

The Synonymous Mutations In Cancer database (SynMICdb) is a curated database of synonymous mutations in cancer. SynMICdb allows biologists to easily extract and download synonymous mutations in cancer as well as orthogonal data using multiple search options. It also integrates the predicted impact of synonymous mutations on structural changes in RNA using structural prediction algorithms.

Several independent search criteria are available in SynMICdb such as the gene name, the genomic coordinates, the position of the mutations within the coding sequence (CDS), their evolutionary conservation, the organ system, organ and tumor type, their link to cancer (Cancer Gene Census) or the SynMICdb score. Each search option is described in detail below.

Search by Gene

This feature allows the user to search for synonymous mutations present in a gene of interest using one of the following nomenclatures (Figure 1):

- 1. HGNC gene symbol
- 2. Gene name
- 3. ENSEMBLID

Alias names for genes (P53 for TP53) are allowed and the search is case-insensitive.

Synonymous Mutations In	Cancer database	UNIVERSITATS KLINIKUM TO TOTATIONAL TO A CONSTITUTION TO TOTATIONAL TO A CONSTITUTION TO TOTATIONAL TO A CONSTITUTION TO A CONSTITUTION OF THE ACCOUNT OF TH
A Home	Search by Gene	
Q Search by Gene	Gene	
Search by Position in CDS	e.g., TP53 or ENST00000288602	
➡ Search by Region	Submit Reset	
🛉 Search by Organ	Download Table Sownload Full Results	
Advanced Search		
? About		

Figure 1. Search option "Search by Gene".

For example, Figure 2 shows the results page for the gene *KRAS*. The summary information in Cancer Gene Census¹ for the gene is shown. The link to Genecards² for the gene is also provided.

¹ http://cancer.sanger.ac.uk/census/

A Home	Search bu (-											
Q Search by Gene	Gene	bene											
 Search by Position in CDS Search by Region Search by Organ Advanced Search About 	eg, TP3 or FASTANO	IS is summary iristen rat sarcoma 2 vi 45 12:23289795-25245384 K-RAS, RASK2, K-RAS2B, RRA	ral oncogene ho	molog SZA, K-RAS4A, KRAS	2, K1-RA5, N53, PI	1116, 3845							
	Show 10 0 entries Mutation 10	Gene Transcript ID	Mutation	Mutation Genome Position	Average Mutation Load	Alternative Events	SNP	Conservation	Structure Change Score (remuRNA)	Structure Change Significance (RNAsnp)	SynMiCdb Score	Search: Signature- normalized Frequency	Frequency
	@ C05M253757	KRAS ENST000003119	86 c.180T>A	12-25227344- 25227344	191	cassetteExon	n	1	1	0.811	6.6737	5.75	6
	 COSM3753105 	KRAS ENST000003119	6 c.519T>C	12:25209843- 25205643	1851		У	0.999	0	0.997	4.0511	2.63	3
	e COSM1159170	KRAS ENST000003119	16 c.367%G	12-25245349- 25245349	н		х	1	4	0.891	5.6839	1.95	2
	e COSM1605974	KRAS ENSTODODO3119	6 c.30A+C	12-25245355- 25245355	129		'n	i -	5	0.014	6.091	1.95	2
	e COSM523	KRAS ENST000003119	16 c.36T-C	12.25245345 25245349	61		n	1	1	0.901	6.0684	1.75	2
	e CO5M1162237	KRAS ENSTOLOOOJ119	96 c.177A>T	12-25227347- 25227347	44	cassetteExon	n	i :	5	0.0964	5.8608	0.96	1
	# COSM1168050	KRAS ENSTODODOJ119	6 c.1807>C	12:25227344- 25227344	167	cassettellixon	у	1	1	0.999	3.2775	0.88	1

Figure 2. Example of result page for "Search by Gene" in SynMICdb.

