

Appendix A. Search queries

In this appendix, the search queries used for the Scopus, Web of Science, and PubMed databases are displayed in table A1.

Table A1. Search queries for Scopus, Web of Science, and PubMed databases.

Database	Query
Scopus	TITLE-ABS-KEY ((bio-inspir* OR bioinspir* OR "Biolog* inspire*" OR biomim* OR "Nature inspir*" OR Nature-inspir* OR bionic*) AND (*needle*)) AND (LIMIT-TO (LANGUAGE , "English")) AND (EXCLUDE (DOCTYPE , "cr"))
WoS	TS=((bio-inspir* OR bioinspir* OR "Biolog* inspire*" OR biomim* OR "Nature inspir*" OR Nature-inspir* OR bionic*) AND (*needle*)) Refined By: Languages: English
PubMed	(bioinspir*[Title/Abstract] OR "Biolog* inspire*" [Title/Abstract] OR biomim*[Title/Abstract] OR "Nature inspir*" [Title/Abstract] OR bionic*[Title/Abstract]) AND (*needle*[Title/Abstract])

Appendix B. Tables of the classifications based on needle-tissue interaction and propelling

In this appendix, the collected articles are displayed, where table B1 shows the articles presenting needle designs that aim to reduce or enlarge grip and table B2 shows the articles presenting needle designs that alter the needle propulsion.

Table B1. Classification of grip enlarging and reduction strategies for bioinspired needles. Author(s), year of publication, key application(s), source(s) of bioinspiration, corresponding category in the classification of the collected articles, needle outer diameter, needle length, and evaluation stage, where 0 indicates a mechanical strength test, 1 indicates tested by computer simulation, 2 indicates tested in tissue phantom, 3 indicates tested *ex vivo* on animal tissue and 4 indicates tested *in vivo* on animal tissue. n/a = not available. **estimated value*

Author	Pub. Year	Medical application	Bioinspiration	Classification	Needle diameter [mm]	-	Needle length [mm]	Eval. stage
Aoyagi et al. [32]	2008	Percutaneous procedure	Mosquito	Form; Translation	0.09	-	1*	1, 2
Bloemberg et al. [69]	2022	Biopsy, Focal therapy	Parasitoid wasp	Translation	0.23		200	3
Burrows et al. [91]	2017	Percutaneous procedure	Parasitoid wasp	Translation	0.84		300	2
Burrows et al. [74]	2013	Percutaneous procedure	Parasitoid wasp	Translation	4		200	1
Cai et al. [18]	2022	Drug delivery, Biomarker monitoring	Honeybee	Rotation	8		1.2	1, 3
Chen et al. [29]	2018	Percutaneous procedure	Honeybee	Form, Interlocking	0.21		2	1, 3
Chen et al. [33]	2018	Drug delivery	Honeybee	Form, Interlocking	0.3*		1.4*	3
Cho et al. [20]	2012	Percutaneous procedure	Porcupine	Form, Interlocking	0.6*		2.5*	2, 3
Deng et al. [22]	2022	Wound healing	Lamprey	Interlocking	1.5*		1.5, 2.5	3, 4
Frasson et al. [34]	2008	Percutaneous procedure	Parasitoid wasp	Form	4.4		80	3
Frasson et al. [35]	2008	Percutaneous procedure	Parasitoid wasp	Form	4.4*		80*	3
Frasson et al. [92]	2010	Percutaneous procedure	Parasitoid wasp	Translation	4.4		120*	3
Frasson et al. [70]	2012	Percutaneous procedure	Parasitoid wasp	Translation	9, 12		200	2
Fu et al. [64]	2022	Drug delivery	Octopus	Sucking	0.45*		0.6*	3, 4
Gidde et al. [39]	2020	Biopsy	Honeybee, Mosquito	Form, Translation	4		180	2, 3
Gidde et al. [37]	2022	Percutaneous procedure	Mosquito	Form, Translation	3		180	3
Gidde et al. [38]	2023	Percutaneous procedure	Mosquito	Form, Translation	3		180	2
Giovannini et al. [42]	2017	Biopsy	Mosquito	Form	2.4		3.84*	2
Girija Sravani et al. [43]	2022	Drug delivery	Snake	Form	0.08		0.75	1
Gittard et al. [44]	2009	Drug delivery	Mosquito	Form, Interlocking	0.032		0.5	n/a
Guo et al. [25]	2021	Wound healing	Shark	Interlocking	0.6		1	4
Han et al. [45]	2020	Drug delivery	Mosquito, Honeybee, Porcupine	Interlocking	0.4		4	2, 3
Hara et al. [47]	2016	Blood extraction	Mosquito	Form	0.07		2.2	n/a
Hara et al. [46]	2016	Blood extraction	Mosquito	Form	0.05		5	2
Izumi et al. [48]	2008	Blood extraction	Mosquito	Translation, Interlocking	0.06		1	2
Izumi et al. [30]	2009	Percutaneous procedure	Mosquito	Interlocking	0.03		1*	2
Izumi et al. [49]	2011	Blood extraction	Mosquito	Translation, Interlocking	0.03		1	2
Jeon et al. [26]	2019	Wound healing	Endoparasite	Interlocking	0.25		0.75	3, 4
Joymungul et al. [65]	2021	Drug delivery	Octopus	Sucking, Adhering	1.08		260*	3
Kim et al. [8]	2018	Drug delivery	Mosquito	Translation	0.06-0.14		5	3
Ko and Rodriguez Baena [76]	2012	Percutaneous procedure	Parasitoid wasp	Translation	12		200	2
Ko et al. [71]	2011	Percutaneous procedure	Parasitoid wasp	Translation	12		200	2

