

IARC Monograph Volume 118: Welding, Molybdenum Trioxide, and Indium Tin Oxide

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SUMMARY OF EVALUATIONS

Table 1. Summary of evaluations from IARC Monograph Volume 118, by agent and subgroup⁽¹⁾⁽²⁾⁽³⁾

Evaluations	Welding fumes	UV radiation from welding	Molybdenum trioxide	Indium tin oxide
Humans (cancer)	Sufficient (lung); Limited (kidney)	Sufficient (ocular melanoma)	No data	No data
Animals (evaluation)	Limited (gas metal arc-stainless steel welding fumes)	No data	Sufficient	Sufficient
Mechanisms (key characteristics)	Strong (chronic inflammation, immunosuppression)	No data	Weak	Strong (chronic inflammation)
Overall evaluation	1	1	2B	2B
Previous evaluation	2B in 1999*	none	none	none
Occurrence/Notes	*2B evaluation based on 'limited evidence' in humans and 'inadequate evidence' in experimental animals	'UV radiation' was classified as Group 1 in 2009	High-production volume; mostly used in steel production; exposure occurs in occupational settings (eg, welding) but rare from environment	Low-production volume; mostly used for producing conductive films on panels used in electronic devices; exposure mainly from ITO production and processing
Overall evaluations:	Group 1, Carcinogenic to humans; Group 2B, Possibly carcinogenic to humans			

BACKGROUND: Welding

- Welding is the process of joining metals through coalescence
- Predominant techniques: gas (fuel gases used to generate heat), arc (electricity used to generate arc)
- Predominant metals welded: mild steel, stainless steel (SS, contains chromium and nickel compounds which are Group 1 carcinogens)
- Tobacco smoking and asbestos are potential confounders for assessing lung cancer
 - Welders may smoke more than the general population
 - Asbestos exposure: work in shipyards, electrodes, heat protective equipment worn by welders
- Welders are co-exposed to several substances already evaluated by IARC (Table 2)

Table 2. Occupational exposures of welders that have been evaluated by the IARC Monographs, by welding types

Agent	Evidence for Carcinogenicity	Overall Evaluation	Most recent Volume (Year)	Occurrence	Welding types***	Organ Sites (sufficient or limited evidence in humans)
Asbestos and inorganic arsenic compounds	Sufficient	Sufficient	1	1000 (2012)	Impurity in some mild stainless welding fumes	Lung, skin, urinary bladder, prostate, kidney, liver
Asbestos	Sufficient	Sufficient	1	1000 (2012)	Insulation material and in heat-protective equipment of welders and the weld	Mesothelioma, larynx, lung, ovary, pharynx, stomach, colon and rectum
Beryllium and beryllium compounds	Sufficient	Sufficient	1	1000 (2012)	Hardening agent in copper, magnesium, aluminum alloys and electrical contacts	Lung
Cadmium and cadmium compounds	Sufficient	Sufficient	1	1000 (2012)	Platings on base metals, SS containing cadmium	Lung, kidney, prostate
Chromium VI compounds	Sufficient	Sufficient	1	1000 (2012)	Alloy in stainless steel, also in welding rods	Lung, nasal sinuses and nose
Electric fields, extremely low-frequency	Inadequate	Inadequate	3	80 (2002)	Electrical currents from welding processes	Childhood leukaemia
Formaldehyde	Sufficient	Sufficient	1	100F (2012)	Metal coatings, degreasing solvents	Nasopharynx, nasal sinuses, leukaemia
Inorganic lead compounds	Limited	Limited	2A	8F (2006)	In solder, brass and bronze alloys, welding on lead containing or coated materials	Stomach
Magnetic fields, extremely low-frequency	Limited	Inadequate	2B	80 (2002)	Electrical currents from welding processes	Childhood leukaemia
Nickel Compounds	Sufficient	Sufficient	1	1000 (2012)	Alloy in stainless steel, also in welding rods	Lung, paranasal sinuses, nasal cavity
Silica dust, crystalline, in the form of quartz or cristobalite	Sufficient	Sufficient	1	1000 (2012)	Some welding fluxes contain silica	Lung
Titanium dioxide	Inadequate	Sufficient	2B	93 (2010)	Found in SMAW (MMA) electrodes	Ocular melanoma, cutaneous malignant melanoma, squamous cell carcinoma of the skin
Ultraviolet Radiation**	Sufficient	Sufficient	1	1000 (2012)	Arcs from welding guns	Lung
Iron Oxides (iron and steel fuming)	Sufficient	Sufficient	1	100F (2012)	Main component of steel	Lung
Vanadium pentoxide	Inadequate	Sufficient	2B	86 (2006)	Alloy in stainless steel	Lung
Outdoor Air Pollution (PM 2.5)	Sufficient	Sufficient	1	100 (2016)	PM _{2.5} generated from all welding processes	Lung
Welding Fumes	Limited	Inadequate	2B	46 (1980)	Generated from welding processes	Lung

