGI+NLYKSGLFQF FL LAGRSC++					
Sbjct	1	MGQFISFMQEIPTFLQEALNIALVAVSLIAIIKGIIVNLYKSGLFQFFVFLALAGRSCTEE					60
Query	61	TFKIGLHTEFQSVTFTMQRLLANHSNELPSLCMLNNSFYMKGGANIFLIRVSDVSVLMK					120
		FKIGLHTEFQ+V+F+M L +N+ ++LP LC LN S Y+KGG F+I D++VL+					
Sbjct	61	AFKIGLHTEFQTVSFSMVGLFSNNPHDLPLLCTLNKSHLYIKGGNASFMISFDDIAVLLP					120
Query	121	EYDVSVYEPEDLGNCNLNKSDSSWAIHWFSIALGHDWLMDPPMLCRNKTKEGSNIQFNIS					180
		+YDV + P D+ C D W WF A+GHDW +DPP LCRN+TK EG Q N S					
Sbjct	121	QYDVVIQHPADMSWCSKSDDQIWLSQWFMNAVGHDWHLDPFLCRNRTKTEGFIFQVNTS					180
Query	181	KADES RVYGKKIRNGMRHLFRGFYDPCEEGKVCYVTINQCGDPSSF EYCGTNYLSKCQFD					240
		K + Y KK + GM HL+R + D C GK+C + P+S+ +C D					
Sbjct	181	KTGVNENYAKKFKTGMHHLYREYPDSC LNGKLCLMK----AQPTSWPL-----QCPLD					229
Query	241	HVNTLHFLVRSK 252					
		HVNTLHFL R K					
Sbjct	230	HVNTLHFLTRGK 241					

Anatomy of a BLAST result

glycoprotein precursor [Junin virus]

Sequence ID: [gb|ABI51595.1|](#) Length: 485 Number of Matches: 1

Range 1: 1 to 241 [GenPept](#) [Graphics](#)

▼ Next Match ▲ Previous Match

		Score	Expect	Method	Identities	Positives	Gaps
		278 bits(710)	1e-86	Compositional matrix adjust.	137/252(54%)	168/252(66%)	11/252(4%)
Query	1	MGQLISFFQEIPVFLQEALNIALVAVSLIAV					
		MGQ ISF QEIP FLQEALNIALVAVSLIA+ IKGI+NLYKSGLFQF FL LAGRSC++					
Sbjct	1	MGQFISFMQEIPTFLQEALNIALVAVSLIAI IKGI+NLYKSGLFQF FL LAGRSC++					
Query	61	TFKIGLHTEFQSVTFTMQRLLANHSNELPSI CMLNNSFYMKGGANIFLIRVSDVSVLMK					
		FKIGLHTEFQ+V+F+M L +N+ ++LP ICGISFQFEEVELALAGDSCTF					
Sbjct	61	AFKIGLHTEFQTVSFSMVGLFSNNPHDLPLLCTLNKSHLYIKGGNASFMISFDDI AVL LP					
Query	121	EYDVSVYEPEDLGNCNLNKSDSSWAIHWFSIALGHDWLMDPPMLCRNKTKEGSNIQFNIS					
		+YDV + P D+ C D W WF A+GHDW +DPP LCRN+TK EG Q N S					
Sbjct	121	QYDVVIQHPADMSWCSKSDDQIWLSQWFMNAVGHDWHLDP PFLCRNRTKTEGFIFQVNTS					
Query	181	KADES RVYGKKIRNGMRHLFRGFYDPCEEGKVCYVTINQCGDPSSF EYCGTNYLSKCQFD					
		K + Y KK + GM HL+R + D C GK+C + P+S+ +C D					
Sbjct	181	KTGVNENYAKKFKTGMHHLYREYPDSC L NGKLCLMK----AQPTSWPL-----QCPLD					
Query	241	HVNTLHFLVRSK 252					
		HVNTLHFL R K					
Sbjct	230	HVNTLHFLTRGK 241					

number and % of exact
matches, near matches,
and no matches

Anatomy of a BLAST result

glycoprotein precursor [Junin virus]

Sequence ID: [gb|ABI51595.1|](#) Length: 485 Number of Matches: 1

Range 1: 1 to 241 [GenPept](#) [Graphics](#)