Ko, Seong Young and Rodriguez y Baena [72]	2013	Percutaneous procedure	Parasitoid wasp	Translation	4	180	1
Leibinger et al. [77]	2016	Percutaneous procedure	Parasitoid wasp	Translation	4	200	2
Li et al. [93]	2019	Neurosurgery	Mosquito	Form, Interlocking	0.5	18	1
Li et al. [50]	2020	Biopsy	Mosquito	Interlocking	1	20*	2
Li et al. [52]	2021	Drug delivery	Limpet	Form	0.05-0.2	0.5	2, 4
Li et al. [15]	2021	Performance monitoring	Golden margined century plant	Form, Interlocking	0.35*	2	2, 4
Li et al. [31]	2022	Drug delivery, Information storage	Mushroom	Interlocking	0.2-0.6	0.6-1	3, 4
Liu et al. [28]	2020	Drug delivery, Biomarker monitoring	Spiny-headed worm	Interlocking	0.108	1	3
Liu et al. [53]	2020	Drug delivery, Biomarker monitoring	Spiny-headed worm	Interlocking	0.09*	0.26	0
Lu et al. [54]	2022	Myocardial infarction treatment	Honeybee	Interlocking	0.25	3	2, 3, 4
Matheson and Rodriguez y Baena [78]	2020	Percutaneous procedure	Parasitoid wasp	Translation	2.5	n/a	2
Matheson et al. [1]	2018	Percutaneous procedure	Parasitoid wasp	Translation	2.5	100*	1
Matheson et al. [79]	2019	Percutaneous procedure	Parasitoid wasp	Translation	2.5	120*	1
Mizuno et al. [55]	2021	Drug delivery	Bird bill	Form	0.5	0.9	3, 4
Oka et al. [56]	2002	Blood extraction	Mosquito	Form	0.085	1	2
Oldfield et al. [80]	2014	Percutaneous procedure	Parasitoid wasp	Translation	6	100	2
Oldfield et al. [81]	2015	Biopsy	Parasitoid wasp	Translation	4.00	n/a	1
Plamadeala et al. [57]	2020	Drug delivery	European true bugs	Interlocking	0.0097	0.0397	3
Sahlabadi and Hutapea [14]	2018	Percutaneous procedure	Honeybee	Form	1-3	180	2, 3
Sahlabadi and Hutapea [40]	2018	Percutaneous procedure	Honeybee	Form	3	180	2
Sahlabadi et al. [5]	2017	Percutaneous procedure, Neurosurgery	Honeybee	Form	3	180*	2, 3
Sahlabadi et al. [41]	2018	Percutaneous procedure	Honeybee	Form	3	180	3
Scali et al. [12]	2017	Percutaneous procedure	Parasitoid wasp	Translation	1.55	250	2
Scali et al. [3]	2017	Percutaneous procedure	Parasitoid wasp	Translation	1.2	160	2
Scali et al. [67]	2019	Percutaneous procedure	Parasitoid wasp	Translation	0.8, 0.6, 0.4	390	2
Schneider et al. [36]	2009	Neurosurgery, Biopsy	Parasitoid wasp	Form	4*	90*	3
Secoli et al. [82]	2018	Percutaneous procedure	Parasitoid wasp	Translation	8	200	2
Sprang et al. [73]	2016	Percutaneous procedure	Parasitoid wasp	Translation	2	200	2
Suzuki et al. [17]	2015	Blood extraction	Mosquito	Form, Translation, Interlocking	0.1	1	2
Suzuki et al. [4]	2015	Blood extraction	Mosquito	Form, Translation, Interlocking	0.1	1	2
Suzuki et al. [59]	2015	Blood extraction	Mosquito	Form, Translation, Interlocking	0.06	2	2

