Review article:

CUTTING FORCE MEASUREMENT: HAND TOOL INSTRUMENTATION USED IN SLAUGHTERHOUSES – A SYSTEMATIC REVIEW

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ABSTRACT

Workers' intensive use of hand tool cutting in the meat packing industry is a risk factor for occupational health, mainly by mechanical compression of tissues in the upper limbs, which can cause Work-Related Musculoskeletal Disorders (WMSDs). This systematic review aimed to identify the characteristics and measured variables of instrumented knives and determine how they should be designed. The review process and article extractions occurred through an analysis of the (article) titles, keywords and abstracts, followed by reading the full texts by two reviewers independently. Searches were conducted in Medline, Web of Science, Science Direct, Scopus, Ebsco and Engineering Village for articles published in peer-reviewed journals from January 2000 to March 2019, in the English language. The result of (the) search included 1289 potentially eligible studies, with 894 duplicated/triplicated/quadruplicated articles that were excluded, resulting in 404 remaining articles of which 33 were considered eligible, with 36 additional articles, totaling 69 evaluated full texts. After the review, none of the 14 analyzed studies, were rated as having good methodological quality. In addition, four types of instrumented knives were used. Data acquisition was performed in both laboratory and meat processing plants. It is noteworthy that only one knife was submitted to a validation process and that the articles did not provide complete technical information about the knives. The result demonstrated that the cutting force varies within and between subjects, tasks, plants and blade finishings. All knives used some type of electrical connection via cable or wires. Of the articles found, none considered the influences that the workers are subject to when they do not use the same tool daily for data acquisition. Therefore, the development of different types of instrumented knives, with wireless data transmission and more rigorous studies are necessary to expand the knowledge of the cutting force and development of WMSD in slaughterhouse workers who perform meat cutting.

Keywords: Tool, knife, ergonomics, force, meat packing, slaughterhouse

INTRODUCTION

Statistically, Brazil is the world's largest exporter of chicken (ABPA, 2020) and beef (ABIEC, 2020), and pork occupies fourth place (ABPA, 2017). Consequently, Brazil employs many workers in this sector, according to OSHA (2013), where several occupational risk factors are present: repetitive work, artificially cold environments, use of

gloves and hand tools, resulting in the application of force in the tasks.

As stated by the Brazilian Work Accident Statistics report, in the period between 2015 and 2017, the economic sector of slaughtering pigs, poultry, and other small animals was 3rd place among the sectors that most developed occupational diseases in workers at the national level, with the cattle sector in 9th place (Ministério da Fazenda, 2017).

WORK-RELATED MUSCULOSKELE-TAL DISORDERS (WMSDS)

Ergonomics-related risk factors that may lead to the development of WMSDs in poultry processing facilities include, among other factors, the amount of physical effort to perform a demanding task (such as heavy lifting, hanging/rehanging poultry, pulling skin) or to maintain control of equipment or tools (OSHA, 2013).

Workers must use a knife that is sized and designed for the task performed (OSHA, 2013). Besides, the type, shape and texture of the knife grip should be appropriate for the hand of the worker and the eventual use of gloves (Ministério do Trabalho e Emprego, Brasil, 2013). According to the Brazilian norm (NR-36) regarding slaughterhouses (Ministério do Trabalho e Emprego, Brasil, 2013), the employer must implement a control system for sharpening knives, establishing mechanisms for the constant replenishment of sharp knives.

Several studies checked that poultry slaughterhouse workers were exposed to moderate risk, which meant an incidence of upper-limb work-related musculoskeletal disorders (UL-WMSDs) from 10.6 to 21.5 % (Reis et al., 2016, 2107, 2019). The Brazilian standard for slaughterhouses refers to the fact that the process organization and the speed of the production line must take into account the time variability required by different productions and processes, at least the time required for knife sharpening operations (Ministério do Trabalho e Emprego, Brasil, 2013).

The force demand is considered a risk factor to developing UL-WMSDs on the OCRA Checklist method and this assessment is carried out using the Borg Scale (Colombini and Occhipinti, 2014). In one study, most slaughterhouse workers perceived tool sharpening as very sharp (63.1), however, the exertion applied when cutting the leg, breast and sassami (cleaning) as mild (48.7 %) and moderate (42.1 %). In general, 54 % of the workers felt discomfort in their upper limbs, 38.8 % in the shoulder and 28.9 % in the hand (Tirloni et al., 2019). Szabo et al. (2001) state that too little reconditioning has the undesirable consequence of increasing forceful exertions and effort needed to accomplish the manual cutting task. In their study, when reconditioning took place after every 6 cutting cycles for the high-force job and 9 cutting cycles for low-force, knife dulling increased cutting force by 15 % for the same cut in carrageenan gel as compared with a fresh knife. The cutting force increased by 30 % after 13 and 21 cycles of the high- and low-force jobs, respectively.

As there was a considerable variation among workers in sharpness differences, Dempsey and McGorry (2004) suggest that one potential administrative control would be to maintain knife sharpness so that exposure is minimized, and another option would be more frequent substitution of knives for freshly-sharpened ones.

In Brazil, the Ministry of Agriculture, Livestock and Food Supply – Brazil recommends the sterilization of knives and scissors at least twice a shift. Nevertheless, as found by Tirloni et al. (2019), the tools were sharpened and sterilized four times throughout the workday in a specific room. Karltun et al. (2016) verified that the median value of knife usage time for the 12 individuals varied from about 1 h 20 min to almost 3 h. For a working day of 8 h, the meat cutters in this study needed 3-6 freshly sharpened knives/ day to be able to perform their work and be content with the sharpness of their knives

during the entire day. In the study of Dempsey and McGorry (2004), there was variation among workers in sharpness differences between the initial reading and 2- and 5-hour readings.

Due to studies that confirm the effect of knife sharpening on the cutting force, it is suggested to follow the recommendations of OSHA (2013), where employers train poultry slaughterhouse employees on tool sharpening, maintenance schedules, and good cutting techniques, to assure that knives, scissors, and other tools used for cutting are sharp and workers do not exert excessive force. Along these lines, Marsot et al. (2007) declared that suitable training of knife users should be carried out to achieve best possible cutting performance. Claudon and Marsot (2006) highlight the importance of training operators in knife honing/sharpening to ensure they have knives that cut easily. In addition, when analyzing the cut in a carrageenan gel, Szabo et al. (2001) revealed that significant force increases may be anticipated for too infrequent reconditioning, in which this increase may increase fatigue onset and the risk of WMSDs.