*Evaluation specific to iron and steel fuming; **Based on mechanistic upgrade and 'sufficient evidence' in humans for 'UV-emitting tanning devices'; ***SMAW = shielded metal arc welding; MMA = manual metal arc welding; GMAW = gas metal arc welding; FCAW = flux cored arc welding; GTAW = gas tungsten arc welding; SS = stainless steel; Compiled by the Working Group

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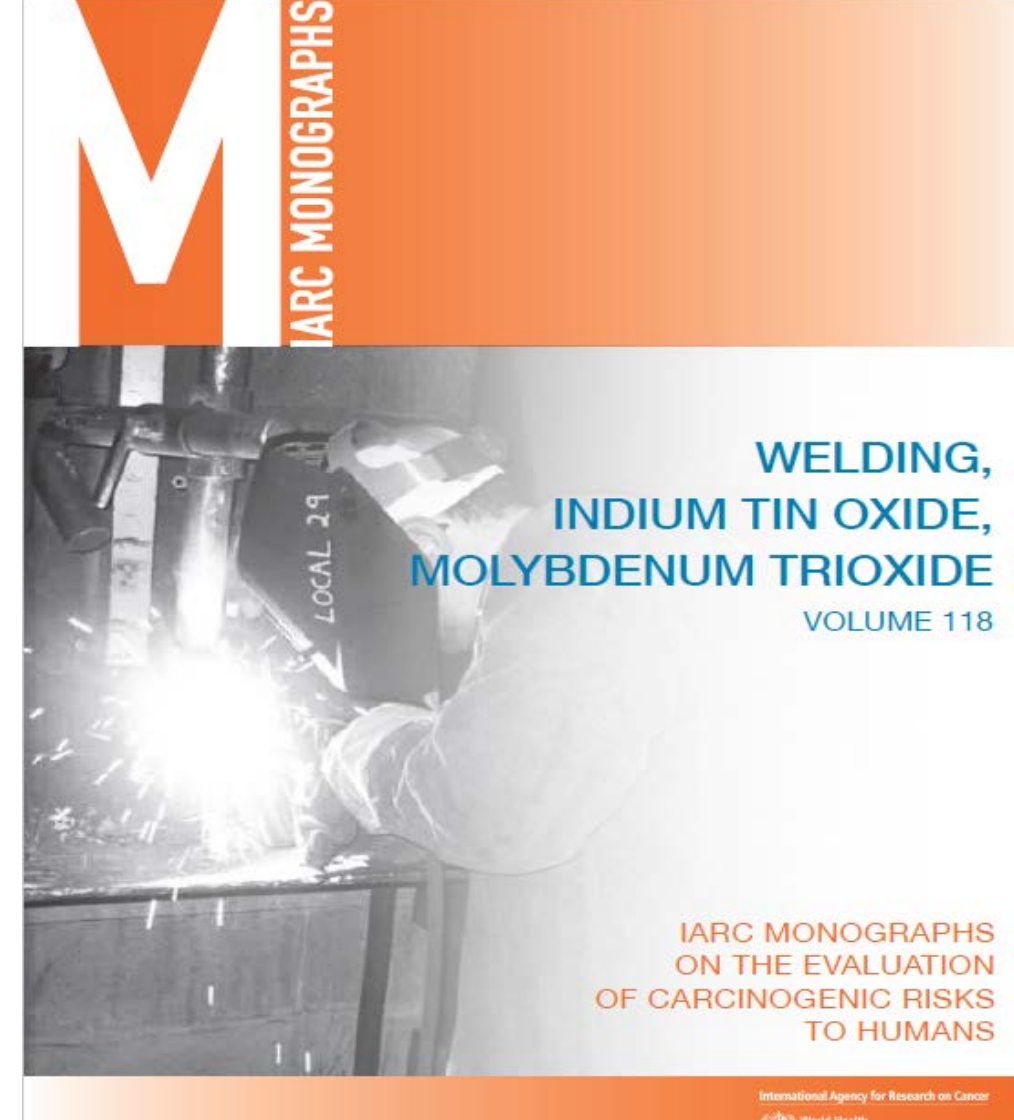
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IARC Working Group Meta-Analysis