The result columns provide the following information:

- **Mutation ID**: Unique identifier of each mutation (as present in COSMIC database).
- Gene Name: Abbreviated name of the gene.
- **Transcript ID**: ENSEMBL transcript ID for the corresponding mutation.
- **Mutation nt**: Number and nucleotide change of mutation: e.g. c.36T>G indicates a change of coding nucleotide number 36 from T to G.
- **Mutation genome position**: Genomic coordinates of each respective mutation in human genome assembly GRCh38 (chromosome:start-end).
- SynMICdb Score: The SynMICdb score shall reflect the probable impact of the synonymous mutation and is based on the mutation frequency, the probability due to mutational bias by mutation signatures, the average mutation load of the tumors with this mutation, the evolutionary conservation, the listing of the affected gene as cancer gene in the Cancer Gene Census, the listing of the mutation in the SNPdb, the FATHMM-MKL score, the CADD score and the predicted impact on RNA secondary structure. The score ranges from -4 to +12 and high numbers indicate a higher likelihood of a functional impact of the synonymous mutation. The distribution of the SynMICdb score is illustrated by the following table and violin plot:

	5
<u>Quantile</u>	SynMICdb Score
top 50%	0.89
top 25%	1.83
top 10%	2.70
top 1%	4.38
top 0.1%	5.83
top 0.01%	8.08



Thus, a SynMICdb score of above 4.38 indicates that the synonymous mutation is among the top 1% of synonymous mutations in this study.

- **Average Mutation Load**: This column indicates the average number of mutations found in the genome-wide analysis of the tumor samples harboring this specific mutation.
- Alternative Events: This column provides information about alternative events as indicated by GENCODE like alternative splicing and other events that result in more than a single transcript from the same gene characterized by the UCSC genome browser³.
- **SNP**: This column provides information whether this mutation has been listed as a Single Nucleotide Polymorphism (SNP) in the SNP database. y = yes, n = no.
- **Conservation**: This column lists the conservation scores of human vs. 99 vertebrate genomes (PhastCons100). The score ranges between 0 to 1 with 1 indicating the highest conservation levels among the 100 species.
- Structure Change Score (remuRNA): This column depicts scores for structural change predictions for the respective mutation calculated by remuRNA. The score ranges from 5 to +20 and high numbers indicate a higher likelihood of a structural change caused by the mutation.
- **Structure Change Significance (RNAsnp)**: This column has *p-values* for significant structural change predictions for the respective mutation calculated by RNAsnp p0. The p-value ranges from 0 to 1 and low numbers indicate a higher likelihood of a structural change caused by the mutation.
- **Exon Type**: This column displays information about the exon type (1 = first exon, 2 = internal exon, 3 = last exon, 4 = monoexonic transcript).
- **Distance to Closest Exon Bundary**: This column indicates the distance to the closest exon boundary for each synonymous mutation in nucleotides.
- Any ESE/ESS Change: This column lists the gains and losses of exonic splicing enhancer (ESE) or exonic splicing silencer (ESS) motifs according to RegRNA 2.0 or SpliceAidF. Details for this analysis for ESEs and ESSs separately for the two prediction algorithms are provided in the full data table upon "Download Full Results". Please note that 23 motifs were assigned "ESE" as well as "ESS" properties in SpliceAidF and hence are listed separately as "ESE & ESS".
- **Signature-normalized Frequency**: In this column, the Frequency of the mutation has been corrected for the mutation bias due to mutational signatures frequently observed in cancer thus, the Frequency has been multiplied with (1 p) with p indicating the probability of the nucleotide change according to the most prevalent mutational signature in cancer.
- **Frequency**: This column shows the recurrence level of each mutation. The number in this column represents the total number of tumor samples in which the respective mutation was found.

By default, the results are grouped by Mutation ID and sorted by their frequency. For each Mutation ID, only one line is given in this view.

Detailed information for each sample can be viewed by clicking on the \oplus icon.

Figure 3 shows an example of sample information for mutation ID COSM253757.



Figure 3. Detailed sample information for all samples having the Mutation ID COSM253757 in the table of results.

Download Options

The user can download the results using one of the following two options:

- **Download Table**: This button allows the user to download the displayed results as a csv file.
- Download Full Results: This button allows user to download the displayed results plus additional information like affected codon and amino acid, the mutation load of each affected sample, the position of the mutation within the CDS as well as the classification by the Cancer Gene Census (CGC).