Despite the guidelines, several studies cited that knife use is a risk for health workers (OSHA, 2013; Ministério do Trabalho e Emprego, Brasil, 2013), the slaughterhouse workers had a greater chance of feeling cold in the hands (Tirloni et al., 2018). Increased cutting force may intensify fatigue onset and the risk of WMSD (Szabo et al., 2001; Dempsey and McGorry, 2004). The use of a badly sharpened knife can increase upper limb biomechanical stresses (Claudon and Marsot, 2006). Although most poultry slaughterhouse workers perceived the tool's sharpness as very sharp (63.1 %), most determined that the exertion applied when cutting the product as mild (48.7 %), as well as moderate (42.1 %) (Tirloni et al., 2019).

Moreover, the meat cutters had an extremely high prevalence of disorders in wrists/hands and shoulders (Arvidsson et al., 2012). Tirloni et al. (2018) analyzed some studies on the discomfort of slaughterhouse workers and verified that hand discomfort was cited by 18–29 % of them.

Finally, one study applied the Occupational Repetitive Action (OCRA) method, with 101 participants from three slaughterhouses. The workers were asked to evaluate the perceived effort (Borg scale) if they are cutting the meat with a badly sharpened knife and a very sharp one. It was possible to identify the influence of the knife edge on the risk of developing musculoskeletal disorders and it was found that there was a significant increase (29 %) of this risk when the knife is "badly sharpened". Therefore, maintaining well-sharpened knives for optimal performance of the cutting task (fewer technical actions) is suggested, as well as including knife sharpening in the standard operating procedure (Tirloni et al., 2020).

STUDY QUESTIONS

For McGorry (2001), the lack of field data is due, in part, to the current inadequacy of instrumentation measurement and its apparent lack is widespread. Additionally, this absence of data makes it difficult to study the potentially causal relationship between risk factors and injury, to validate the redesign of tasks, or to identify high-risk techniques for performing a specific task.

Therefore, many reasons justify this systematic review, because it detects the technologies used in the instrumented knives and the limitations of the studies; making it possible to create guidelines to build an instrumented knife that can reliably measure the force applied during cutting. In addition, there is a gap regarding quantitative data on the cutting force to cut animals of different sizes in slaughterhouses, considering the complexity of the cut and the state of meat/piece (freezing level and meat with or without bone).

This systematic review aimed to identify the characteristics and measured variables of instrumented knives, and to determine how they should be designed.

This study had the following specific research questions:

a) What are the characteristics of instrumented hand cutting tools?
- was the tool used the same as or different from those used in the company surveyed?
- was data transmission wired or wireless?
- has the tool weight changed?
- what was the data acquisition environment?
b) What variables can be obtained by these instruments?
c) How should instrumented hand cutting tools be designed?

MATERIALS AND METHODS

Search strategy

Searches were conducted in six electronic databases in international journals in the areas of Engineering and Health Sciences: Pubmed (Medline), Web of Science, Science Direct, Scopus, EBSCO (Medline complete), and Compendex (Engineering Village); in the English language with publications from January 2000 to March 2019. Additional records were identified in the screening step of this research through an analysis of the articles' references included for eligibility.

The principles of PICO were used (population, intervention, comparison, and outcomes) to group the search terms. As this study was not clinical research, three principles were considered and two Boolean operators were used (OR, AND): population ("meat processing industry" OR "meat processing plant" OR "meat industry" OR "meat packing" OR "meat cutting" OR slaughterhouse OR abattoir) AND intervention (cutting OR tool OR hand OR handle OR knife OR sharp) AND outcomes (force OR effort OR exertion OR strength OR "upper limb" OR "musculoskeletal disorders" OR ergonomics).

The search terms were defined based on the list of terms used in MeSH Database (NCBI, 2019). The studies were collected in databases of 28-29 March 2019 and explored the word roots and found all term variants (singular/plural, past tense, gerund, comparative and superlative adjective; when possible). The following filters were used for the subject area: ergonomics, medicine, engineering (industrial, biomedical, electrical electronic, manufacturing and mechanical), robotics, health professions, material science, multidisciplinary and public environmental occupational health, according to availability in the database.

Inclusion and exclusion criteria

The eligible studies contained the following criteria: (1) performed study with cutting manual tool; (2) the tool should be an instrumented knife; (3) written in English; (4) full text papers published in peer-reviewed journals; and (5) with adult humans (+19 years old).

The exclusion criteria were studies that used apparatus with blade or knife, not a hand tool; those that approached cutting meat using robots; and finally, no studies with cutting manual task using knife. The search results were exported to EndNote® basic software online, where duplicates/triplicates/quadruplicates were removed, data extraction was obtained in full text after the analysis of the possible eligibility of the articles.

Study analysis

In relation to the studies' eligibility, the review process occurred through an analysis of the titles, keywords and reading the abstracts by two reviewers independently in EndNote® basic software online. When in doubt of eligibility, the full text was reviewed. In the cases of any disagreement between the two reviewers, a decision was reached by consensus, or a third researcher provided further review and the decision was made by arbitration.

Methodological quality assessment of studies

The quality of the eligible studies was assessed by tools proposed by the United States National Institutes of Health (NIH) (NIH, 2018). This study included the tools to

evaluate the Quality Assessment of Controlled Intervention Studies and Cross-Sectional Studies (both with 14 criteria). The NIH website (NIH, 2018) provides the assessment tools and guidance for determining the quality of each type of study containing explanatory information about each item that should be analyzed in the paper.

The quality rating was classified as good, fair, or poor, allowing the general analysis of the evaluators considering all the items (NIH, 2018). Each item of the assessment tool chosen, depending on the type of study, received a positive appraisal (+) when the study attended the item, negative (-) when it did not attend as well as other options (cannot determine - CD, not applicable – NA and not reported - NR).

According to Wong et al. (2008), observational studies with rating ≥ 67 % of the positive item attended were an indication of good quality, with 34-66 % of the positive checks were of fair quality, and ≤ 33 % of poor quality. The quality studies that allowed internal and external validity criteria were used (Sanderson et al., 2007).

Data extraction

Two independent reviewers accomplished the data extraction and review process, in cases of disagreement; consensus was reached through discussion between them or through arbitration with a third reviewer.

The following study's characteristics were extracted and described: authors' names, title of the article, publication year; country where the study was conducted; design and objective of the study; characteristics of participants; environment of data acquisition (laboratory or company); what product was cut; type of hand cutting knife (same as used by workers in the company, wireless or not, weight); outcomes measured by the knife; follow up and results. Data of this study were presented descriptively and followed the PRISMA Statement for reporting flow diagram (Moher et al., 2009), and the NIH checklist for systematic reviews (NIH, 2018).