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EXPOSURE DATA: WELDING

- The IARC Working Group (WG) estimated 11 million persons work as welders worldwide and ~ 110 million workers incur welding related exposures (in jobs that routinely or intermittently weld) (Table 3)
- Welders were estimated to represent 0.31% of the economically active population using census microdata gathered from 60 countries from 1973-2015⁽⁴⁾; ILO 2010 estimate of economically active population worldwide (3.5 billion) was applied

Table 3. Estimates of number of welders worldwide based on publicly available population data, sorted by the number of welders

Country	Census year	Occupational designation	Number	Percent welder**
China	1990	Welders	1 798 300	0.27%
United States	2010	Welding, soldering, and brazing workers	727 122	0.40%
India	2004	Welders and flame cutters	499 219	0.14%
Viet Nam	2009	Metal moulders, welders, sheet-metal workers, structural metal prepares, and related workers	339 106	0.71%
Brazil	2010	Welders and flame cutters	292 365	0.34%
Spain	2001	Welders, laminators, metal structure assemblers, blacksmiths, toolmakers, and similar	262 620	1.61%
United Kingdom	2001	Metal forming, welding and related trades	227 044	0.55%
Mexico	2010	Welders and flame cutters	191 819	0.45%
Nigeria	2010	Welders and flame-cutters	190 637	0.27%
Philippines	2000	Metal moulders, welders, and sheet-metal workers	185 060	0.32%
Islamic Republic of Iran	2006	Welders and flame cutters	150 439	0.87%
Indonesia	2005	Welders and flame cutters	142 572	0.16%
South Africa	2007	Metal moulders, welders, sheet-metal workers, structural-metal preparers, and related trades workers	121 635	0.99%
Germany (West)	1987	Welder	110 040	0.39%
Canada	2006	Welder	103 000	0.61%
Egypt	2006	Metal moulders, welders, sheet-metal workers, structural-metal preparers, and related trades workers	99 070	0.49%
Thailand	2000	Metal moulders, welders, sheet-metal workers, structural-metal preparers, and related trades workers	97 626	0.20%
Australia**	2011	Structural steel and welding trades workers	86 400	0.77%
Morocco	2004	Moulders, welders, and sheet metal workers	85 320	0.91%
Romania	2002	Welders and flame cutters	80 460	0.95%
Portugal	2011	sheet and structural metal workers, moulders and welders, and related workers	76 580	1.55%
Netherlands*	1996	Mold-press workers, welders, laminators, boiler-makers, assemblers of metal structures, and similar	75 000	1.21%
Venezuela	2001	Mold-press workers, welders, laminators, boiler-makers, assemblers of metal structures, and similar	70 170	0.31%
Malaysia	2000	Metal moulders, welders, sheet metal workers, structural metal preparers and related trades workers	43 400	0.53%
Cuba	2002	Molders, welders, panel beaters, assemblers	39 710	0.92%
Ecuador	2010	Sheet and structural metal workers, moulders, and welders, and related workers	37 640	0.64%
Peru	2007	Plumbers and pipe fitters, welders and flame cutters, sheet metal workers, and structural-metal preparers and erectors	37 350	0.36%
France	2011	Skilled metal workers	36 164	0.14%
Senegal	2002	Metal moulders, welders, sheet-metal workers, structural-metal preparers, and related trades workers	25 550	0.80%
Bolivia	2001	Molder, welders, laminators, boiler-makers, assemblers of metal structures, and similar	22 090	0.27%