Suzuki et al. [58]	2018	Blood extraction	Mosquito	Form, Translation, Interlocking	0.05	1	2
Suzuki et al. [66]	2020	Puncture	Mosquito	Translation	0.1	4	2
Tran et al. [60]	2019	Percutaneous procedure	Honeybee	Form, Interlocking	0.38	1.3	2
Tsuchiya et al. [61]	2007	Blood extraction	Mosquito	Form	0.05	n/a	1
Velivela et al. [62]	2021	Wound healing	Kingfisher, Porcupine	Interlocking	0.58	3.9	1
Virdyawar and Y Baena [84]	2018	Percutaneous procedure	Parasitoid wasp	Translation	2.5	n/a	2
Virdyawar et al. [83]	2018	Percutaneous procedure	Parasitoid wasp	Translation	4	n/a	2
Wang et al. [63]	2016	Percutaneous procedure	Mosquito	Form	n/a	n/a	1
Wang and Cong [19]	2013	Percutaneous procedure	Mole cricket, Chinese sturgeon	Form, Rotation	1.6	30*	2
Yang et al. [27]	2013	Drug delivery	Endoparasite	Interlocking	0.28	0.7	3
Zhang et al. [23]	2019	Drug delivery	Mantis	Interlocking	0.25	0.6	3, 4
Zhang et al. [6]	2020	Drug delivery	Bacteria, Mussel, Octopus	Sucking	0.3	0.6	3, 4
Zhang et al. [21]	2021	Wound healing	Wasp, Ladybug	Interlocking	0.6*	1*	3
Zhang et al. [24]	2021	Wound healing	Eagle	Interlocking	0.41	0.75	3, 4
Zhang et al. [16]	2021	Drug delivery	Ice	Form	0.5	0.88	2, 3, 4

Table B2. Classification of external and internal propelling strategies for bioinspired needles. Author(s), year of publication, key application(s), source(s) of bioinspiration, and corresponding category in the classification of the collected articles.

Author	Publication Year	Medical application	Bioinspiration	Classification
Aoyagi et al. [32]	2008	Blood extraction	Mosquito	Free hand
Bloemberg et al. [69]	2022	Biopsy, Focal therapy	Parasitoid wasp	Friction manipulation
Burrows et al. [91]	2017	Percutaneous procedure	Parasitoid wasp	Friction manipulation
Burrows et al. [74]	2013	Percutaneous procedure	Parasitoid wasp	Friction manipulation
Cai et al. [18]	2022	Drug delivery, Biomarker monitoring	Honeybee, Fly	Guided
Chen et al. [29]	2018	Percutaneous procedure	Honeybee	Free hand
Chen et al. [94]	2018	Drug delivery	Honeybee	Free hand
Cho et al. [20]	2012	Percutaneous procedure	Porcupine	Free hand
Deng et al. [22]	2022	Wound healing	Lamprey	Free hand
Frasson et al. [92]	2010	Percutaneous procedure	Parasitoid wasp	Friction manipulation
Frasson et al. [35]	2008	Percutaneous procedure	Parasitoid wasp	Free hand
Frasson et al. [34]	2008	Percutaneous procedure	Parasitoid wasp	Free hand
Frasson et al. [70]	2012	Percutaneous procedure	Parasitoid wasp	Friction manipulation
Fu et al. [64]	2022	Drug delivery	Octopus	Free hand
Gidde et al. [39]	2020	Biopsy	Honeybee, Mosquito	Guided
Gidde et al. [37]	2022	Percutaneous procedure	Mosquito	Guided
Gidde et al. [38]	2023	Percutaneous procedure	Mosquito	Guided
Giovannini et al. [42]	2017	Biopsy	Mosquito	Free hand
Girija Sravani et al. [43]	2022	Drug delivery	Snake	Free hand
Gittard et al. [44]	2009	Drug delivery	Mosquito	Friction manipulation
Guo et al. [25]	2021	Wound healing	Shark	Free hand
Han et al. [45]	2020	Drug delivery	Mosquito, Honeybee, Porcupine	Free hand
Hara et al. [46]	2016	Blood extraction	Mosquito	Free hand
Hara et al. [47]	2016	Blood extraction	Mosquito	Free hand
Izumi et al. [49]	2011	Blood extraction	Mosquito	Friction manipulation
Izumi et al. [30]	2009	Percutaneous procedure	Mosquito	Friction manipulation
Izumi et al. [48]	2008	Blood extraction	Mosquito	Friction manipulation
Jeon et al. [26]	2019	Wound healing	Endoparasite	Free hand
Joymungul et al. [65]	2021	Drug delivery	Octopus	Free hand
Kim et al. [8]	2018	Drug delivery	Mosquito	Free hand