RESULTS

The search results included 1298 potentially eligible studies. Firstly, 894 duplicated/triplicated/quadruplicated articles were excluded and, of the 404 remaining articles, 33 were considered eligible based on the review of the titles, keywords, and abstracts. Additional studies (36) were included after searching in the eligible article references, totaling 69 full texts for evaluation. After reviewing them, 55 studies were ineligible, ending the process with 14 studies for quality assessment (Figure 1).

The collections of the 14 final studies were performed only in a laboratory (6), in meat packing and meat processing plants (6) and in both environments (2), involved four types of instrumented knives, additionally, included three countries: United States, New Zealand and Denmark (Table 1). Only two studies' design types were found in this review, however, the majority were controlled intervention studies (9) (as randomized, a randomized trial, a randomized clinical trial, or a Randomized Control Trial – RCT) (Table 1). Four types of knives were identified by the study, which will be detailed later in Table 3.

Table 2 presents the assessment of the methodological quality of studies. The analysis showed that most of the papers have fair (11) methodological quality and do not have research with good classification. In the control intervention studies, it is negatively highlighted that all studies mentioned randomizing the variables (subjects/groups/tools/height/knives/force level/dynamometer/trials/blades), but did not cite how it was done; the evaluations and treatment were not blinded, the studies did not calculate the sample size and test power. Thus, in the cross-sectional studies, the population was not specified, the participation rate of eligible persons was less than half; the sample size justification was not provided; the variable measures were not obtained prior to the outcomes; the time frame was insufficient to see an association between exposure and outcome; a single

assessment was made; the outcome assessors were not blinded, and finally, potentially confounding variables were not measured and adjusted statistically.

Four instrumented knives were found in the review, where IK-A was the most used in the research (9) and the only ones that had gone through a validation process, are described in Murphy et al. (2000). All knives used some type of electrical connection via cable or wire and were not completely the same as the tool used daily by the worker. During data collection, if there was a module attached to the knife user's body, no study cited battery life (hours, days) or any kind of radio frequency transmission. The tool characteristics are described in Table 3.

Table 4 shows the main results of the studies analyzed and the referred instrumentalized knives – IK (Instrumented Knife).
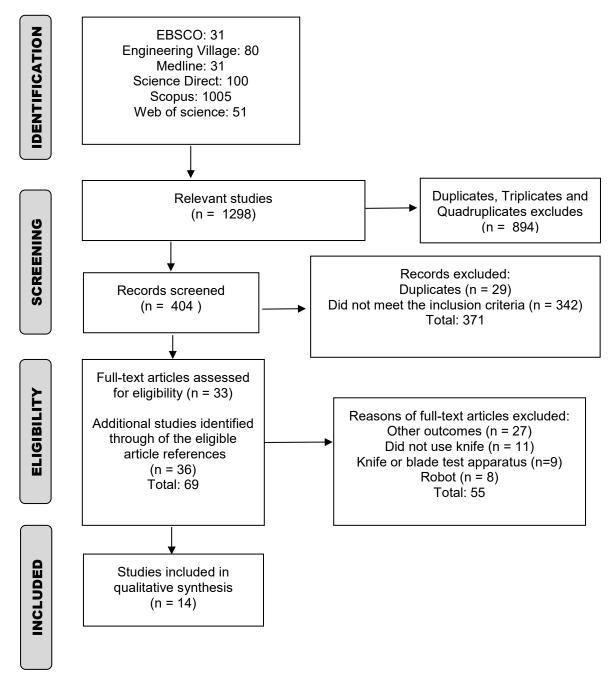

Figure 1: Flow diagram of systematic review process

Table 1: Characteristics of the study design included in this review

Author/year	Data acquisition environment	Country/data collection	Type of instrumented knife (IK)	Study design	
				CI	CS
Murphy et al., 2000	Laboratoy	USA	IK-A		x
McGorry et al., 2000	Laboratory and poultry processing plant	USA Plant – NR	IK-A		x
McGorry, 2001	Laboratoy	USA	IK-A	x	
Juul-Kristensen et al. 2002	Poultry processing plant	NR	IK-C		x
McGorry et al., 2003	Meatpacking plants	New Zealand	IK-A	x	
Waddell et al., 2003	Poultry processing plants	USA	IK-D		x
Dempsey and McGorry, 2004	Pork processing plants	NR	IK-A		x
McGorry et al., 2004a	Laboratory	USA	IK-A	x	
McGorry et al., 2004b	Laboratory and meat packing plants	USA Plants – NR	IK-A	x	
McGorry et al., 2005a	Lamb processing plants	New Zealand	IK-A	x	
McGorry et al., 2005b	Meat packing plants	New Zealand	IK-A	x	
Pontonnier et al., 2011	Laboratory	Denmark	IK-B	x	
Pontonnier et al., 2012	Laboratory	Denmark	IK-B	x	
Pontonnier et al., 2014	Laboratory	Denmark	IK-B	x	
CI – Control Intervention; CS – Cross Sectional; NR – Not reported					

Table 2: Assessment of the methodological quality of the studies

Author/year	Quality assessment tools														T (n/t)	QR
	Controlled intervention studies															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14		
McGorry, 2001	x	-	-	-	-	x	x	x	x	x	x	-	-	x	8/14	Fair
McGorry et al., 2003	x	-	-	-	-	x	x	x	x	x	x	-	-	x	8/14	Fair
McGorry et al., 2004a	x	-	-	-	-	-	x	x	x	x	x	-	-	x	7/14	Fair
McGorry et al., 2004b	x	-	-	-	-	-	x	x	x	x	x	-	-	x	7/14	Fair
McGorry; et al., 2005a	x	-	-	-	-	x	x	x	x	x	x	-	-	x	8/14	Fair
McGorry et al., 2005b	x	-	-	-	-	x	x	x	x	x	x	-	-	x	8/14	Fair
Pontonnier et al. 2011	x	-	-	-	-	NA	NA	NA	NA	x	x	-	-	NA	3/14	Poor
Pontonnier et al., 2012	x	-	-	-	-	x	x	x	x	x	x	-	-	x	8/14	Fair
Pontonnier et al., 2014	x	-	-	-	-	x	x	x	x	x	x	-	-	-	7/14	Fair
	Cross-sectional studies															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14		
Murphy et al., 2000	x	NA	NA	NA	NA	NA	NA	NA	x	-	-	NA	NA	-	2/14	Poor
McGorry et al., 2000	-	-	-	-	-	-	-	-	x	-	x	-	x	-	3/14	Poor
Juul-Kristensen et al., 2002	x	-	-	x	-	-	-	x	x	-	x	-	-	-	6/14	Fair
Waddell et al., 2003	x	-	-	x	-	-	-	x	x	-	x	-	x	-	6/14	Fair
Dempsey and McGorry, 2004	x	-	x	x	-	-	-	x	x	-	x	-	x	-	7/14	Fair

x (yes), - (no), NR – not reported, NA – not applicable, CD – cannot determine, T – total, (n/t) - frequency/total, QR – Quality Rating (≥ 67 % = Good, 33-66 % = Fair, ≤ 33 % = Poor) = Quality tool