Panama	2010	Molders, welders, boiler-makers, fitters of metallic structures and related	21 550	1.53%
Cameroon	2005	Sheet and structural metal workers, moulders and welders and related workers	19 940	0.40%
El Salvador	2007	Metal moulders, welders, sheet-metal workers, structural-metal preparers, and related trades workers	17 930	0.91%
Guinea	1996	Metal moulders, welders, sheet-metal workers, structural-metal preparers, and related trades workers	17 070	0.50%
Kenya	1989	Welder	15 680	0.21%
Zimbabwe	2007	Metal moulders, welders, sheet-metal workers, structural-metal preparers, and related trades workers	14 490	0.18%
Malawi	2008	Plumbers, welders, sheet metal and structural metal preparers and erectors	14 240	0.34%
Costa Rica	2008	Molders, welders, locksmiths, boiler-makers, metal structure builders and similar	13 810	1.06%
Mali	2009	Welder	12 860	0.23%
Zambia	2010	Metal moulders, welders, sheet metal workers, structural metal preparers, and related trades workers	12 620	0.32%
Pakistan	1973	Welders and flame cutters	12 353	0.07%
Nicaragua	2005	Metal moulders, welders, sheet-metal workers, structural-metal preparers, and related trades workers	12 040	0.69%
Greece	2001	Welders and flame cutters	11 330	0.27%
Jamaica	2001	Metal moulders, welders, sheet-metal workers, structural-metal preparers, and related trades workers	11 263	1.17%
Ireland	2006	Welders and steel erectors	10 090	0.41%
Ethiopia	1994	Welders, metal moulders, and related trades workers	9,297	0.04%
Haiti	2003	Metal moulders, welders, sheet-metal workers, structural-metal preparers, and related trades workers	7,990	0.38%
Uruguay	2006	Metal moulders, welders, sheet-metal workers, structural-metal preparers, and related trades workers	7,553	0.58%
Uganda	2002	Welders, sheet metal workers, metal moulders	7,380	0.10%
Kyrgyz Republic	1999	Welders and flame cutters	7,220	0.42%
Cambodia	2008	Sheet and structural metal workers, moulders and welders, and related workers	6,650	0.10%
Puerto Rico	2010	Welding, Soldering, and Brazing Workers	5,220	0.33%
Armenia	2011	Sheet and structural metal workers, moulders and welders and related workers	4,930	0.45%
Iraq	1997	Welders and flame cutters	4,320	0.11%
Sri Lanka	2007	Welders and flame cutters	3,240	1.34%
Switzerland	2000	Workers for metal smelting, foundry, welding, metal sheet work, boiler making, metal frame for houses and buildings, and assimilated	2,670	0.07%
Rwanda	2002	Workers for metal smelting, foundry, welding, metal sheet work, boiler making, metal frame for houses and buildings, and assimilated	2,390	0.07%
Mongolia	2000	Metal moulders, welders, sheet-metal workers, structural-metal preparers, and related trades workers	1,810	0.23%
Paraguay	1982	Oxyfuel cutters; welders, soldering by hand or machine, electrical welders, and blowtorch welding	1,460	0.15%
Jordan	2004	Metal moulders, welders, sheet-metal workers, structural-metal preparers, and related trades workers	1,050	0.10%

Compiled by the Working Group; Data, unless otherwise specified, compiled from IPUMS-International; **Data for the Netherlands compiled from Simmetnik (1996); ***Data from Australia compiled from Australian Bureau of Statistics; **Percent of the economically active population for each country that the number of persons employed in the occupational designation represents.