Search by Position in CDS

This option allows the user to search for mutations on the basis of their location within the coding sequence (CDS) of genes (e.g. Figure 4 shows mutations present within the first 20% of the CDS). This facilitates the user to study synonymous mutation within a specific region of interest, for example towards the 5'-end of the coding region within the translation initiation and ramping region.

Home Q Search by Gene C Search by Position in CDS C Search by Region	Search by	Positio	on in CDS	D5 3'											
T Search by Organ	Total number of	mutations:	119478											Searchi	
? About	Mutation	Gene Name	Transcript ID	Mutation nt	Mutation Genome Position	Average Mutation Load	Alternative Events	SNP	Conservation	Structure Change Score (remuRNA)	Structure Change Significance (RNAsnp)	SynMICdb Score	Position in CDS	Signature- normalized Frequency	Frequency
	@ COSM245968	NCOAS	ENST00000374796	c.807G=A	20:34757941- 34757941	157		У	0.425	5	0.184	1.5079	0.13	20.44	63
	@ C05M248220	UPF3A	EN5T00000375299	c.271C>T	13:114282084- 114282084	105	cassetteExon	п	1	1	0,363	3.9361	0.19	11.68	36
	© CO5M479363	PLINAL	EN5T00000393409	c.1087>G	3:126988701- 126988701	172		У	0.001	5	0.0214	4.3823	0.02	24.36	25
	e COSM3807493	C10orf108	ENST00000441152	c.75G~A	10:650297- 650297	3540		у	0.006	4	0.321		0,11	7.46	23
	@ COSM442074	HSP01	ENST00000388968	c.72G+A	2:197498777- 197498777	102		0	0.902	0	0.72	3,6048	0.04	6.17	19
	© COSM1135783	RP11- 231C14.2	ENST00000524087	C81C>7	16-29403722- 29403722	179		•	0.6	3	0.0317	2.3721	0.02	5.84	38
	@ COSM121768	RPL34	ENST00000394665	c.2485T	4:108621983- 108621983	173	altPromoter	<u>e</u> .	0	4	0.978	5.2158	0.07	17.25	н
	@ COSM290337	RIMS2	ENST00000436393	c.603T>G	8:103885868 103885868	299		n	0.94	4	0.163	6.3337	0.15	15.59	16
	e COSM3749693	TMEN131	ENST00000186436	c.132C+A	2:97995531- 97995531	316		у	0.711	5	0.697	4.2617	0.02	14.24	36

Figure 4. Example of results page for "Search by Position in CDS".

Search by Region

This option allows the user to search for mutations present within a region defined by genomic coordinates of human genome assembly GRChg38 (note: chromosome 23 = X, 24 = Y and 25 = M). For example, Figure 5 shows the list of mutations present in chromosome 5 region 50000-500000.

A Home	Se	arch by F	Region												
	Chro	mesome				NO.	Dou (Genome asse	imply version: GRUP	(10)						
G Search by Position in CDS	5			•			0000-500000								
➡ Search by Region	So Show	smit Reset												Search:	
Search by Organ		Mutation ID	Gene Name	Transcript ID	Mutation nt	Mutation Genome Position	Average Mutation Load	Alternative Events	SNP	Conservation 1	Structure Change Score (remuRNA)	Structure Change Significance (RKAsnp)	SynMICdb Score	Signature- normalized Frequency	Frequency
Advanced Search	.0	CO5M4159883	SLC9A3	EN5T00000264938	€.1443G>C	5:482071-482071	1177		y	0	10	0.338	1.9916	3.91	4
? About		CO5M2156476	PLEXHG48	ENST00000283426	c.2304G-A	5:163444-163444	72		0	0.029	0	0.928	0.6626	0.97	3
		C05M290516	PLEKHG48	ENST00000283426	c.3540C>T	5:182047-182047	258		n	0.11	1	0.723	0.3317	0.97	3
		COSM3661771	LRRC14B	ENST00000328278	c.516C>T	5:192018-192018	49		n	0	3	0.775	1.8718	0.97	3
		COSM1064864	PLEXH648	ENST0000283426	t.1178G>A	5:156103-156103	574		'n	0.001	3	0.855	0.1348	0.65	2
		CO5M1065397	PLEKHG4B	ENST00000283426	c.2190C-T	5:163330-163330	9246		0	0.018	1	0.688	-0.9943	0.65	2
		CO5M1065817	PLEXHG4B	ENST00000283426	c.2829C>T	5:171291-171291	2408			0.612	0	1	0.3535	0.65	2
		CO5M1067044	SDHA	ENST00000264932	c.477G>A	5:225903-225903	8210	cassetteExon strangeSplice		0	3	0.276	-1.0929	0.65	2
		CO5M1068370	AHRR	ENST00000316418	c.882C>T	5:427914-427914	279		n	0	1	0.0555	0.1058	0.65	2
		COSMIDGESIE	EXOC3	ENST00000315013	c.1605G-A	5:462259-462259	960		0	0	0	0.706	-0.0671	0.65	2