Table 3: Characteristics of the instrumented knives used in the articles included in this systematic review

Variables	IK-A	IK-B	IK-C	IK-D
Objective	To produce a portable device for the measurement of the frequency and magnitude of the reactive forces applied to or by the hand during a manual task	Measure: force	Measure: force	Measure: force and torque
Instrumented	knife handle core; boning knife used in meat packing industry	knife - part instrumented between handle and blade	Knife handle core	Blade - external sensor additioned to the blade, increase this by 2.5 cm
Initial weight	NR	0,348 - 0,748 kg (calculated weights of the real knife)	NR	NR
Final weight	Increase of the weight: 130-133 mg (Murphy et al., 2000). The knife weight was imperceptible to the user. 59 g heavier (McGorry, 2001)	0,948 kg (0.2 – 0.6 heavier than a real knife)	NR	One monolithic transducer: 1.9 oz = 53.9 g Total weight - NR
Knife length	24.5 cm	25.9cm	NR	NR
Blade	Removable blade; 15 cm	6.5 cm; shape real knife, one type	Removable	A normal cutting knife. Removable
Handle	Polyurethane without finger flutes; removable; handles of various sizes and shapes can be mounted to the grip core	Handle diameter was similar to knives used in the Danish slaughterhouses. Length – 13.0 cm	Removable	Removable
Sensor	Victorinox 40515, Ibach, Switzerland; 2 pair of strain gauges attachment of the blade; 6 strain gauges in the knife handle; the grip core was fabricated from 15.6 mm hexagonal bar stock (14-4 stainless steel)	3D force sensor (FS6-2000, AMTI, Watertown, MA, USA). Length – 6.4 cm	Full bridge strain-gauge transducers	Six transductor ATI Industries force-torque sensor (Assurance Technologies, Inc., Garner, NC)
Electric cable or wire	The cable was secured to the upper arm of the worker. The cable length was adjusted to worker preference but did not mention the length range.	There was, but the length was not reported	There was, but the length was not reported	The cable length was 6.1 m
Battery	6 AA standard alkaline batteries in the pack attached to the workers abdomen guard belt power the unit.	NR	NR	NR

Variables	IK-A	IK-B	IK-C	IK-D
Limit of force (range)	Maximum of 700 N – grip force	NR	NR	(ATI Mini 20-lb force/40 in-lb-torque); All transducer resolutions were below 0.96 oz with maximum sensing capabilities of 60 lbs in Fz and 20 lbs in Fx and Fy
Output	A/D converter from data logger	A/D converted (12 bits A/D converter, Nidaq 6024, National Instruments, Austin, TX, USA)	From data logger	All analog channels from the EWAS were wired to a 16-channel CIO-DAS16 A/D board and an SSH-amplifier from Computer Boards, Inc. (Middleboro, MA)
Amplification and sampled	50 Hz and 100 Hz	Force signals were low-pass filtered (10.5 Hz) and amplified 2000 times. Sampled at 60 Hz	A portable amplifier (Alborg University, Denmark). Voltage divider were connected to a data logger (Logger Teknologi HB, A (karp, Sweden). Sampled at 20 Hz	Sampled at 1,000 Hz
Data Processing	Hand-held (0.8 kg; Six AA standard alkaline batteries) for signal conditioning, data acquisition and processing. Data download to a personal computer. Allows saving data for nine separate tasks for up to 1 h	Recorded through a custom made program in LabView 8.2	The data from the six gauges in the handle were averaged to produce a single mean grip force value for each data sample	Signal processing hardware and portable computer
Software	BASIC and C language. Records and displays in real-time the force and frequency data	Program LabView 8.2 (National Instruments, Austin, TX, USA)	NR	LabView software
Calibrated	With known weight; 12 calibrated weights (0.45-72.8 kg).	NR	With a weight of 2 kg at a predetermined distance from the knife shaft	NR
Tool validation	Working range Overload capacity Sensitivity (counts/units) Linearity (% of FS) Repeatability (% error) Hysteresis (% error) Resonant frequency (Hz)	NR	NR	NR

IK = Instrumented Knife; NR = not reported; References: IK-A (McGorry et al., 2000, 2005; McGorry, 2001; Murphy et al., 2000); IK-B (Pontonnier et al., 2011, 2014); IK-C (Juul-Kristensen et al., 2002; Madeleine et al., 1999) and IK-D (Waddell et al., 2003)

Table 4: Description of the studies included in this review

Author/year	Objective	Participants/product/tasks	Instruments/procedures	Outcome	Follow up	Results
Murphy et al., 2000	To present a system for field measurement of manual tasks	No participants. Sensitivity and linearity of each tool was assessed by applying five loads progressively within the working range of the tool, in three repeated trials.	Manual task evaluator (MTE) = Instrumented tools: boning knife (IK-A), pair of small pliers and a screwdriver-like handle. Digital oscilloscope.	Weight, working range, overload capacity, sensitivity, linearity, repeatability, hysteresis.	Immediately	About Knife, weight increased 130-133 mg; follow data in vertical and horizontal axis, respectively = overload capacity: 22.6, 3.4 Nm; sensitivity: 40.8, 100.2; linearity: 2.2, 1.4; repeatability (% error) 1.0 for both; hysteresis (% error) 1.2, 2.1.
McGorry et al., 2000	To produce a portable device for the measurement of the frequency and magnitude of reactive forces applied to or by the hand during a manual task.	Experiment 1 - Laboratory, 8 males (ages 22-56 years; cutting task. Experiment 2 - Poultry processing plants, 10 subjects: Plant 1 - 6 males and Plant 2 - 4 males; cutting task.	Experiment 1 – a large boning knife used in the meat packing industry; 15 cuts on each of four materials = thicknesses of nylon strips - 0.254, 0.38 , 0.508 and 1.59 mm. 5 min rest between trials, knife was sharpened - 25 strokes of each side of the blade against a sharpening stone. Experiment 2 - IK-A; Three trials. Aquisitions - 10 Hz for 30 s, Post-processing - 45 s	Cutting force; cutting torque (mean and peak at the center of the knife handle); time torque; estimated torque - center of the wrist join; number of cutting cycles per 30 s trial period	Immediately	Experiment 1 - the thickness of the material being cut had a significant effect on average peak torque, F (3,294)=89.5, p <0.0001; Experiment 2 - Mean quantity of work performed over the trial period = 32.86 ± 10.02 N; mean cutting torque = 1.93 ± 0.31 N/m; peak cutting torque = 5.25 ± 0.88 N/m; mean length of time torque = 7.53 ± 1.76 s; cutting estimated torque at the wrist = 2.89 ± 0.46 N/m; cutting cycles per 30 s trial period = 17.06 ± 4.74.
McGorry, 2001	To develop of a system that can simultaneously resolve grip forces and applied moments produced using non-powered, single-handled tools, and an evaluation of the utility of the proposed device under simulated working conditions.	5 female, 5 male (ages: 18-65 years); Randomized: thick or thin clay slab.	IK-A Experiment: 2 x 2 Precision cutting task: 10 and 15 cm in width; Clay slab thickness: thick (1.9 cm) and thin (1.25 cm). 4 vertical cuts in the slab for all trials. No instructions about cut speed.	Grip force; grip-moment applied torque during the initial phase of low- and high-precision cutting tasks; error in localization.	Immediately	Grip force x the applied cutting moment r=0.979; The grip force and applied moment were significantly greater for high-precision than for low-precision tasks during the initial phase (25 %) of the cutting replications at both the thick and thin levels of clay thickness; the error in localization decayed exponentially with increasing load. Errors of 3 mm or less were observed with loads exceeding 25 N. The working range exceeds 700 N for gripping forces, and 28 and 16 Nm for the two applied moment axes.