- Exposure assessment methods of epidemiologic studies were reviewed systematically to inform the evaluation (Table 4)

Table 4. Detailed review of exposure assessment methods of epidemiologic studies

Exposure assessment method	Description	Strengths	Limitations	Reference	Exposure metrics reported
Expert assessment	Prospective cohort study, men and women aged 55-69 years in September 1986.	Exposure to welding fumes assessed specifically.	No quantitative data on welding fumes.	van Loon et al. (1997)	Probability of exposure to welding fumes (particularly stainless steel welding), exposure: possible exposure < 30%; probable exposure 30-90%; nearly certain exposure > 90%, with the following weights given 0; 0.15; 0.6; 0.95.
Job history	Job history was obtained via self-administered questionnaire, collecting data on job title, company and department, and period.	Blinded exposure assessment. Any exposure misclassification therefore likely to be non-differential.	Job histories only up to start of follow-up, so may have missed up to 10 years of the end of career.		Cumulative probability of exposure was assigned based in the combination of probability weight and duration in years.

WELDING AND LUNG CANCER

- Increased lung cancer risk was associated with welding in the majority of studies
 - >20 case-control, >20 cohorts, some overlapping, several of high-quality
 - Increased risks were observed regardless of welding technique, study design, occupational setting, geographic region, time period, adjustment for tobacco smoking and asbestos exposure
- The WG conducted a meta-analysis to quantitatively characterize the risks and explore sources of heterogeneity (Figures 1-3)

Figure 1. Forest plot of studies reporting on lung cancer in welders included in the meta-analysis