▼ Next Match ▲ Previous Match

Score	Expect	Method	Identities	Positives	Gaps
278 bits(710)	1e-86	Compositional matrix adjust.	137/252(54%)	168/252(66%)	11/252(4%)
Query	1	MGQLISFFQEIPVFLQEALNIALVAVSLIAV	number and % of exact matches, near matches, and no matches		
		MGQ ISF QEIP FLQEALNIALVAVSLIA+ IKGI+NLYKSGLFQF FL LAGRSC++			
Sbjct	1	MGQFISFMQEIPTFLQEALNIALVAVSLIAI IKGI+NLYKSGLFQF FL LAGRSC++			
Query	61	TFKIGLHTEFQSVTFTMQRLLANHSNELPSI CMLNNSFYMKGGANIFLIRVSDVSVLMK	120		
		FKIGLHTEFQ+V+F+M L +N+ ++LP ICGD++VL+			
Sbjct	61	AFKIGLHTEFQTVSFSMVGLFSNNPHDLPLLCTLNKSHLYIKGGNASFMISFDDIAVLLP	120		
Query	121	EYDVSVYEPEDLGNCNLNKSDSSWAIHWFSIALGHDWLMDPPMLCRNKTKEGSNIQFNIS	180		
		+YDV + P D+ C D W WF A+GHDW +DPP LCRN+TK EG Q N S			
Sbjct	121	QYDVVIQHPADMSWCSKSDDQIWLSQWFMNAVGHDWHLDPFPLCRNRTKTEGFIFQVNTS	180		
Query	181	KADES RVYGKKIRNGMRHLFRGFYDPCEEGKVCYVTINQCGDPSSF EYCGTNYLSKCQFD	240		
		K + Y KK + GM HL+R + D C GK+C + P+S+ +C D			
Sbjct	181	KTGVNENYAKKFKTGMMNLYREYPDSCNLNGKLCLMK----AQPTSWPL-----QCPLD	229		
Query	241	HVNTLHFLVRSK	252	exact match	
		HVNTLHFL R K			
Sbjct	230	HVNTLHFLTRGK	241		

Anatomy of a BLAST result

glycoprotein precursor [Junin virus]

Sequence ID: [gb|ABI51595.1|](#) Length: 485 Number of Matches: 1

Range 1: 1 to 241 [GenPept](#) [Graphics](#)

▼ Next Match ▲ Previous Match

Score	Expect	Method	Identities	Positives	Gaps
278 bits(710)	1e-86	Compositional matrix adjust.	137/252(54%)	168/252(66%)	11/252(4%)
Query	1	MGQLISFFQEIPVFLQEALNIALVAVSLIAV	number and % of exact matches, near matches, and no matches		
		MGQ ISF QEIP FLQEALNIALVAVSLIA+ IKGI+NLYKSGLFQF FL LAGRSC++			
Sbjct	1	MGQFISFMQEIPTFLQEALNIALVAVSLIAI IKGI+NLYKSGLFQFQEVEVETALACPSCTIE			
Query	61	TFKIGLHTEFQSVTFTMQRLLANHSNELPSI	CMLNNSFYVMKGGANFTLRVSDVSVLMK 120		
		FKIGLHTEFQ+V+F+M L +N+ ++LP I	D++VL+ 120		
Sbjct	61	AFKIGLHTEFQTVSFSMVGLFSNNPHDLPLL	CTLNKSRLYIKGGNASFMISFDDIAVLLP 120		
Query	121	EYDVSVYEPEDLGNCNLNKSDSSWAIHWFSIALGHDWLMDPPMLCRNKTKEGSNIQFNIS	180		
		+YDV + P D+ C D W WF A+GHDW +DPP LCRN+TK EG Q N S			
Sbjct	121	QYDVVIQHPADMSWCSKSDDQIWLSQWFMNAVGHDWHLDPFLCRNRTKTEGFIFQVNTS	180		
Query	181	KADES RVYGKKIRNGMRHLFRGFYDPCEEGKVCYVTINQCGDPSSFEYCGTNYLSKCQFD	240		
		K + Y KK + GM HL+R + D C GK+C + P+S+ +C D			
Sbjct	181	KTGVNENYAKKFKTGMHHLRYEYPDSC LNKGLCLMK----	AQPTSWPL-----QCPLD 229		
Query	241	HVNTLHFLVRSK 252	near match (positive)		
		HVNTLHFL R K			
Sbjct	230	HVNTLHFLTRGK 241			

number and % of exact
matches, near matches,
and no matches

near match (positive)