Author/year	Objective	Participants/product/tasks	Instruments/procedures	Outcome	Follow up	Results
Juul-Kristensen et al., 2002	To investigate and compare the physical workload before and after the introduction of new technology in poultry processing, i.e. the replacement of manual deboning with a mechanical deboning process.	13 healthy women; age: 33.2±12 years; two tasks: 1) manual deboning - cutting along the chicken chest bone and twisting the meat to the side with the thumb, and cutting off the meat on each side of the chest bone; 2) mechanical deboning, where the meat was cut mechanically along the chest bone, leaving the deboners to pull off the meat manually.	IK-C; surface electromyography (EMG); electrogoniometer; camcorder camera (15 min at each of the two worktasks); a scale to measure the muscular strength (1:light–5:near maximal).	Muscle activity during mechanical and manual deboning (cutting and cutting off task): (Extensor Carpi Ulnaris (ECU), FCU, m. flexor carpi ulnaris; FDS, m. flexor digitorum superficialis; ECR, m. extensor carpi radialis); maximum wrist extension and flexion forces; flexion and deviation of the dominant wrist; cutting forces during manual deboning; Observations subjective: estimate of external force demands at the knife hand in combination with the wrist joint.	Immediately	The muscular activity was significantly higher in ECU, FCU and FDS (50th and 90th percentiles) during the cutting task while in ECR, the muscular activity was significantly higher during mechanical deboning. Estimated cutting forces during manual deboning: 6.25 N and 20.71 N (median and peak levels). The intra individual variation during the 50 cuts in the cutting task was small with a coefficient of variation (cv) = 12–32 %. In manual and mechanical deboning, the peak force was 11 kg (107.91 N) and 10 kg (98.10 N), respectively. Extreme positions of the hand in ulnar deviation were larger in cutting than mechanical deboning ($p > 0.05$).
McGorry et al., 2003	1) To quantify the cutting moments and grip forces in several meat cutting operations performed by professionals in meat packing plants. 2) Provide insight into the effect of blade sharpness on the grip forces and cutting moments.	15 meat cutters (14 male and one female; 36.1±11.9 years) working on the production line at lamb and beef processing plants in New Zealand; Three tasks: lamb shoulder deboning, rib beef and loin beef. Randomized: blade sharpness and knives.	IK-A; surface electromyograms (EMG); knife sharpness tester. Experiment: 3 x 2 replications (analysis). Three sharpness groups: sharp, medium and dull. 10 working knives	Cutting moments and grip forces exerted during the three tasks; Ninety data files were processed (15 subjects: 3 sharpness conditions and 2 replications) 2nd and 3rd replications of each condition were used for the analysis.	Immediately	Mean and peak cutting moments were 4.7 and 17.2 Nm for the shoulder boning, 3.5 and 12.9 Nm for the rib trim, and 2.3 and 10.6 Nm for the loin trim, respectively. Expressed as percent of MVC, mean grip forces of 28.3 % and peak grip forces of 72.6 % were observed overall. Blade sharpness was found to effect gripping forces, cutting moments and cutting time, with sharper blades requiring statistically significantly lower peak and mean cutting moments, and gripping forces than dull knives. The lamb shoulder deboning had the highest peak gripping forces.