Figure 5. "Search by Region" using genome coordinates.

Search by Organ

This option allows the user to search for synonymous mutations in cancer on the basis of their site of origin in a hierarchical manner. The user first selects an organ system and then a site and histology of interest. Nine organ systems are listed (as depicted in Figure 6): Cardiovascular System, Digestive System, Endocrine System, Genitourinary System, Integumentary System, Lymphatic System, Musculoskeletal System, Nervous System and Respiratory System.

A Home	Search by Organ System			
Q Search by Gene	Organ System	Site		Histology
A	Cardiovascular System	Blood Vessels	-	Angiosarcoma
Search by Position in CDS	Digestive System			Hemangioblastoma
	Endocrine System			
t Search Synchron	Genitourinary System			
Search by Organ	Integumentary System			
	Lymphatic System			
Advanced Search	Musculoskeletal System			
	Nervous System			
? About	Respiratory System			

Figure 6. "Search by organ" - selection of the organ system of interest.

After selecting the organ system, the user selects first the primary site and optionally the histology of interest. The following example depicts a search and result of synonymous mutations present in the "Digestive System" as organ system following the selection of the "Large Intestine" as primary site (Figure 7) and "Adenocarcinoma" as histology (Figure 8).

Home Q Search by Gene	Search by Organ System	Site	Histology
A	Digestive System 🔹	Large Intestine	Adenocarcinoma
Search by Position in CDS	Submit Reset	Esophagus Gallbladder Large Intestine	Adenoma
Search by Organ		Liver Pancreas	
• Advanced Search	Z Download Table Z Download Full Results	Peritoneum Salivary Gland	
? About		Stomach	

Figure 7. "Search by Organ" - selection of primary site.

 Home Search by Gene 	Search by Organ System	Organ	System			Site					Histo	legy				
G Search by Position in CDS	Digestive System					Large Intestin	ie .		*			lenocarcinoma lenoma				
≓ Search by Region	Submit Reset															
🛊 Search by Organ	Total number of	mutations:	126811													
Q Advanced Search	Show 10 ¢ entrie	15												\$	arch:	
? About	Mutation ID	Gene Name	Transcript ID	Mutation nt	Mutation Genome Position	Average Mutation Load	Alternative Events	SNP	Conservation	Structure Change Score (remuRNA)	Structure Change Significance (RNAsnp)	SynHiCdb Score	Site	Histology	Signature- normalized Frequency	Frequency
	@ C05M3749126	MUC6	ENST00000421673	c.5733G+A	11:1017068- 1017068	199		y	0	3	0.66	1.1992	Large Intestine	Adenocarcinoma	8.76	26
	⊕ C05M3749691	THEM131	ENST00000186436	c.132C+A	2-97995531- 97995531	316		3	0.711	5	0.697	4.2617	Large Intestine	Adenocarcinoma	14.24	16
	@ C05M4290842	C200rf80	ENST00000278882	c.495G>A	20:30398004 30398004	230		У	1	0	0.97	2.1754	Large Intestine	Adenocarcinoma	5.19	15
	@ C05M4290843	FRG18	ENST00000278882_v61	c.495G#A	20:30398004 30398004	230		. X	1	0	0.97	2.1754	Large Intestine	Adenocarcinoma	5.19	15
	@ CO5M3750027	PURB	ENST00000395699	e.3217>6	7.44885028 44885028	541		Y	0.005	1	0.772	3.117	Large Intestine	Adenocarcinoma	12.67	12
	# COSM1025520	C20orf80	ENST00000278882	c.\$226>A	20.30396031 30398031	251		у	1	2	0.987	2.3322	Large Intestine	Adenocarcinoma	4.87	11
	@ C05M1025521	FRG18	ENST00000278882_v61	c.522G>A	20:30398031 30398031	251		y	1	2	0.987	2.3322	Large Intestine	Adenocarcinoma	4.87	11

Figure 8. "Search by Organ" - selection of primary histology and results.