Anatomy of a BLAST result

glycoprotein precursor [Junin virus]

Sequence ID: [gb|ABI51595.1|](#) Length: 485 Number of Matches: 1

Range 1: 1 to 241 [GenPept](#) [Graphics](#)

▼ Next Match ▲ Previous Match

Score	Expect	Method	Identities	Positives	Gaps
278 bits(710)	1e-86	Compositional matrix adjust.	137/252(54%)	168/252(66%)	11/252(4%)
Query	1	MGQLISFFQEIPVFLQEALNIALVAVSLIAV	number and % of exact matches, near matches, and no matches		
		MGQ ISF QEIP FLQEALNIALVAVSLIA+			
Sbjct	1	MGQFISFMQEIPTFLQEALNIALVAVSLIAI			
Query	61	TFKIGLHTEFQSVTFTMQRLLANHSNELPSI			
		FKIGLHTEFQ+V+F+M L +N+ ++LP I			
Sbjct	61	AFKIGLHTEFQTVSFSMVGLFSNNPHDLPLL			
Query	121	EYDVSVYEPEDLGNCNLNKSDSSWAIHWFSIALGHDWLMDPPMLCRNKTKEGSNIQFNIS			
		+YDV + P D+ C D W WF A+GHDW +DPP LCRN+TK EG Q N S			
Sbjct	121	QYDVVIQHPADMSWCSKSDDQIWLSQWFMNAVGHDWHLDPFPLCRNRTKTEGFIFQVNTS			
Query	181	KADES RVYGKKIRNGMRHLFRGFYDPCEE GKVCYVTINQCGDPSSF EYCGTNYLSKCQFD			
		K + Y KK + GM HL+R + D C GK+C + P+S+ +C D			
Sbjct	181	KTGVNENYAKKFKTGMHHLRYYPDSC LNKGLCLMK----			
Query	241	HVNTLHFLVRSK	252	no match (gap)	
		HVNTLHFL R K			
Sbjct	230	HVNTLHFLTRGK	241		

Anatomy of a BLAST result

glycoprotein precursor [Junin virus]

Sequence ID: [gb|ABI51595.1|](#) Length: 485 Number of Matches: 1

Range 1: 1 to 241 [GenPept](#) [Graphics](#)

▼ Next Match ▲ Previous Match

Score		Expect Method		Identities	Positives	Gaps	
278 bits(710)		1e-86	Compositional matrix adjust.	137/252(54%)	168/252(66%)	11/252(4%)	
Query	1	MGQLISFFQEIPVFLQEALNIALVAVSLIAVIKGIINLYKSGLFQFIFFLFLAGRSCSDG					60
		MGQ ISF QEIP FLQEALNIALVAVSLIA+IKGI+NLYKSGLFQF FL LAGRSC++					
Sbjct	1	MGQFISFMQEIPTFLQEALNIALVAVSLIAIIKGIIVNLYKSGLFQFFVFLALAGRSCTEE					60
Query	61	TFKIGLHTEFQSVTFTMQRLLANHSNELPSLCMLNNSFYMKGGANIFLIRVSDVSVLMK					120
		FKIGLHTEFQ+V+F+M L +N+ ++LP LC LN S Y+KGG F+I D++VL+					
Sbjct	61	AFKIGLHTEFQTVSFSMVGLFSNNPHDLPLLCTLNKSHLYIKGGNASFMISFDDIAVLLP					120
Query	121	EYDVSVYEPEDLGNCNLNKSDSSWAIHWFSIALGHDWLMDPPMLCRNKTKEGSNIQFNIS					180
		+YDV + P D+ C D W WF A+GHDW +DPP LCRN+TK EG Q N S					
Sbjct	121	QYDVVIQHPADMSWCSKSDDQIWLSQWFMNAVGHDWHLDPFPLCRNRTKTEGFIFQVNTS					180
Query	181	KADES RVYGKKIRNGMRHLFRGFYDPCEEGKVCYVTINQCGDPSSFEYCGTNYLSKCQFD					240
		K + Y KK + GM HL+R + D C GK+C + P+S+ +C D					
Sbjct	181	KTGVNENYAKKFKTGMHHLYREYPDSC LNGKLCLMK----AQPTSWPL-----QCPLD					229
Query	241	HVNTLHFLVRSK		252			
		HVNTLHFL R K					
Sbjct	230	HVNTLHFLTRGK		241			