Author/year	Objective	Participants/product/tasks	Instruments/procedures	Outcome	Follow up	Results
Waddell et al., 2003	To monitor workers in an unencumbered fashion as they performed two different poultry cutting tasks.	3 poultry processing plants; 3 groups of 5 experienced poultry deboners - at least one year (n=15, 6 men and 9 women); tasks: wing and tender cuts.	EWAS - Ergonomic Work Assessment System: electrogoniometer; surface electrodes (EMG), IK-D and signal processing hardware. Experiment: Two wing cuts Two tender cuts	Six force and torque components (Fx, Fy, Fz, Tx, Ty, Tz), wrist flexion/extension angle and radial/ulnar deviation; sites: Fx, Fy, Fz; muscle activity (flexor/extensor of the forearm)	Immediately (one collection day)	There were between-subject differences by site (p = .014), within-subject differences by cut (p = 0.000), and cut-by-site (p = 0.024) for knife forces. Forearm EMG for the wing cut was significantly smaller than the tender cut in both the flexor and extensor compartments. The total range of motion of the wing cut was dramatically larger than those required for the tender cut.
Dempsey and McGorry, 2004	Primary – to perform an initial investigation into the extent of within- and between-subject variation in grip forces and cutting moments exerted on a knife handle, through direct measurement techniques. Secondary – to perform an observational study of knife sharpness.	9 male workers; pork slaughterhouse; task: pork shoulder deboning operation.	IK-A; apparatus: tape measure and video camera; computer. Experiment: Three cycles of the soulder deboning task	Anthropometric and demographic characteristics; grip forces; cycle and cutting time; number of cuts and sawing motions; cutting moments. 3 cycles for each worker were used for analysis.	Immediately	The average grip force values during the task were between 11 and 35 % of the maximum voluntary grip force. There was high between-subject variation in exposure to integrated grip forces and cutting moments, and also high between-subject variation in cutting time. There was variation in knife maintenance among workers during a 5-hour period. Peak cutting moment (Nm) – 16.2 (3.1) Mean cutting moment (Nm) – 4.0 (0.6) Peak grip force (N) – 130.9 (26.5) Mean grip force (N) – 39.9 (4.4)
McGorry et al., 2004b	To investigate the effects of learning and experience, measurement system, and the nature of the task on grip force estimate accuracy.	Experiment 1 - 10 male subjects; age: 40±14 years; no professional experience in meat cutting; Randomized: force level and participants. Experiment 2 - 12 males; age: 39.1±15.9 years; no professional experience in meat cutting; 4 session in laboratory; task: clay cutting. Randomized: dynamometer and the test handle. Experiment 3 - 15 professional meat cutters (14 male, 1 female); age: 36.1±11.9 years; meat packing plants; meat	Hand dynamometer; IK-A (test handle). Experiment 1 Four test conditions 4-s data acquisition period To squeeze the handle or dynamometer with the same force applied during the preceding task. Experiment 2 3 tracings on the clay during each of 144 trials in 4 sessions.	Experimental 1 – estimate errors at four grip force level: 44.5 N, 89 N, 133.5 N, 178 N. Experiment 2 – grip force; grip force and grip estimates; Experiment 3 - grip force and cut moment; effect of blade sharpness.	Immediately	Estimate accuracy varied greatly from individual to individual. No significant effect of learning on estimate accuracy was observed. Errors were greatest for both measurement devices (dynamometer and IK-A) at the lowest force level. Mean grip force – 55.2±16.2 N Mean estimate error – 194.7±129.1 % with the dynamometer and 133.4±114.0 % with the test handle. Mean peak forces – all the cutting simulation trials – 123.8±37.3 N. Mean error – 30.6±55.9 % for the dynamometer, and 3.4±49.7 % for the test handle. Mean peak grip force – 103.0±36.3 N for the field meat cutting study.

		boning and trimming operations. Randomized: Not reported	Experiment 3 – 9 trials (3 replications x 3 blade sharpness) After the last replications: 2 grips the knife handle with the same force of the previous meat cutting operation.			
McGorry et al., 2004a	To investigate factors related to force and postural exposure during a simulated meat cutting task.	12 male participants (experimental subjects or workers); age: 39.1±15.9 years; 9 of the group had professional meat cutting experience. Four session in laboratory; task: clay cutting. Randomized: subjects; 36 trials.	IK-A; goniometer; Experimental design: 3 X 3 X 2 X 2 X 2; - Surface angle (0°, 30°, 60°) - Surface heights: high (elbow height), medium (12.5 cm below elbow height) and low (25 cm below elbow height); - Knife angle (0°, 30°) - Cut complexity (simple and complex) - Work pace (self and production paced).	Grip force; cut time; cutting moment; wrist kinematics: flexion/extension and radial/ulnar desviation; elbow elevation.	Minimum duration – 5 days – 2 training sessions of 36 trials followed by 2 experimental sessions each composed of 36 of the 72 possible combinations.	There was a significant difference in mean cutting time between the production and self paced tasks, 2.47 (1.10) s and 4.02 (1.43) s per replication, respectively. Participants used greater grip force and cutting moment when working at a pace based on productivity. The interactions of the work surface height and orientation indicated that the use of an adjustable workstation could minimize wrist deviation from neutral and improve shoulder posture during cutting operations. Angling the knife blade also interacted with workstation variables to improve wrist and upper extremity posture, but this must be weighed against the potential for small increases in force exposure.
McGorry et al., 2005b	Describe the development and evaluation of a "sharpness tester" designed to meet the criteria that the system be portable for field use at meatpacking plants, requires no special skills to operate, provides a non-destructive test of the entire blade edge, and incorporates a test motion that is	15 meat cutters; boning and trimming operations; Laboratory: mesh cut (polypropylene-coated fiberglass screening); Two New Zealand Meat packing plants: beef cut. Blades: sharp and dull. Randomized: meat and mesh targets; 10 knives; blade sharpness.	IK-A; apparatus – knife sharpness tester; 10 boning knives. Experiment: 2 trials; Sharpness process: 1, 3, 5 and 7 passes through the sandpaper; Two knives per meat cutter. Beef: cut into strips 3 cm wide, 25 cm long, and 2 cm thick. 2 trials at each sharpness level.	Mean cutting force; distance from blade tip (cm); number of pass through sandpaper; mean and peak of the grip forces, cutting moments and cutting time.	Immediately	The force required to cut the mesh increased as the number of passes through the sandpaper increased and the effect was generally consistent along the length of the blade. Cutting forces for mesh and meat were correlated (r = 0.89), the materials behavior was very similar. The differences between the sharp and dull groups were statistically significant for sharpness test force, mean grip force, mean and peak cutting moment and cutting time.

	representative of meat cutting.					
McGorry et al., 2005a	To investigate the effect of blade edge angle and the effect of post-sharpening finishing on the grip forces and cutting moments exerted by professionals during two different meat packing operations.	21 meat cutters; age: 39.6±10.1 years; 2 lamb processing plants; 2 cutting tasks: lamb shoulder fleecing and Y-cut operations. Randomized: blade edge and blade finish conditions.	IK-A Experiment: 3 x 3 Blade angles: 20°, 30°, and 45°; Levels of blade finishing: coarse - 5 passes on a 400 grit stone; smooth - 10 passes on a 600 grit stone and polished - 10 passes on a 900 grit stone	Grip force, cutting moment and cut time; anthropometric and work history;	Immediately	There was no significant effect of blade edge angle on the force exposure or the speed of meat cutting; Cutting time, peak and mean grip force and cutting moment decreased with increasing quality (decreasing coarseness) of the blade finish only for the lamb Y-cut task.
Pontonnier et al., 2011	To investigate two different cutting tasks in terms of muscle load and posture.	One man; 39 years; laboratory; cutting task.	IK-B; and surface electromyography (EMG). Experiment: 20 seconds - 10 cycles task in two cutting directions: 1) arm flexion and, 2) a combination of arm internal rotation and abduction.	Motion data; muscles forces and joint coordinates during cutting tasks. Muscle activity: Deltoideus Medialis and anterior, biceps brachii and triceps long head.	Immediately	For both cutting directions biceps and triceps forces are similar. Deltoidus and Trapezius forces highlight that the second cutting direction led to a higher shoulder tension for a lower cutting force intensity. In addition, in the "x and z- directions" that corresponds to a greater extent of flexion of the upper arm and elevation of the shoulder. This can partially explain the increase of the global tension in the shoulder during this task.
Pontonnier et al., 2012	To provide data for a complete analysis of the cutting force and the activation of representative synergistic muscles in relation with the workbench height and the cutting direction. To analysed the trend of relative activations (normalized to the cutting task force and the cutting task duration) to define the best workstation configuration.	Seven subjects; age: 29±5 years; laboratoy; cutting tasks; 4 work planes. Randomized: 4 trials	IK-B; surface electromyographic (EMG) and oscilloscope. Experiment: 4 trials – 20 s each; 4 heights (0 cm, 10 cm, 20 cm and 30 cm below the elbow height) and; 2 directions of cutting: 1) arm flexion and, 2) a combination of arm internal rotation and abduction.	Cutting force and muscle activity: trazezius, deltoideus medialis and anterior, biceps brachii and triceps long head.	Immediately	Direction 1 leads in general to lower muscle activation levels than direction 2. Direction 1 tends to increase the barycentre y-position shift of the trapezius activity and the average matrix entropy. Height decrease tends to lower the muscle activation levels, excepted for the deltoideus medialis. The shoulder motion during the task showed important changes in shoulder internal rotation for direction 2.