Ko et al. [71]	2011	Percutaneous procedure	Parasitoid wasp	Friction manipulation
Ko and Rodriguez y Baena [76]	2012	Percutaneous procedure	Parasitoid wasp	Friction manipulation
Ko, Seong Young and Rodriguez y Baena [72]	2013	Percutaneous procedure	Parasitoid wasp	Friction manipulation
Leibinger et al. [77]	2016	Percutaneous procedure	Parasitoid wasp	Friction manipulation
Li et al. [50]	2020	Biopsy	Mosquito	Guided
Li et al. [93]	2019	Neurosurgery	Mosquito	Free hand
Li et al. [31]	2022	Drug delivery, Information storage	Mushroom	Free hand
Li et al. [52]	2021	Drug delivery	Limpet	Free hand
Li et al. [15]	2021	Performance monitoring	Golden margined century plant	Free hand
Liu et al. [28]	2020	Drug delivery, Biomarker monitoring	Spiny-headed worm	Free hand
Liu et al. [53]	2020	Drug delivery, Biomarker monitoring	Spiny-headed worm	Guided
Lu et al. [54]	2022	Myocardial infarction treatment	Honeybee	Free hand
Matheson and Rodriguez y Baena [78]	2020	Percutaneous procedure	Parasitoid wasp	Friction manipulation
Matheson et al. [79]	2019	Percutaneous procedure	Parasitoid wasp	Friction manipulation
Matheson et al. [1]	2018	Percutaneous procedure	Parasitoid wasp	Friction manipulation
Mizuno et al. [55]	2021	Drug delivery	Bird bill	Free hand
O’Cearbhaill et al. [68]	2019	Percutaneous procedure	Chameleon	Guided
Oka et al. [56]	2002	Blood extraction	Mosquito	Free hand
Oldfield et al. [80]	2014	Percutaneous procedure	Parasitoid wasp	Friction manipulation
Oldfield et al. [81]	2015	Biopsy	Parasitoid wasp	Friction manipulation
Plamadeala et al. [57]	2020	Drug delivery	European true bugs	Free hand
Sahlabadi and Hutapea [40]	2018	Percutaneous procedure	Honeybee	Free hand
Sahlabadi et al. [41]	2018	Percutaneous procedure	Honeybee	Guided
Sahlabadi et al. [5]	2017	Percutaneous procedure, Neurosurgery	Honeybee	Free hand
Sahlabadi and Hutapea [14]	2018	Percutaneous procedure	Honeybee	Free hand
Scali et al. [3]	2017	Percutaneous procedure	Parasitoid wasp	Friction manipulation
Scali et al. [67]	2019	Percutaneous procedure	Parasitoid wasp	Friction manipulation
Scali et al. [12]	2017	Percutaneous procedure	Parasitoid wasp	Friction manipulation
Schneider et al. [36]	2009	Neurosurgery, Biopsy	Parasitoid wasp	Free hand
Secoli et al. [82]	2018	Percutaneous procedure	Parasitoid wasp	Friction manipulation
Sprang et al. [73]	2016	Percutaneous procedure	Parasitoid wasp	Friction manipulation
Suzuki et al. [59]	2015	Blood extraction	Mosquito	Friction manipulation
Suzuki et al. [17]	2015	Blood extraction	Mosquito	Friction manipulation
Suzuki et al. [58]	2018	Blood extraction	Mosquito	Friction manipulation
Suzuki et al. [4]	2015	Blood extraction	Mosquito	Friction manipulation
Suzuki et al. [66]	2020	Puncture	Mosquito	Guided
Tran et al. [60]	2019	Percutaneous procedure	Honeybee	Free hand
Tsuchiya et al. [95]	2004	Blood extraction	Mosquito	Guided
Tsuchiya et al. [61]	2007	Blood extraction	Mosquito	Guided
Velivela et al. [62]	2021	Wound healing	Kingfisher, Porcupine	Free hand
Virdyawar et al. [83]	2018	Percutaneous procedure	Parasitoid wasp	Friction manipulation
Virdyawar and Y Baena [84]	2018	Percutaneous procedure	Parasitoid wasp	Friction manipulation
Wang and Cong [19]	2013	Percutaneous procedure	Mole cricket, Chinese sturgeon	Free hand
Wang et al. [63]	2016	Percutaneous procedure	Mosquito	Free hand
Yang et al. [27]	2013	Drug delivery	Spiny-headed worm	Free hand
Zhang et al. [21]	2021	Wound healing	Wasp, Ladybug	Free hand
Zhang et al. [24]	2021	Wound healing	Eagle	Free hand
Zhang et al. [23]	2020	Drug delivery	Bacteria, Mussel, Octopus	Free hand
Zhang et al. [6]	2019	Drug delivery	Mantis	Free hand
Zhang et al. [16]	2021	Drug delivery	Ice	Free hand