Advanced search

This search option allows the combination of multiple search parameters and offers additional search criteria including Gene Names, Cancer Gene Census genes, Conservation, Location within CDS, SynMICdb Score, Organ System, Site, and Histology of synonymous mutations. Here, users can also perform batch searches by providing a list of up to 100 genes (Figure 9).

Synonymous Mutations In	a Cancer database		UNITY IST CLINICUM	ATS Cerman Cancer Consortium Partner site freiburg
 Home Search by Gene 	Advanced search	Conservation Score	Location within CDS	
Search by Position in CDS	contract in contract the discrete strategy second discrete discrete strategy	· · · · · · · · · · · · · · · · · · ·) COS 37	cos 3'
➡ Search by Region		SynMICdb Score		
t Search by Organ				
Q Advanced Search	Limit to CGC genes			
	Organ System	Site	Histology	
7 About	Digestive System *	Large Intestine -	Adenocarcinoma	
	Submit Reset			
	▲Download Table ▲Download Full Results			

Figure 9. Panel of the "Advanced Search".

Below is an example of search for synonymous mutations that are >80% conserved and only present in the first 30% of the CDS (Figure 10). The user can limit the output to genes listed as cancer genes in the Cancer Gene Census (CGC) database by clicking the "Limit to CGC genes" option.

 Home Q. Search by Gene ⊕ Search by Publish in COS ⇒ Search by Region ₱ Search by Orgon 	Advanc Gene list Prote a fist of g	s	onservation Score	- 13 - 14				COS 9 COS 9									
Q Advanced Search	🗆 Limit to CG	C genes															
? About	Organ System Digestive Sys	Dem	•			s	ite Large Intestine		•			Histolog	y ocarcinoma				
	Submit F Total numb Shew 10 \$	er of nuti entries	ations: 13345												Se	narch:	
	Mutation ID	Gene Name	Transcript ID	Mutation nt	Hutation Genome Position	Average Mutation Load	Alternative Events	SNP	Conservation	Structure Change Score (remuRNA)	Structure Change Significance (RNAsnp)	SynMICdb Score	Site	Histology	Position in CDS	Signature- normalized Frequency	Frequency
	CO5M290337	RIM52	ENST00000436393	c.6037>G	8:103895868- 103885868	299		n	0.94	4	0.163	6.3337	Large Intestine	Adenocarcinoma	0.15	15.59	7
	C05M3750114	PLEC	ENST00000322810	¢.3961T>C	8:143927616- 143927616	134		¥	1	0	0.819	3.7009	Large Intestine	Adenocarcinoma	0.28	7.88	Ť
	CO5M1076231	твр	ENST00000230354	c.2196>A	6:170561955- 170561955	80	retainedintron strangeSplice	У	0.938	4	0.196	2.7091	Large Intestine	Adenocarcinoma	0.22	5.84	6
	CO5M1132306	CXorf38	ENST00005327877	¢.76T>C	23:40647445- 40647445	380	bleedingExon	¥	1	1	0.786	4.2548	Large Intestine	Adenocarcinoma	0.08	7.01	6
	CO5M468769	хрот	ENST00000332707	e.423C>G	12:64419028- 64419028	432			0.954	7	0.37	6.0736	Large Intestine	Adenocarcinoma	0.15	10.75	6
	CO5M1442363	TBP	ENST00000230354	c.234G×A	6:170561970- 170561970	163	retainedIntron strangeSplice	y :	0.998	4	0.312	2.0349	Large Intestine	Adenocarcinoma	0.23	3.25	8

Figure 10. "Advanced Search" - results listing synonymous mutations in the large intestinal tumors with a conservation score >= 0.8 and mutation position within the first 30% from the 5' end of the CDS.