Author/year	Objective	Participants/product/tasks	Instruments/procedures	Outcome	Follow up	Results

Pontonnier et al., 2014	To validate the musculoskeletal model of the upper limb for standardized meat cutting task.	Seven male subjects; age: 29±5 years; laboratoy; cutting tasks; four work planes.	IK-B; 3D force sensor; force transducer, surface electromyographic (EMG); active marker motion capture system; and musculoskeletal model.
			
			Experiment:
			4 trials – 20 s each;
			4 heights (0 cm, 10 cm, 20 cm and 30 cm below the elbow height) and;
			2 directions of cutting:
			    1) arm flexion and,
			    2) a combination of arm internal rotation and abduction.
				Cutting force and muscle activity: trazezius, deltoideus medialis and anterior, biceps brachii and triceps long head.	Immediately	The model predicted the muscle forces exerted during the task.
						Direction 1 presented lower levels of activation. The optimal bench height for meat cutting tasks should be between 20 and 30 cm below the worker's elbow height.
						The range of motion of elbow flexion, shoulder abduction, and wrist flexion was small, approx. 4-8 % of the joint capabilities whereas the shoulder internal/external rotation and shoulder flexion were performed at approx. 7-30 % of the joint capabilities.
						The cutting task duration and the resultant cutting force varied from 0.6 to 2.5 s and 18-67 N.

Grip force

The grip force (standard deviation) varied among the studies found, the peak was 71.2 (20.8) N (McGorry et al., 2004a) and 130.9 (26.5) N (Dempsey and McGorry, 2004), in addition, the mean grip force was 52.7 (15.7) N (McGorry et al., 2004a), 55.2 (16.2) N (McGorry et al., 2004b), and 39.9 (4.4) N (Dempsey and McGorry, 2004). The same occurred with the peak cutting moment, it was 16.2 (3.1) Nm (Dempsey and McGorry, 2004), 8.94 (2.07) Nm (McGorry et al., 2004a) and the mean cutting moment was 4.0 (0.6) Nm (Dempsey and McGorry, 2004) and 6.30 (1.38) Nm (McGorry et al., 2004a). In addition, the average grip force during the task in a pork slaughterhouse were between 11 and 35 % of the maximum voluntary grip force (Dempsey and McGorry, 2004).

For McGorry (2001), the working range exceeded 700 N for gripping forces, and 28 and 16 Nm for the two applied moment axes, with the upper limits of these variables being larger than the studies presented. The knife forces may vary between-subject differences by site, performing the same meat cutting tasks, within-subject differences by cut, and cut-by-site (Waddell et al., 2003). Corroborating results of mean and peak cutting moments were 4.7 and 17.2 Nm for the shoulder boning, 3.5 and 12.9 Nm for the rib trim, and 2.3 and 10.6 Nm for the loin trim, respectively (McGorry et al., 2003).

The study by Juul-Kristensen et al. (2002) also found that there was a difference between different production processes to carry out the same task (cut chicken). They established that the cutting forces were significantly higher during the cutting task compared to the isolated cutting task. However, there was a small intra-individual coefficient of variation during the 50 cuts in the cutting task.

McGorry (2001) found that the grip force and applied moment during the initial phase (25 %) of the clay cut were greater for a high-precision task than for a low-precision task, regardless of the thickness level of the clay cut. On the other hand, McGorry et al. (2000)

verified that the thickness of the material being cut had a significant effect on the average peak torque.

Different factors interfere in applied force; one of them is the work pace. McGorry et al. (2004a) certified that the production pace requiring a grip force of 58.9 (14.6) N and cutting moment of 6.79 (1.40) Nm as compared to 46.6 (14.4) N and to 5.80 (1.20) Nm for the self-pace task, respectively. Another factor is the workers' experience level of the task. For McGorry et al. (2000), experienced workers spent less time applying torque than less experienced workers, but there were no between-group differences in the number of cutting cycles per trial (30 s).

Cutting force

Pontonnier et al. (2014) verified that the range of the cutting force was 18-67 N. In the study by Juul-Kristensen et al. (2002), the estimated cutting forces during manual deboning were of 6.25 N and 20.71 N (median and peak levels).

Task and person-related factors were found to influence the power required to perform the task (McGorry et al., 2000), the same differences were observed between plants for the same cut (Waddell et al., 2003). In the development of cutting measurement equipment, according to McGorry et al. (2005b), the cutting forces for fiber mesh and the meat were very similar, however, the force required to cut the mesh increased with the number of passes through the dulling sandpaper.

McGorry et al. (2004a) analyzed the cutting force applied in different combinations of workstation configuration and blade angle. The results showed that with a bent blade, the required grip force was significantly higher, 54.9 (16.1) N, than when a straight blade was used, 50.5 (15.0) N. Likewise, a significant difference was also found for the effect of cut complexity, with a complex cut as 49.8 (14) N vs. a simple cut operation with 55.5 (16.8) N.

Posture

The the workstation configurations and the direction that the cut is made affects the

working posture. One study identified that extreme positions of the hand in ulnar deviation were larger in cutting than mechanical deboning (p> 0.05) (Juul-Kristensen et al., 2002).

In relation to the cut direction performed in the shoulder abduction, there was a demand between 7-30 % of joint capabilities (Pontonnier et al., 2014). The height decrease of the workbench tended to lower the muscle activation levels, except for the deltoideus medialis (Pontonnier et al., 2012).