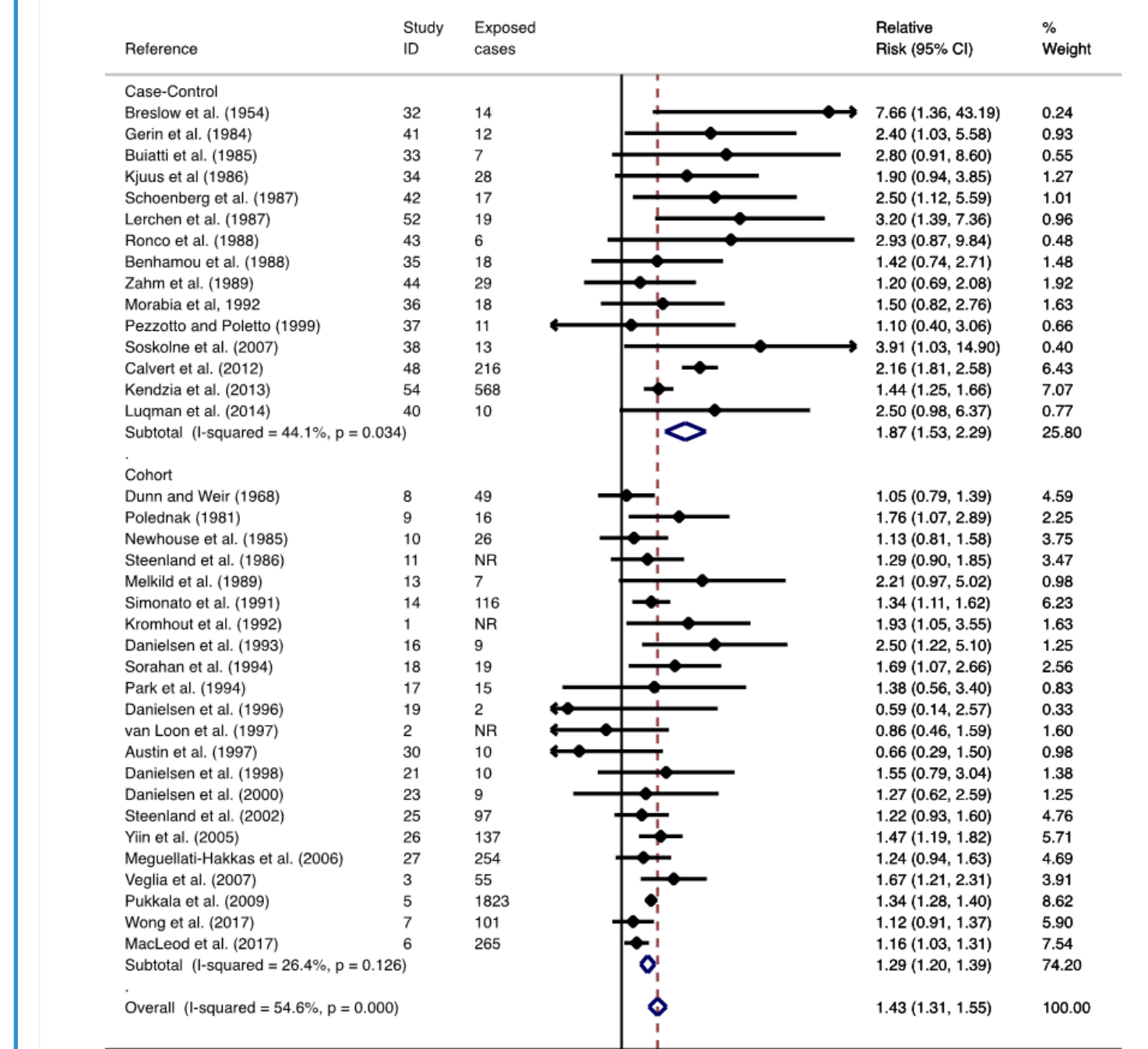


Figure 2. Summary of results of the IARC WG meta-analysis of lung cancer in welders

Analysis	N	I ²	RR (95% CI)	References of included studies
Overall	37	54.6%	1.43 (1.21-1.55)	(28,30,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75)
Cohort	22	26.4%	1.29 (1.20-1.39)	(28,30,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75)
Population-based	6	59.7%	1.27 (1.12-1.44)	(28,30,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75)
Case-control	15	44.1%	1.47 (1.53-2.29)	(28,30,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75)
Hospital-based	6	0.0%	1.94 (1.36-2.49)	(28,30,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75)
Population-based	6	13.0%	2.03 (1.61-2.67)	(28,30,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75)
Meat	2	70.9%	1.92 (0.91-4.08)	(28,30)
Major Confounders				
Smoking and asbestos	8	41.2%	1.17 (1.04-1.30)	(28,30,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75)
Asbestos exposure	11	52.7%	1.22 (1.09-1.32)	(28,30,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75)
Smoking	20	61.1%	1.34 (1.15-1.55)	(28,30,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75)
Pack-year	8	65.9%	1.46 (1.05-2.02)	(28,30,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75)
Confounders	3	47.8%	1.19 (1.03-1.20)	(28,30,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75)
meat	9	41.3%	1.39 (1.13-1.71)	(28,30,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75)
Type of welding				
Arc welders	5	62.0%	1.23 (0.89-1.84)	(28,30,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75)
Gas welders	5	53.2%	1.45 (1.07-1.91)	(28,30,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75)
Type of material welded				
Stainless steel	5	68.1%	1.38 (0.89-2.13)	(28,30,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75)
Mild steel	3	39.9%	1.44 (1.07-1.95)	(28,30,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75)
Histologic subtype				
Squamous cell carcinoma	7	58.1%	1.53 (1.31-1.80)	(28,30,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,75)
Adenocarcinoma	7	51.6%	1.35 (1.15-1.57)	(28,30,34,35,36,37,38,39,40,41,42,