Analyzing the posture during the cutting task at four workbench heights, Pontonnier et al. (2014) found that the range of motion's standard deviations were large, underlining the notably different motions from one subject to another, especially for shoulder rotation and flexion. Waddell et al. (2003) proved that in one cutting task, the forearm flexor and extensor muscle activity were significantly smaller when compared to another task, but the total range of motion in this task was larger.

The optimal bench height for the meat-cutting task requiring force of approx. 50 N, which should be between 20 and 30 cm lower than the worker's elbow height (Pontonnier et al., 2014). The surface height had a significant effect on the grip force requirements, but the magnitude of the difference was around 2 N (McGorry et al., 2004a).

Knife sharpness

As reported by McGorry et al. (2005b), sharpness affects force exposure, but also cutting efficiency, in relation to cutting time. Blade sharpness was found to effect grip forces, cutting moments, and cutting time, with sharper blades requiring statistically and significantly lower peak and mean cutting moments, and grip forces than dull knives (McGorry et al., 2003). Therefore, efforts to provide and maintain sharp blades can have a significant impact on force exposure (McGorry et al., 2003). In one of the two analyzed tasks, McGorry et al. (2005a) found that the quality of the blade finish decreased the cutting time, the average and peak grip strength and cutting moment, however, this result was not generalized. This corroborates

the findings of Waddell et al. (2003) where the results of knife strength varied between the tasks analyzed under the same conditions. Dempsey and McGorry (2004) verified considerable variations among workers in the sharpness differences between the initial reading and 2- and 5-hour readings, which could lead to different levels of exposure.

Based on the results of this study, the specific research questions are answered as follows:

a) Characteristics of instrumented manual cutting tools:
   All knives used some type of electrical connection via cable or wires, even the most recent study (Pontonnier et al., 2014). No knife researched was completely the same as the tool used daily by workers.
   All knives used for data acquisition had changes in their weight (mass).
   Of the 14 studies, 6 were exclusively in the laboratory and 6 exclusively on the factory floor, with 2 studies in both locations.

b) Variables that can be obtained by the researched knives:
   Cutting force; cutting torque; cutting time; grip force and number of cutting cycles per time.

c) How should instrumented hand-cut tools be designed?
   By analyzing related articles it is possible to understand which instrumentalization (action of instrumenting) characteristics can interfere during data acquisition in the real environment of developing the workers' tasks. In this sense, the instrumentalization of manual cutting tools should consider some basic points: the visual non-mischaracterization of the tool, that is, maintaining the original features of the knife. When boarding an electronic system in a tool, there should be no increase in weight or change in the center of mass. Essential questions for this approach are the use of wireless data transmission and battery charging via magnetic induction.

In this research field, there would be instrumentation entirely associated with the work tool and imperceptible by the worker. In

this regard, deeper studies without adjacent variables should be performed. Reliable data acquisition of the task would be one example since the worker does not experience physical and psychological interference due to the tool's instrumentalization. Physical, in terms of obstructing the natural movement. By altering the shape of the cable and adding an electric cable or electrical connection wires would change the weight and center of mass. Psychological, in the sense of removing the spontaneity of the movement by knowing that it is being observed and measured. According to Prates and Barbosa (2003), in data collection techniques, one of the challenges for evaluators is to be able to observe without interfering in the context or inhibiting the user.

DISCUSSION

Key indicators of the measuring instrument quality are the reliability and validity of the measurements (Kimberlin and Winterstein, 2008), nevertheless, the results of this study introduced that only one knife was submitted to both processes (IK-A). The validity is the extent to which an instrument measures what it purports to measure but requires reliability (correctly calibrated) (Kimberlin and Winterstein, 2008). It is noteworthy that two studies mentioned performing knife calibration but did not refer to how they did it.

The results showed that IK-A was the most used in papers (n=9), but in a short period 2000-2005, besides the experimental studies were classified as fair. Evidencing that more robust studies are needed for data generalization with better descriptions of the used tools.

Of the fourteen studies found, half of them were developed in the laboratory. According to Scott and Renz (2006), it is unlikely that scenarios developed in the laboratory will become directly applicable solutions to solve industrial problems. In this sense, there is a need for more field research (factory floor) to elucidate all the reflexes caused to the slaughterhouse worker, who uses the knife as a work tool daily.

Although more field studies are welcome to describe the worker's daily scenario more accurately, some precautions are important during data collection. Westgaard and Winkel (1997) argue that the main disadvantage of conducting research in the area is that experimental research "in loco" is less controlled than in the laboratory, due to numerous exogenous factors that are beyond the researcher's control. Therefore, the use of a tool identical to that used daily by the worker can contribute to a reduced number of exogenous variables during data acquisition.

Regarding the variables obtained in the researched studies, it is observed that the new technologies were not present, for example, the measurement of movement by means of accelerometers and gyroscopes embedded in different types of cables. This form of measurement would obtain more complete answers, as it could be integrated into the production line. Thus, it would then identify what was registered in the study by Tirloni et al. (2020) as a frequent additional risk factor in work completely determined by machines in 94 % of tasks.

LIMITATIONS

One of the limitations of this study was how the articles were selected, as it was only an analysis of the data in the title, keywords and abstract that were initially reviewed. The other was that most studies carried out many experiments/analyses in the same manuscript, which did not make the methods and results description judicious. Specifically, the instrumented knife characteristics were not found, along with some information that had been identified elsewhere in the paper or other articles (knife description). Finally, the studies data were not collected over days or weeks, so conclusions are limited to the studied conditions.

CONCLUSION

Four knives with instrumented handles were found in this systematic review, data acquisition was performed in laboratory and

meat processing plant. It is noteworthy that only one knife was submitted to the validation process and that the articles provided incomplete technical information about the knives. The methodological quality of the studies was poor and fair.

Although the number of instrumented knives, as well as studies on instrumented knives, was limited, some of them attempted to provide data on the effects of sharpening, strength, cutting moment and grip.

Although a classification was made to try to obtain the details of each instrumentation presented in the articles, none of them considered the influences that the workers are subject to when they do not use the same tool daily.

The use of new technologies could promote the development of a low-cost wireless data transmission knife, where the instrumentation was imperceptible by the user, due to the absence of physical changes, maintaining the characteristics of the original knife used by the worker.

Therefore, an instrumented knife or handle should be developed to meet the requirements of the present study, as well as conducting future studies with this instrumented knife in slaughterhouses. These studies have shown the need to deepen knowledge about cutting force and the relationship with the risks of developing WMSD, plus the use of gloves, the ambient temperature of the workplace, the experience of worker, the effects of boning training, the frequency of using the knife sharpener to keep the knife sharp, and the effects on increasing technical actions.

Conflict of interest

The authors declare that they have no conflict of interest.

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